Semantics Visualization as a User Interface in Business Information Searching

Helena Dudycz

Semantics Visualization as a User Interface in Business Information Searching

Helena Dudycz(✉)[0000-0002-4304-6207]

Wrocław University of Economics and Business, Wrocław, Poland
helena.dudycz@ue.wroc.pl

Abstract The article sets out to present conclusions from the conducted research into semantic network visualization as a user interface applied for the purpose of searching for business information. The article describes the results of the research comprising literature analysis as well as the validation of prototypes developed in Protégé. Based on the analysis of publications covering the latest research, four areas of research into semantic network visualization were identified, i.e. the development of new software, the application of techniques, technologies, and solutions making it possible to perform various operations concerning the semantic network visualization view, the verification of the use of various graphic designations, as well as users' validation of interactive semantic network visualization. For each area, the main directions of research are specified, along with an indication of publications that describe them. Furthermore, the article provides conclusions from the validation of prototypes of ontologies for the area of users' (experts') analysis of economic and financial indicators using semantic network visualization. The research in question allowed the identification of three potential problems related to the use of semantic network visualization as a visual interface in searching for economic information.

Keywords: Semantic visualization · Interface · Visual interface · Knowledge visualization · Ontology

1 Introduction

Visualization is currently treated as one of the basic solutions for the presentation of both information and knowledge obtained from systems supporting enterprise management. Particular attention is paid to graphic methods enabling knowledge visualization. One of them is the semantic network, which can present an ontology containing knowledge pertaining to a specific field. Along with the visualization of information and the visualization of knowledge, the concept of Semantics Visualization has appeared, describing technologies associated with ontology and visualizing semantic structures search [1-3]. The visualization of semantic searches is essential, as it allows users to more easily notice and understand various semantic and structural dependencies between topics. Using semantic network visualization, the user should be able to interactively select the elements of interest to them, i.e.

concepts and relationships between them. There is an increasing focus on developing methods and tools to graphically visualize ontologies, which could be an effective representation of ontologies in order to fully understand the structures [4-5]. The issues of searching for information using semantic networks, based on a created ontology for a selected field, is the subject of numerous studies and concerns various domains [6-10].

Semantic visualization can play a dual role. First of all, as a visual, interactive method for presenting knowledge belonging to a given domain. Secondly, as a visual, interactive interface allowing the user's active involvement in the process of searching for unique information. The combination of data visualization in the shape of a semantic network and personalized navigation can become an effective and efficient tool for carrying out a variety of business information analyses [11]. This is possible on condition that the semantic network visualization applied is a useful and easy interface for users. This statement became a premise for undertaking the research.

This article aims to present the conclusions of the conducted research dedicated to semantic network visualization as a user interface applied in searching for business information. The research covers two areas. The first one covers an analysis of the literature describing the latest research into the application of semantic network visualization as a visual interface. The second one consists in the validation of ontology prototypes for the area of users' (experts') analysis of economic and financial indicators using semantic network visualization. The structure of the article is as follows. The next section briefly discusses visualization, ontology, and semantics visualization. The following section presents the conclusions from the research conducted into literature as well as experts' tests of prototypes created with the Protégé software. The article ends with a summary.

2 Theoretical Background

There are numerous definitions of visualization in the literature. Among the many of them, due to the subject of this article, the following may be mentioned. Visualization is the process of representing data as a visual image [12], offering "a link between the human eye and the computer, helping to identify patterns and to extract insights from large amounts of information" [13, p. 139]. Visualization is defined also as "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" [14, p. 477]. Interactive visualization actively includes the user in the process of finding information, enabling him or her to build more accurate queries for a specific set of data [15]. Particular attention is paid to the role of visualization, which is multifaceted and enables interactive visual search for information [16-17].

Visualization has also begun to be interpreted not only as a way of transmitting information by means of graphic elements, but also as a method of data set exploration, helping the user to identify patterns, correlations, etc. [13], or as a method of knowledge representation aiming to improve knowledge transfer [18] between two or more people [19]. Visualization of knowledge is "an essential element of knowledge management and aims to support the process of knowledge transfer and creation using

visualization techniques" [20]. Knowledge visualization methods include the following: the knowledge map, hierarchical semantic visualization, relational semantic visualization, and semantic visualization based on entities (discussed in [20]).

One of the ideas of collecting and searching for data is the semantic network, which besides the data itself contains also information on relations between them [21]. It is a directed or undirected graph, where the vertices represent concepts while the edges represent relations between the concepts. The graph's pathways can reflect implicit knowledge [7, 20]. Formalized domain knowledge using created ontologies forms the basis of the semantic network. Ontology describes "the concepts and relationships in an area of knowledge using a logic-based language and have a related graphical representation" [4]. A wide review of ontology is presented in [22]. Ontology is a model describing a given field in a formalized manner, reproducing knowledge with the use of identified notions and links existing between them including mutual relations, cause-effect relationships, and properties. In recent years, researchers have developed a variety of techniques to visually present ontologies [23-26]; various ontology visualization tools are presented in [5, 27-28]. Ontology-driven applications are already used in knowledge management, intelligent integration of information resources, commerce etc. (see for example [4, 7]). In the literature, the visualization of ontologies using a semantic network began to be referred to as Semantics Visualization [1-3]. Information search using a semantic network is the subject of many studies and the concern of various fields [29-34].

Human interaction with semantic visualization plays an important role in acquiring knowledge [2]. The basic assumption of navigation in the visualization of a semantic network is that it should allow the user to look at fine-detail (focused) information and full-system context simultaneously, thereby presenting an overview of the whole knowledge structure [3]. In this interactive process, the user can concentrate on the interesting data elements by filtering uninteresting data, and focusing (zooming in) on the interesting elements, until finally, details are available for an interesting subset of the analyzed elements. Each action performed (choice of a node, mouse click on a node, etc.) expresses knowledge specific to the user of this application [20]. In order for the user to easily move from the global view to the detailed view by interacting with the visualization interface, many approaches have been developed, for example: "overview + details" and "focus + context". This method of searching for information by means of a semantic network meets the basic principle of visualization proposed by Shneiderman (overview first, zoom and filter, then details on demand) [35].

3 Description of the Research

3.1. Research Questions

The conclusions presented in this article stem from the research into the use of semantic network visualization as an interface in searching for business information. The research undertaken is expected to provide answers to the following questions:

- What research work is being carried out with respect to the application of semantic network visualization in users' searching for information?
- Can semantic network visualization be a friendly interface for users (experts) seeking to gain economic knowledge?

The next section presents the conclusions resulting from the research conducted into the literature on the application of semantic visualization as a visual interface employed for the purpose of searching for information. Section 3.3 presents the most important conclusions from the validation of prototypes created in Protégé with the participation of experts.

3.2. Results of the Literature Research

The research was carried out based on the approach described in [36]. The study aimed to identify the most recent research into the application of interactive semantic network visualization for the purpose of users' searching for information. Therefore, the Google Scholar search engine was chosen, which allows obtaining information about the latest publications from various databases. Due to the adopted criterion according to which the subject of examination has to be the latest research, the dates for publications to be considered were set from 2010 to 2019.

First, a Google Scholar search was conducted for the terms "Semantic Network Visualization" + "interface" and "Semantic web Visualization" + "interface". As a result of setting the keywords in this way, in either set, the result was fewer than forty indications, of which just under than ten remained after the preliminary analysis. However, in order not to omit important publications pertaining to this area, another search was conducted for the combination of the following terms: "Semantic Visualization" + "interface". As a result - without time limits - 500 publications were received, while in 2010-2019 there were 362. After a preliminary analysis, 49 out of 362 were chosen. After another analysis of publications and the application of the snowballing technique, 13 publications related to the research question were received.

The analysis of the research described in the publications obtained allowed the identification of four areas. The first of these concerns the development of software for the visualization of semantic networks as an interactive tool applied by users to search for information or knowledge. Special attention should be paid to the development of software for the semantic search visualization, an import research area in the context of semantic visualization. A far as this area is concerned, the following software under development should be mentioned:

- Knowledge cockpit with many tools for visualizing semantic information [37];
- TopicViz [38];
- SemaZoom [39]
- SemaTime [40]
- NavigOWL (a plug-in for Protégé) [5];
- MUCK [41];
- ONTOLIS [4];
- MCVGraphViz [20].

The second area concerns techniques, technologies, and solutions enabling the user to modify the view of semantic network visualization. The visual interface should allow navigation between topics in a highly interactive manner. Interesting nodes can be put in the foreground by zooming, panning, and rotating. For instance, users should be able to hide irrelevant branches of the tree or expand interesting ones as well as to perform "overview + details" and "focus + context". Research into this area is described in the following publications:

- manipulating the visualization by adding, rearranging, or removing topics [3, 5, 37, 39-40];
- applying different colours to the graph elements (i.e. nodes and lines) [3, 5, 39, 42];
- viewing the graph as a whole or obtaining a partial view by disabling certain nodes and edges [3, 5, 20, 37, 39, 41-42];
- applying semantics-based filtration [3, 5, 20, 37-41];
- creating a system of tooltips - to refine the access to the knowledge represented in the model [20].

The third area concerns the graphic designations used. The typically used graphic elements are rectangles, which symbolise terms (nodes), and lines in various colours, which indicate types of connections between these terms. The publication [20] proposes a circle as a node symbol. The diameter of the circle depends on the number of other nodes linked to it, while its colour is defined by the category to which the node belongs. This method of coding may help the user to detect the nodes (terms) in which they are interested in semantic network visualization.

The fourth area is research involving users in the use of visualization of a semantic network for obtaining information. The literature points to various potential problems that can occur in semantic network visualization software, which could be caused by a very considerable number of displayed nodes and lines in the semantic network and the use of multiple colours to mark the lines [5]). Therefore, research with user involvement is being conducted to verify the usability of semantic network visualization as a user interface (this issue is widely discussed in [3]). These are the following publications:

- [25] - The main conclusions of their study are as follows: (1) the graph visualization is more controllable, intuitive and more suitable for overviews than indented tree hierarchies; (2) the graph visualization is more controllable and intuitive without visual redundancy, particularly for ontologies with multiple inheritances than indented tree hierarchies, and (3) the graph visualization is more suitable for overviews.
- [11] - The main conclusions of this study are as follows: (1) identification of potential problems related to the use of a semantic network as a visual interface in searching for economic information, which concern errors occurring during the ontology conceptualisation process for economic knowledge as well as the functionality of semantic network visualization software; (2) the application causes that us-

ers do not find it a problem that a semantic network contains many nodes and lines in many different colours.

- [43] - The main conclusions of this study are as follows: (1) information clearly presented by the system; (2) supporting the decision-making process;(3) the use of semantic analysis and complex networks as conjugated techniques can help in the decision-making process.

The four research areas specified in this section in relation to the application of semantic network visualization as a visual interface do not constitute separate groups.

3.3. Results of the Validation of Prototypes of the Created Ontology

We have been conducting research related to the use of semantic visualization for the analysis of business data. The purpose of our research is to present the potential applications of semantic visualization in management, which involves models of knowledge pertaining to the analysis of financial and economic indicators. This required creating ontologies for selected fields of economic knowledge. These ontologies were constructed using the approach presented in [44]. As of now, the following case studies have been developed:

- early warning system ontology [45];
- ontology of chosen financial indicators [46];
- Company's Liquidity ontology [47];
- ontology of emergency policy workflow [7];
- financial assessment ontology [48].

The created ontologies were coded using the Protégé software. Figure 1 presents a sample semantic visualization of business knowledge in the OntoGraf module in the Protégé software. This is the prototype of a financial assessment ontology.

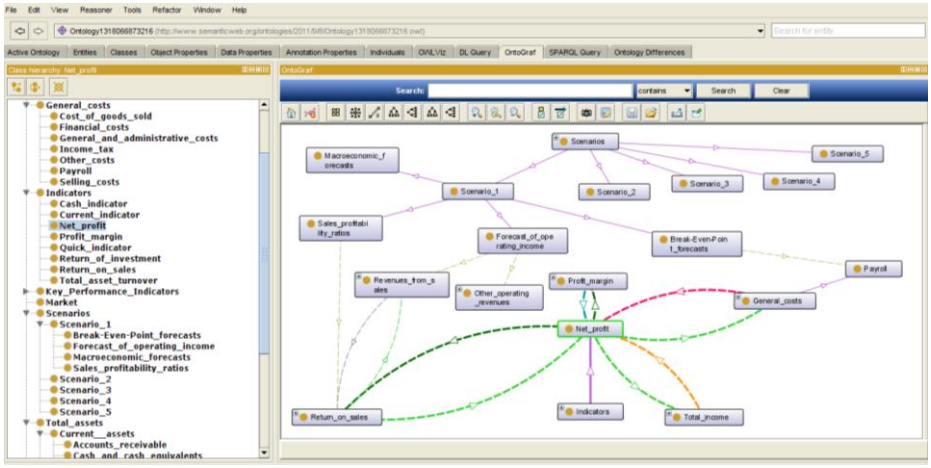

Fig. 1. An example of semantic visualization of business knowledge (Source: an application created on the basis of Protégé)

One of the stages of creating an ontology for a selected field of economic knowledge is the validation and evaluation stage of the created ontology. At this stage, the encoded ontology is checked to ensure that it meets the users' needs. Validation is carried out in three areas. Firstly, validation is performed by experts, who will potentially use it, with respect to the usefulness and correctness of the created ontology. Secondly, the evaluation of the application with the created ontology is carried out by users. Finally, the validation of predefined use cases is carried out.

At the stage of validation and evaluation, these case studies were tested by experts using pre-set usage scenarios. Several of them have been described in publications, for example [7, 46-48]. We prepared use cases and validated the created ontology. Experts searched for economic information using semantic network visualization in Protégé's OntoGraf module. Our goal concerning the OntoGraf module – which proved to be sufficient for the research – was to verify the usefulness of semantic network visualization in searching for business information that is contextually connected.

In the course of the validation of prototypes, two groups of problems were identified. The first group includes problems resulting from the ontology created. The most frequently reported problem concerned interpreting the names of semantic relations between concepts. This means that the usefulness of applying semantic network visualization depends on a good definition of semantic relations at the ontology conceptualization stage. The fundamental rule should be to use such relationship names that are understandable to users. Therefore, special attention should be paid to the ontology conceptualization stage. The second group includes problems related to software (in this case, the OntoGraf module in Protégé). The most frequently reported problem was the random arrangement of concepts in the visualization window - e.g. after making the relationships expand or collapse.

To summarize, validation of prototypes of created ontologies confirmed that the application of semantic visualization as a visual interface for the analysis of financial and economic indicators can be useful. Nevertheless, the conceptual model of ontology and the functionality of programs created for semantic network visualization should be noted.

4 Conclusions

This article presents the results and conclusions from the conducted research into the semantic network visualization as a visual interface enabling the acquisition of information and knowledge. The basis of a semantic network is a developed ontology covering knowledge pertaining to a given area. Based on the analysis of publications dedicated to the latest research (since 2011), four interrelated research areas were identified, concerning the development of new software, the application of techniques, technologies, and solutions enabling various operations concerning the view of semantic network visualization, verification of the use of various graphic designa-

tions and users' validation of interactive semantic network visualization. The research shows that the combination of semantic network visualization and user navigation can be an effective and efficient tool for various analyses, including those of business data.

The conclusions from the encoding of ontologies for economic knowledge using the Protégé software as well as experts' testing of prototypes indicate the possibility of using a semantic network as a visual interface. The research confirms that semantic network visualization can be a useful visual interface for acquiring economic knowledge by users (managers). The combination of data visualization in the form of semantic network and personal navigation can become an effective and efficient tool to perform various analyses, including economic data. The research also aims at identifying potential problems associated with the use of semantic network visualization as a visual user interface. As a result of testing of the created ontologies, the following three groups of problems were identified. The first group concerns understanding the defined semantic relationships between concepts. The second group concerns understanding the operation of the software that displays semantic network visualization. The third group includes the functionality of the semantic visualization module. Finding solutions to minimize potential difficulties can contribute to the use of semantic visualization on a larger scale to represent economic knowledge in systems supporting decision-makers in making decisions.

Acknowledgements The author would like to thank Jerzy Korczak from the International University of Logistics and Transport, Wrocław, Poland, and Bartłomiej Nita, and Piotr Oleksyk from Wrocław University of Economics, Wrocław, Poland for cooperation and their significant contribution to the development and validation of ontologies for financial knowledge.

References

1. Nazemi, K., Breyer, M., Burkhardt, D., Stab, C., Kohlhammer, J.: SemaVis: A new approach for visualizing semantic information. In: Towards the Internet of Services: The THESEUS Research Program Cognitive Technologies, Springer, 191-202 (2014) doi: 10.1007/978-3-319-06755-1_15
2. Nazemi, K., Burkhardt, D., Ginters, E., Kohlhammer, J.: Semantics Visualization – Definition, Approaches and Challenges. In: Procedia Computer Science, Elsevier BV, **75**, 75–83, (2015)
3. Nazemi, K.: Adaptive Semantics Visualization. Studies in Computational Intelligence, **646**, Springer (2016) doi: 10.1007/978-3-319-30816-6
4. Chuprina, S., Nasraoui, O.: Using Ontology-Based Adaptable Scientific Visualization And Cognitive Graphics Tools to Transform Traditional Information Systems into Intelligent Systems. Scientific Visualization, vol. 8, **1**, 23–44 (2016)
5. Hussain, A., Latif, K., Rextin, A. T., Hayat, A., Alam, M.: Scalable visualization of semantic nets using Power-Law Graphs. Applied Mathematics & Information Sciences An International Journal, 8, 355-367 (2014) doi: 10.12785/amis/080145

6. Aritonang, E., M., Seminar, K., B., Wahjuni, S., Purbo, O., W.: Modeling Ontology and Semantic Network of Regulations in Customs and Excise. TELKOMNIKA, vol. 15, **4**, 1934-1942 (2018) doi: 10.12928/telkomnika.v15i4.6590
7. Korczak, J., Dudycz, H., Nita, B., Oleksyk, P.: Semantic approach to financial knowledge specification - case of emergency policy workflow. In: Ziemba E. (ed.) Information Technology for Management: Ongoing Research and Development, Lecture Notes in Business Information Processing, **311**, 24-40 (2018) doi: 10.1007/978-3-319-77721-4_2
8. Krishnan, K., Krishnan, R., Muthumari, A.: A semantic-based ontology mapping–information retrieval for mobile learning resources. Int. J. Comput. Appl., vol. 39, **3**, 169-178 (2017) doi: 10.1080/1206212X.2017.1309223
9. Selvalakshmi, B., Subramaniam, M.: Intelligent ontology based semantic information retrieval using feature selection and classification. Cluster Comput., vol. 21, 1-11 (2018) doi: 10.1007/s10586-018-1789-8
10. Zhang, G., Li, Y.: Multiple Disciplines Product Design Knowledge Representation Strategy Based on Ontology and Semantic Network. TELKOMNIKA, vol. 11, **10**, 6074–6079 (2013) doi: 10.11591/telkomnika.v11i10.3467
11. Dudycz, H.: Usability of Business Information Semantic Network Search Visualization. In: Sikorski, M., Dittmar, A., Marasek, K., de Greef, T. (eds.) Proceedings of Multimedia, Interaction, Design and Innovation MIDI'15, ACM Digital Library, Article no. 13, 1-9 (2015) doi: 10.1145/2814464.2814477
12. Ward, M., Grinstein, G., Keim, D.: Interactive Data Visualization Foundations, Techniques, and Applications. Taylor & Francis Group (2015)
13. Zhu, B., Chen, H.: Information visualization. Annual Review of Information Science and Technology, **39**, 139–177 (2005) doi: 10.1002/aris.1440390111
14. Burkhard, R.A., Meier, M.: Tube map visualization: Evaluation of a novel knowledge visualization application for the transfer of knowledge in long-term projects. Journal of Universal Computer Science, vol. 11, **4**, 473-494 (2005)
15. Lopes, A. A., Pinho, R., Paulovich, F. V., Minghim, R.: Visual text mining using association rules. Computer & Graphics, **31**, 316-326 (2007)
16. Grand, B., L., Soto, M.: Topic maps, RDF graphs, and ontologies visualization. In: Geroimenko, V., Chen, C. (eds.) Visualizing the Semantic Web. XML-Based Internet and Information Visualization, Springer-Verlag, London, 59–79 (2010) doi: 10.1007/1-84628-290-X
17. Wienhofen, L., W., M.: Using Graphically Represented Ontologies for searching Content on the Semantic Web. In: Geroimenko, V., Chen, C. (eds.) Visualizing the Semantic Web. XML-Based Internet and Information Visualization, Springer-Verlag, London, 137-153 (2010) doi: 10.1007/1-84628-290-X
18. Eppler, M., E.: Facilitating knowledge communication through joint interactive visualization. Journal of Universal Computer Science, 10, **6**, 683–690 (2004)
19. Eppler, M. J., Burkhard, R. A.: Knowledge Visualization Towards a New Discipline and its Fields of Application. Universit`a della Svizzera Italiana, January (2004).
20. Azzi, R., Desprès, S., Nobécourt, J.: MCVGraphviz: a web tool for knowledge dynamic visualization. IEEE-RIVF International Conference on Computing and Communication Technologies (RIVF), 1-6 (2019) doi: 10.1109/RIVF.2019.8765697
21. Reeve, L., Han, H., Chen, C.: Information visualization and the semantic web. In: Geroimenko, V., Chen, C. (eds.) Visualizing the Semantic Web. XML-Based Internet and Information Visualization, London, Springer-Verlag, 19–44 (2010)
22. Arp, R., Smith, B., Spear, A., D.: Building ontologies with basic formal ontology. Mass: MIT Press, Cambridge (2015)

23. Achich, N., Bouaziz, B., Algergawy, A., Gargouri F.: Ontology Visualization: An Overview. In: Abraham, A., Muhuri, P., Muda, A., Gandhi, N. (eds) Intelligent Systems Design and Applications ISDA 2017. Advances in Intelligent Systems and Computing, Springer, **736**, 880-891 (2018) doi: 10.1007/978-3-319-76348-4_84
24. Dudáš, M., Lohmann, S., Svátek, V., Pavlov, D.: Ontology visualization methods and tools: a survey of the state of the art. The Knowledge Engineering Review, vol. 33, **e10**, 1–39 (2018) doi: 10.1017/S0269888918000073
25. Fu, B., Noy, N., F., Storey, M-A.: Indented Tree or Graph? A Usability Study of Ontology Visualization Techniques in the Context of Class Mapping Evaluation. In: ISWC '13 Proceedings of the 12th International Semantic Web Conference - Part I, Springer-Verlag, New York, 117-134 (2013) doi: 10.1007/978-3-642-41335-3_8
26. Lanzenberger, M., Sampson, J., Rester, M.: Ontology visualization: tools and techniques for visual representation of semi-structured meta-data. Journal of Universal Computer Science, 16, **7**, 1036-1054 (2010) doi: 10.3217/jucs-016-07-1036
27. Sivakumar, R., Arivoli, P.V.: Ontology Visualization Protégé Tools – A Review. International Journal of Advanced Information Technology, vol. 1, **4** (2011)
28. Ramakrishnan, S., Vijayan, A.: A study on development of cognitive support features in recent ontology visualization tools. Artificial Intelligence Review, 41, **4**, 595–623 (2014) doi: 10.1007/s10462-012-9326-2
29. Ertek, G., Tokdemir, G., Sevinç, M., Tunç, M.,M.: New knowledge in strategic management through visually mining semantic networks. Information Systems Frontiers, Springer US, 1-21 (2015) doi: 10.1007/s10796-015-9591-0
30. Fu, B., Noy, N., F., Storey, M-A.: Eye Tracking the User Experience - An Evaluation of Ontology Visualization Techniques. Semantic Web Journal – Interoperability, Usability, Applicability, IOS Press (2014)
31. Moshref, M. Al-Sayyad, R.: Developing Ontology Approach Using Software Tool to Improve Data Visualization (Case Study: Computer Network). I.J. Modern Education and Computer Science, **4**, 32-39 (2019) doi: 10.5815/ijmecs.2019.04.04.
32. Khalili, A., Auer, S.: WYSIWYM – Integrated visualization, exploration and authoring of semantically enriched Un-structured Content. Semantic Web Journal 6, 3, 259–275 (2014).
33. Korczak J., Dudycz H., Nita B., Oleksyk P.: Towards Process-Oriented Ontology for Financial Analysis. In: Ganzha, M., Maciaszek, L., Paprzycki, M. (eds.) Proceedings of the 2017 Federated Conference on Computer Science and Information Systems. Annals of Computer Science and Information Systems, **11**, 981-987 (2017) doi: 10.15439/2017F181
34. Stab, C., Nazemi, K., Breyer, M., Burkhardt, D., Kohlhammer, J.: Semantics visualization for fostering search result comprehension. In: The Semantic Web: Research and Applications. Proceedings: ESWC 2012, Lecture Notes in Computer Science, **7295**, 633–646 (2012) doi: 10.1007/978-3-642-30284-8_49
35. Shneiderman, B.: The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. In: Proceedings of the IEEE Symposium on Visual Languages, 336-343 (1996)
36. Kitchenham, B.: Procedures for performing systematic reviews. Joint Technical Report, Keele: Keele University TR/SE-0401 and NICTA 0400011T.1, July (2004)
37. Nazemi 2010 Nazemi, K., Breyer, M., Burkhardt, D., Fellner, D.W.: Visualization Cockpit: Orchestration of Multiple Visualizations for Knowledge-Exploration. International Journal of Advanced Corporate Learning, 3, **4,** 26-34 (2010)
38. Eisenstein, J., Chau, D. H., Kittur, A., Xing, E.: TopicViz: Semantic Navigation of Document Collections, arXiv preprint arXiv:1110.6200, 1-14 (2011) https://arxiv.org/pdf/1110.6200.pdf

39. Burkhardt, D., Nazemi, K., Breyer, M., Stab, C., Kuijper, A.: SemaZoom: Semantics Exploration by Using a Layer-Based Focus and Context Metaphor. In: Kurosu. M. (ed.) Human Centered Design. HCD 2011. Lecture Notes in Computer Science, **6776,** 491-499 (2011) doi: 10.1007/978-3-642-21753-1_55
40. Stab, C., Nazemi, K., Breyer, M., Burkhardt, D., Kuijper, A.: Interacting with Semantics and Time. In: Jacko, J.A. (eds) Human-Computer Interaction. Users and Applications. HCI 2011. Lecture Notes in Computer Science, **6764**, 520-529 (2011) doi: 10.1007/978-3-642-21619-0_64
41. Weiss, R., MUCK: A toolkit for extracting and visualizing semantic dimensions of large text collections. In: Proceedings of the Workshop on Interactive Language Learning, Visualization, and Interfaces, 53–58 (2014)
42. Larrea, M.L., Martig, S.R., Castro, S.M.: Semantics-based colour assignment in visualization. Journal of Computer Science and Technology, 10, **1 (**2010)
43. Lancellotta, P.I., Victor Ströele, V., Braga, R. M. M, David, J. M. N., Campos F.: Semantic Analysis and Complex Networks as Conjugated Techniques Supporting Decision Making. 20th International Conference on Enterprise Information Systems ICEIS'2018 (2), 195-202 (2018) doi: 10.5220/0006662001950202
44. Dudycz, H., Korczak, J.: Process of Ontology Design for Business Intelligence System. In: Ziemba, E. (ed.) Information Technology for Management, Lecture Notes in Business Information Processing, **243**, 17-28 (2016) doi: 10.1007/978-3-319-30528-8_2
45. Dudycz, H.: Approach to the conceptualization of an ontology of an early warning system, In: Jałowiecki, P., Łukasiewicz, P., Orłowski, A. (eds.) Information Systems in Management XI. Data Bases, Distant Learning, and Web Solutions Technologies, no. XI, 29-39 (2011)
46. Korczak, J., Dudycz, H., Dyczkowski, M.: Design of financial knowledge in dashboard for SME managers. In: Ganzha, M., Maciaszek, L., Paprzycki, M. (eds.) Proceedings of the 2013 Federated Conference on Computer Science and Information Systems. Annals of Computer Science and Information Systems, **1**, 1111–1118 (2013)
47. Korczak, J., Dudycz, H., Nita, B., Oleksyk, P., Kaźmierczak, A.: Extension of Intelligence of Decision Support Systems: Manager Perspective. In: Ziemba, E. (ed.) Information Technology for Management: New Ideas and Real Solutions, Lecture Notes in Business Information Processing, **277**, 35-48 (2017) doi: 10.1007/978-3-319-53076-5_3
48. Dudycz, H., Nita, B., Oleksyk, P.: Application of Ontology in Financial Assessment Based on Real Options in Small and Medium-Sized Companies. In: Ziemba, E. (ed.) Information Technology for Management: Emerging Research and Applications, Lecture Notes in Business Information Processing, **346**, 24-40 (2019) doi: 10.1007/978-3-030-15154-6_2