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Improving Argumentation Visualization of Multi-Stakeholder Development Processes - A Prototyping Case

A shared understanding of development argumentation is crucial for a wide range of development processes (such as requirements engineering, change management, eGovernment and eParticipation, public policy) and central to prevent the failure of IT and development projects. Computer-Supported Argumentation Visualization (CSAV) has been used to model and represent discourse information for about 35 years. Although modelling tools have significantly matured and continue to evolve, the visual representation of existing tools does not scale ideally with increasing model complexity. For large-scale argumentation models, existing visualization approaches from argumentation visualization are reported as being too complex for target stakeholders. This prevents them from gaining insights into the development process and may ultimately contribute to the rejection of the development result, causing severe costs for both public and private organizations. In this paper, we employ the 'design science' methodology to incrementally develop two interactive visual representations for argumentation visualization, incorporating best practices from information visualization research. The prototypes are implemented and evaluated in the setting of the project "Research Core Dataset", a nation-wide project involving all major stakeholder groups of the German science system in order to develop harmonized definitions for research information. In our evaluation, both of the visual representations developed are perceived as being much better at providing insights into complex development processes with a high number of stakeholders.

Computer-Supported Argumentation Visualization, CSAV, argumentation visualization, information visualization, design science

1 Introduction

Complex development processes involving many stakeholders are often costly and inherently challenging. Depending on the study and development field, 9–22 % of development projects are failures and another 26–31 % are challenged (i.e. they do not meet time and financial constraints) (El Emam & Koru, 2008; Eveleens & Verhoef, 2010; Glass, 2006; Jørgensen & Moløkken-Østvold, 2006), causing severe costs for public and private organizations. The vast majority of existing studies indicate that large projects with more complex requirements and multiple stakeholders have considerably higher failure rates of 75 % or more (Heeks, 2003; Jones, 2000; Rubinstein, 2007; Sauer & Cuthbertson, 2003; Standish, 2001). Major reasons for project failure in large-scale development processes are a lack of involvement and acceptance among users and stakeholders (Al Neimat, 2005; Cerpa & Verner, 2009; Conklin, 2006; Rittel & Webber, 1973), delivery decisions being made without adequate requirements information (Cerpa & Verner, 2009) and the project scope and objectives changing while the development is being implemented (Al Neimat, 2005; Cerpa & Verner, 2009).

We believe that higher rates of involvement, agreement and acceptance can be achieved if stakeholders and other concerned parties are provided with more detailed and accessible insights into the reasoning behind the decision and development process. For example, it can be important for users to know the reasoning behind the design decisions concerning the amount of private

data to be collected and processed in an HR system, in social media platforms, or resident registration systems.
It has been argued that argument-centred mapping may provide a useful tool for offering such insights (Schoder, Putzke, Metaxas, Gloor, & Fischbach, 2014). A widely used and intensively researched approach for this task is Design Rationale (DR). It aims to present "the design alternatives which were considered, the arguments for and against these alternatives and the reason why final design decisions were made" (Monk, Sommerville, Pendaries, & Durin, 1995). DR has evolved from Kunz and Rittel's proposed Issue-Based Information System (IBIS) (Kunz & Rittel, 1970) notation as a way to structure and document highly complex decision processes, which is still the most widely used notation for argumentation maps (Scheuer, Loll, Pinkwart, & McLaren, 2010). IBIS helps to elicit and clarify the arguments in an intuitive, flexible, and fast way during a debate by documenting them in a semi-formal representation (Shum et al., 2006).
Although modelling tools in the area of DR have significantly matured and continue to evolve, the visual representations provided by existing tools (for example Compendium NG Web Map) do not scale well with increasing model complexity. In real-world large-scale argumentation models, existing visualization approaches from argumentation visualization are reported as being too complex to be of help for target stakeholders. This prevents target stakeholders from gaining insights into the development process and may ultimately contribute to the rejection of the development result, causing severe costs for both public and private organizations.

In this paper, we employ the 'design science' methodology to incrementally develop two interactive visual representations for argumentation visualization, incorporating best practices from information visualization research to reduce the visual complexity.
Following the design science paradigm, we address a real-world problem to generate findings for comparable use cases. As a case study we employ the large-scale development project "Specification of a Research Core Dataset for the German Science System". In this project, a national standard for information about research activities was developed in an incremental multi-stage process involving representatives of all major stakeholder groups in the German science system. An incremental development approach was employed in order to maximize the applicability of the prototypes. The prototypes were presented to the stakeholders in the project. The article is structured as follows: Section 2 provides a brief overview of the case setting and the development context. Section 3 discusses related work in the area of DR as well as information visualization. The methodology of the paper is outlined in Section 4. Section 5 describes the prototypes' development. In Section 6 the evaluation is described. Finally, Section 7 provides an outlook about consequences for development processes and identifies potential for further research in the fields of DR and information visualization.

2 Case Setting

The use case we analyse is the finished standard development project "Research Core Dataset" (RCD). The project was scheduled for 24 months (October 2013 – October 2015) and was initiated by the German Council of Science and Humanities with the aim of developing a shared set of definitions for research information about staff, publications, third-party funding, patents, young researchers and research awards for the German science system. More than 48 different stakeholder groups were directly involved in the process. They included representatives of universities, non-university research institutions, ministries, research information system vendors and scientific societies. The specification process was organized into four groups with eight experts each. Each group held up to six meetings lasting 1–2 days, with 8 hours discussion time per meeting. The project group "definitions and data formats" defined research information for all of the areas stated above. To combine internal expertise with real-world evaluation of the proposed definitions, the procedure combined development workshops and a feedback phase with representatives of pilot organizations, non-university research institutions, funding organizations and research information system vendors. Another discussion phase was conducted after the feedback phase in order to integrate the range of external feedback (more than 1800 feedback messages were incorporated into the project) into the definition specification.

3 Related Work

3.1 Design Rationale

Design Rationale (DR) aims to document "the design alternatives which were considered, the arguments for and against these alternatives and the reason why final design decisions were made" (Monk et al., 1995). DR has evolved from Kunz and Rittel's proposed Issue-Based Information System (IBIS) (Kunz & Rittel, 1970) notation as a way to address "wicked problems". Based on Rittel and Webber (1973), wicked problems are defined as complex design problems "for which no single computational formulation of the problem is sufficient, for which different stakeholders do not even agree on what the problem really is, and for which there are no right or wrong answers, only answers that are better or worse from different points of view" (Introne, Laubacher, Olson, & Malone, 2013, p. 45). Rittel identified ten criteria defining the nature of a wicked problem. We argue that these criteria are met in the case of increasingly complex development projects involving high numbers of stakeholders. We have previously analysed the applicability of Rittel's criteria of a wicked problem for the specification process (Riechert, Biesenbender, Dees, & Sirtes, 2016). A formal content analysis provided a deep insight into the dimensions of complexity. The results of the content analysis underline our interpretation of the development process as a wicked problem according to the criteria stated. As IBIS was implicitly designed to address wicked problems, its application to our case is presumed to offer the best fit. Despite its long-ranging history, IBIS is still the most widely used notation for argumentation maps (Scheuer et al., 2010). Using it helps to elicit and clarify the arguments in an intuitive, flexible and fast way during a debate by documenting them in a semi-formal representation (Shum et al., 2006). IBIS was later extended to graphical IBIS (gIBIS) (Conklin & Begeman, 1988), which has found widespread adoption and application in current tools like Compendium (Selvin et al., 2001). Newer versions of Compendium have since been published, as have numerous studies on the influence of argumentation visualization on the working atmosphere in discussions (we refer to Schneider et al. (2013), Scheuer et al. (2010), and Suthers (2008) for an overview). Computer-Supported Argumentation Visualization (CSAV) widens the scientific debate on argumentation modelling and discussion moderation by also addressing questions of how to present the argumentation. CSAV on the basis of IBIS has been employed in the areas of eGovernment and eParticpation with the goal of presenting argumentation information to enhance participation (Loukis & Wimmer, 2012; Loukis, Wimmer, Charalabidis, Triantafillou, & Gatautis, 2007; Renton, 2006). In eParticipation research, IBIS has been used both without and with minor adoptions. The resulting maps are therefore of high complexity when it comes to real-world argumentation structures. Although user studies found that argumentation maps have advantages over textual representation (Loukis & Wimmer, 2012; Renton, 2006), our pre-tests with more complex argumentation maps showed that high diagram complexity causes serious issues for diagram presentation, comprehensibility and usability, which increases the access barrier and may lead to total rejection of the development results. In order to improve the visual representation of complex argumentation visualizations, we use best practices from information visualization.

3.2 Information Visualization

Interestingly, the academic discourse on argumentation visualization has hitherto been largely independent of the discussion in the literature on information visualization.
The term 'Information Visualization' was introduced by Robertson, Card and Mackinlay (1989) and refined by Card et al. in 1999: "Information visualization is the use of computer-supported interactive visual representations of abstract data to amplify cognition" (Card, Mackinlay, & Shneiderman, 1999). In information visualization research, reducing the complexity of visual information to allow for better information perception and to amplify cognition has been a central topic since the field emerged. Based on research from psychology and perception studies (Treisman, 1985; Ware, 2004; Wertheimer, 1922), several approaches have been discussed for the development of information visualization. The most prominent approaches are the 'visualization mantra' (Shneiderman, 1996; Shneiderman & Plaisant, 2006) and the 'reference model for visualization' (Card et al., 1999), which was later extended to the 'reference model for developing visual representations' (Mazza, 2009). These two approaches aim at different development levels: While the 'visualization mantra' provides general guidelines and functionality for reducing visualization complexity, the reference model aims at providing a detailed process for developing visualizations from raw data.
To the best of our knowledge, the application of information mapping to the elements of argumentation visualization has not yet been discussed by researchers. To reduce the high diagram complexity of argumentation visualizations so as to provide better insights and enhance transparency, we exploratively employ the reference model for developing visual representation (Card et al., 1999, p. 18; Mazza, 2009), along with interactive visualization guidelines from Shneiderman (1996).

4 Method

We employ the Design Science paradigm, which is rooted in engineering and the sciences of the artificial (Simon, 1969) and develops knowledge about a problem domain and its solution in the building and application of the designed artefact (A. R. Hevner, Salvatore, Park, & Ram, 2004). It furthermore allows for the development of a rational reasoning of characteristics and functionality of the developed artefact (Pries-Heje & Baskerville, 2006). We apply the synthesized Design Science paradigm (Gregor & Hevner, 2013; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007) to improve existing argumentation visualizations and develop knowledge about the applicability of existing visualization principles for complex visualizations from information visualization.
To evaluate the prototypes, we conducted a qualitative and a quantitative evaluation phase: First, we used the criteria found in the expert interviews during the development phase as the structure of a semi-formal qualitative evaluation with ten interviewees, who had not seen the prototypes in advance. Each interviewee was asked the same questions systematically and could provide multiple arguments about why the respective criterion was more advantageous in one of the representations. As the focus is to analyse the criteria in detail, we refer to this in the following as the content-oriented evaluation. Details of the sampling are provided in the evaluation section (Section 6). Secondly, we asked the interviewees which one of the representations they preferred. In this evaluation, only one preference is counted per interviewee, which is why we call this evaluation the preference-oriented evaluation. The qualitative evaluation results are then compared to a quantitative evaluation phase, where the same questions were put to 105 new interviewees after seeing two of the visual representations. Details of the sampling and analysis method are provided in the evaluation section (Section 6).

5 Prototype Development

5.1 Requirements

We extracted the requirements from two sources: Firstly, we conducted 6 expert workshops with 8 experts each to model the rationale of the project's results. In each workshop, all stated alternatives and arguments were documented in Compendium NG using the IBIS notation, resulting in an argumentation model of about 1200 interconnected nodes. Secondly, the argumentation maps were made available to cooperation stakeholders. In total, 13 representatives of cooperation stakeholders were included for feedback on the visualization in that phase.
Existing tools for argumentation visualization offer different forms of visual representation of argumentations. In Compendium NG, the graphical model can be exported to bitmap or Compendium Web Maps (an interactive browser map with each sub-map and node opening a new browser window).
The modelling process involving increasing complexity of the argumentation model revealed that Compendium's argumentation maps scale poorly when the issue and argumentation structure grows larger than about 60 nodes per sub-map. One possible **complexity reduction strategy** is to introduce new levels of sub-maps so as to keep visual complexity constantly low when viewing. With the argumentation complexity reached in our case (>1200 nodes in total), this would result in up to nine levels of sub-maps. This was reported to be confusing to the extent that our experts refrained from using these maps. Alternatively, all levels can be modelled using one map, resulting in a huge network map showing all nodes. Although we introduced, documented and explained additional structuring rules, such maps were reported to be too complex to be grasped by the experts involved. This conflicts with Conklin's (2003) claim, which was later reinforced by Awati (2011), that IBIS is intuitive and understandable without prior explanation and documentation. In those studies however, the number of nodes (and, therefore, node complexity) was much lower than in our real-world example. Feedback from our external stakeholders showed that persons not included in the decision process were overwhelmed by the high complexity of the diagram and preferred discussion protocols.
However, discussion protocols are very impractical to explore, as the entire contents need to be shown in text form (more than 150 pages in our case) without the possibility for elaborate information aggregation, navigation or filtering.
As visual representations are potentially stronger in this regard, but the existing Compendium Web Maps are reported to have serious drawbacks, we set visualization quality and complexity reduction as the main requirements for any further development of a visual representation.
Further comments were concerned with **visual quality**, as the Compendium Web Maps are of a relatively low quality (blurry when printed, connecting edges show single pixels). Additionally, the space required to present maps of this size results in high requirements for printing and documentation.
To develop a visualization prototype, two additional requirements were extracted: Firstly, our goal is to provide the **full information depth** that can be provided by the Compendium's Web Map or the protocol form. Secondly, we set the goal of presenting the visualization on a platform available online **to minimize the access barrier** for the stakeholders.
Consequently, the following requirements were extracted from the case:
R1: include functionality to reduce the visual complexity of the argumentation visualization
R2: higher accessibility of the argumentation visualization than Compendium Web Maps
R3: improve information presentation and coding compared to Compendium Web Maps
R4: provide the same depth of information as in Compendium Web Maps

5.2 Prototype Development

The development description is structured based on the 'reference model for developing visual representations' (Mazza, 2009). Each step in the process is described in a subsection.

5.2.1 Information Collection, Data Modelling and Transformation

We collected the discourse knowledge in the form of meeting protocols and a discourse argumentation tree in Compendium NG (using the IBIS notation). Compendium NG was used because it allows for fast and intuitive diagram editing, tagging and export of argumentative models. The meeting documentation spans over 80 hours of discussion time across 7 meetings plus external feedback. The resulting network diagram structure comprises more than collected 1200 nodes (including 614 arguments). Data modelling was performed both during the discussion meetings and in the subsequent review of the protocol. An example of an argumentation model is shown in Figure 1.

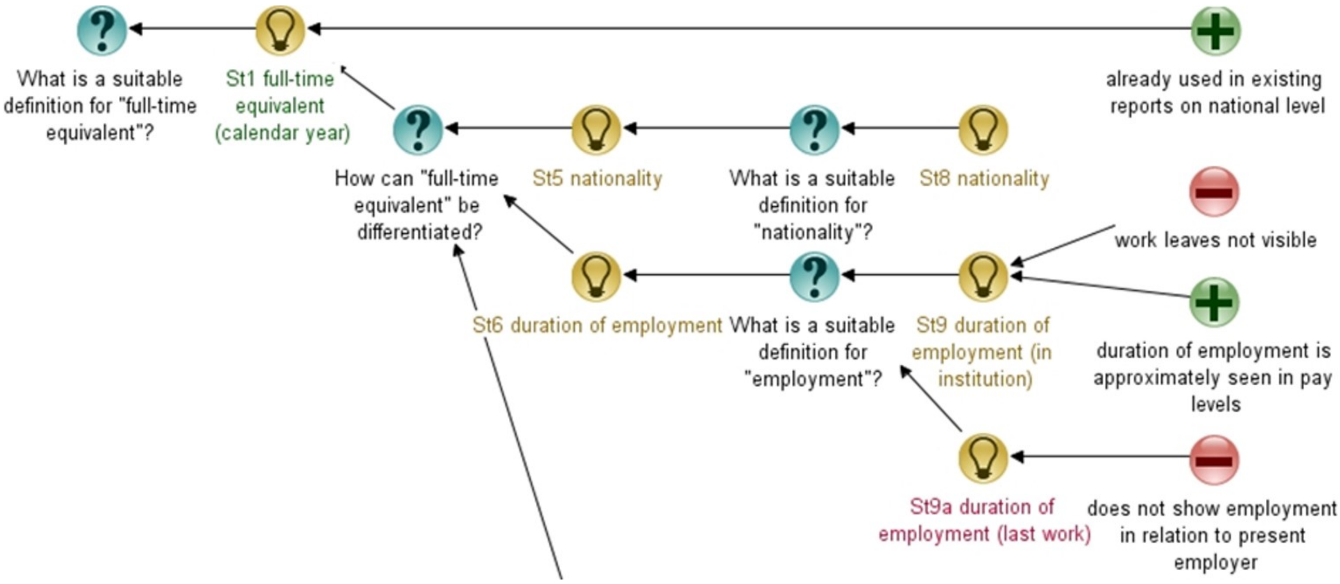

Figure 1: Excerpt from a Compendium Web Map (modelled in IBIS)

The tree starts with a question node. Each question can have one or more answers.
In our case (see Section 2), only three types of questions are required: (1) "What is a suitable definition for …?", (2) "How can … be differentiated?", (3) "What are possible attributes for …?". If more than one alternative has been discussed, they are added as two nodes on the same level. Each node can be supported or challenged by arguments (seen on the right side).
The argumentation model is exported to XML and further computed in a custom-developed transformation program that transforms the argumentation tree structure into a JSON tree structure for later use in the visualization prototype. The transformation is decoupled from the visualization prototype in order to optimize access times of the online platform.

5.2.2 Visual Mapping

After the data is transformed into JSON, the data structures are applied to visual structures. The argumentation model is rooted in a single element, which is refined in sub-questions. The argumentation therefore forms a hierarchical tree. Consequently, we choose two tree visualization approaches for our prototypes: a hierarchical tree node map (HTNM) and a packed circle map (PCM).[1] Hierarchical tree node maps are one of the oldest forms of graphic representation of

[1] A working demo can be found here: HTNM and PCM (texts in German).

hierarchies and show the connection between nodes by links on a map. The most common example of this is the Windows Explorer interface. Packed circle maps were developed by Wang et al. (2006) to provide a clear overview of complex hierarchical structures, and have proven beneficial in initial evaluations (2006). We use the layout algorithms implementing this concept in the D3 JavaScript library,[2] the successor of Protovis (Michael Bostock & Heer, 2009). This makes it possible to render interactive online scalable vector graphics.

5.2.3 View Creation

The view is the central access and interaction point for the visualization users. We based our implementation and further development on existing visualization libraries in D3, as it provides SVG (scalable vector graphics) rendering, can read JSON data and is based on JavaScript. Therefore, it is fully functional in the browser without the need for any installation. For the packed circle maps, the 'circle packing layout' (M Bostock, 2012)[3] was implemented. For the hierarchical trees (HTNM) we developed a new layouting, as the existing 'collapsible tree layout' uses too much vertical space, does not work well with different text lengths and leaves no space for alternatives and arguments.

In order to reduce the visual complexity without reducing the depth of information, the implementation was further developed by implementing functionality from Shneiderman's 'Task by paper type taxonomy' – or the 'visualization mantra' (Shneiderman, 1996):

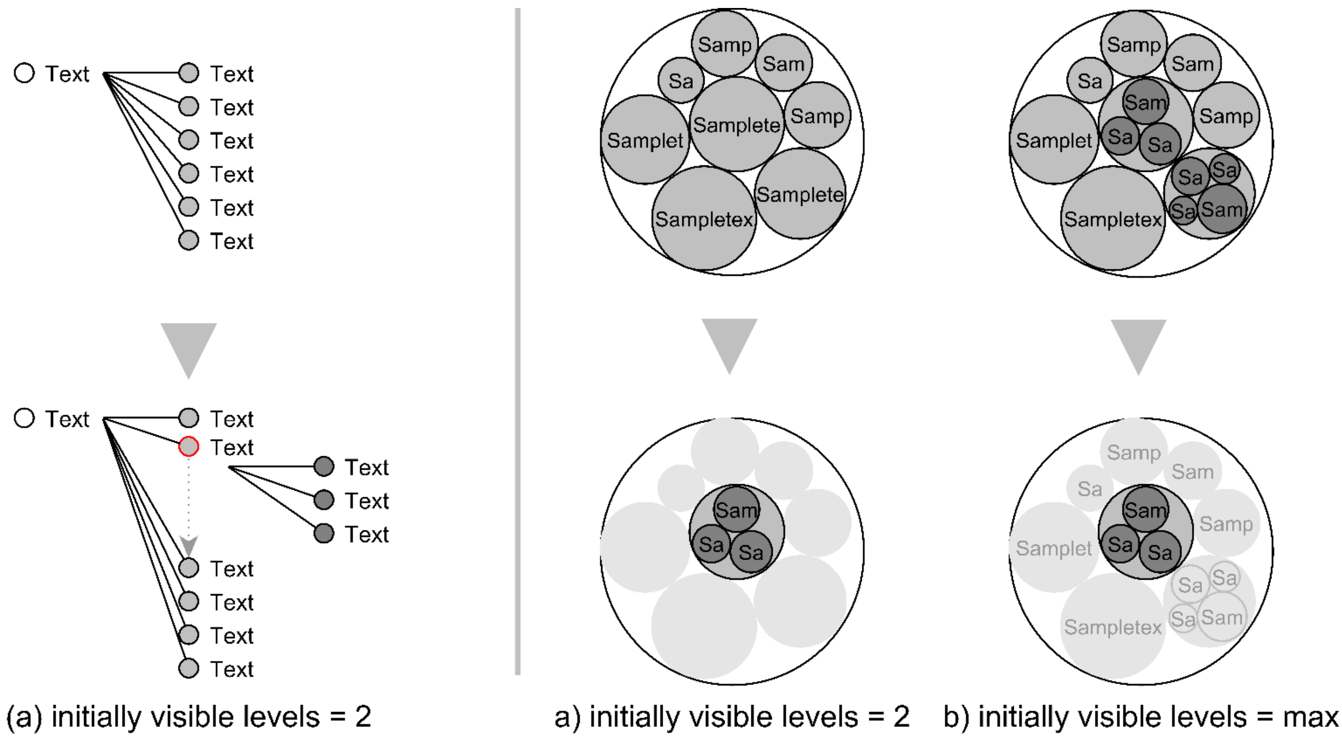

Figure 2: Overview for the hierarchical tree map (HTNM – left) and packed circle map (PCM – right) with two (a) and max (b) initial visible levels

Overview: Gain an overview of the entire argumentation: Mapping all argumentation information is a challenging task. Overall, 1189 nodes (575 answers, questions and notes and 614 arguments) in seven content areas are documented. We developed a visual representation that provided an initial overview showing only 1–3 hierarchy levels (configurable) initially (see section filter) but allowed for interactive

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[2] D3 stands for Data-Driven Documents. http://d3js.org/

[3] A minimal working example can be found at http://bl.ocks.org/mbostock/4063530.

transition into the higher hierarchy levels (see section zoom). Figure 2 shows a sample HTNM on the left and a PCM on the right. The first row shows the initial overview. In (a), only one level below the root element is shown. (b) shows how all levels can be presented in parallel in the PCM. When clicking, the visible elements are rendered as shown in the second row. In the HTNM, the sub-nodes of the clicked element are shown. Note that all other nodes on the same level as the clicked node are moved, to ensure that sub-nodes do not overlap. To keep the visualization structured, the element labels are rendered next to the nodes on predefined hierarchy levels. In the PCM, the sub-nodes of the clicked element are rendered inside the element. The D3 visualization library (Michael Bostock, Ogievetsky, & Heer, 2011) was chosen for the implementation because it renders SVG (scalable vector graphics) maps and allows for user interaction and direct data binding.

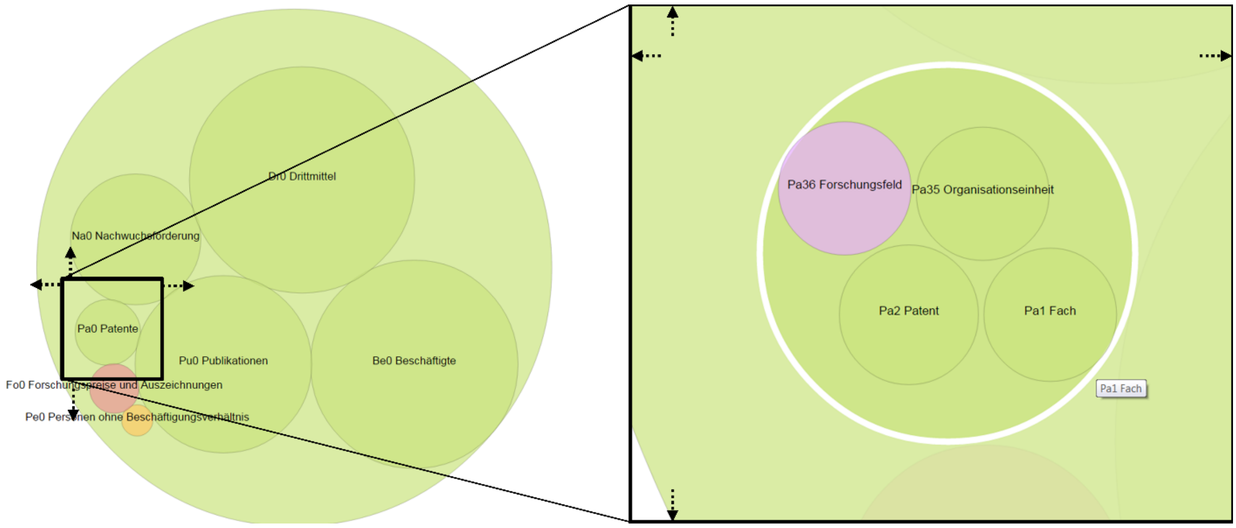

Figure 3: PCM: After clicking on a node, the viewport zooms to the node and its sub-nodes

Zoom: Zoom in on and pan to items of interest: In contrast to Compendium Web Maps, which are only scalable from 100 % to 25 % and become pixelated when zooming in above 100 %, it is possible to zoom in and out of both developed visualizations without any loss of quality for rendering or printing. Zooming can be triggered by using the standard zoom interactions (mouse wheel and gestures) or by clicking on an element on a higher detail level.
Furthermore, the zooming design pattern is also used for focusing on the relevant part of the map in PCM. Figure 3 shows the zoom after clicking the ‘Pa0 Patente’ node.

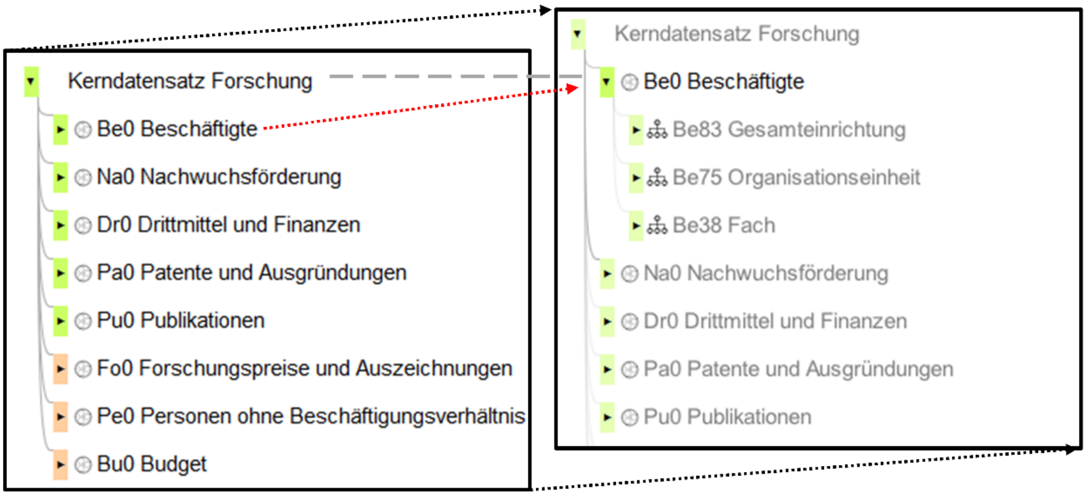

Figure 4: HTNM: After clicking on a node, the viewport is panned to the node and its sub-nodes

In HTNM, pan is used to navigate to the clicked element and the sub-elements displayed (see Figure 4). In order to keep the user's focus, all elements are moved so that the newly focused element is at the position of the previously focused element.
It is important to note that the use of D3 allows for fluent transitions of the visible part of the diagram (viewport) in a browser. No website reload is needed and the user is able to perceive the zoom and pan transitions through the map.
Filter: Filter out uninteresting items: In order to reduce the items visible at the same time, only the highest hierarchy levels (1–3) are shown initially (see overview).
For PCM, a fundamental problem surfaced after implementing the visualization like in the example in D3. As our diagram has more than 1200 nodes, rendering all nodes results in very slow in-browser performance. We therefore developed a concept that reduces the number of nodes rendered in parallel without restricting navigation into the hierarchy and back. Furthermore, we wanted the user to be able to switch branches of the tree by clicking on a parallel branch. Therefore we implemented a recursive visibility concept (shown in Figure 5), that shows elements of higher or the same hierarchy level with high transparency to blend out non-focused nodes. Elements on a lower hierarchy level are shown only up to the number of configured levels below (one level in the example), to allow for intuitive navigation. Elements on the same level but in a different branch of the tree are only shown up to the level that the tree branches off. By only rendering elements in the same branch, the performance can be kept high, while all relevant information about the navigation path and sub-elements (full visibility) and its junctions (transparent) are visible. As circles are packed on top of each other, the displayed text is always shown on the visibility level (clicked level plus configured number of levels) for elements in the branch of the clicked element, and on the circles on the last visible (transparent) level. Texts not in the branch of the selected element are rendered with higher transparency. Note that the viewport in Figure 5 zooms and pans as described a little earlier.

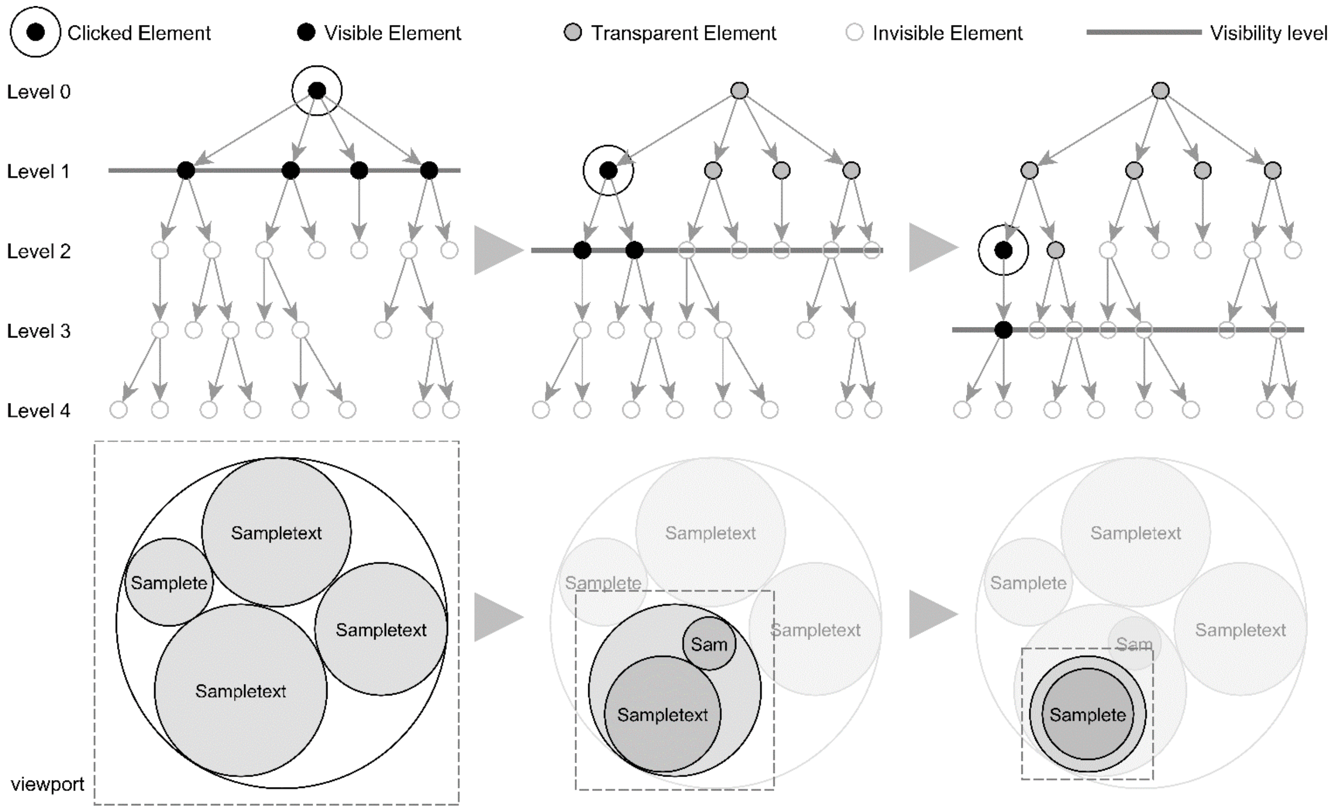

Figure 5: PCM: Visibility concept with the tree structure above and the resulting circle visualization below

For HTNM, the selected element and branch are highlighted by fading non-selected elements to a higher transparency.

A content filter is implemented for both visual representations. Based on the element tags (which are set in Compendium), parts of the diagrams can be filtered. Figure 6 shows the filter menu on the right with the changes when deselecting a content group. This filter uses tags given to the diagram elements in Compendium. Using this approach, whole areas that have a preliminary status or relevance for specific stakeholder groups can be hidden in a flexible way. In contrast to Compendium Web Maps, we do not require a reloaded map or new positioning for the filtering, but the original maps can dynamically fade to the filtered mode. Using this technique, all elements stay in their original position and the navigation history is much clearer for the user.

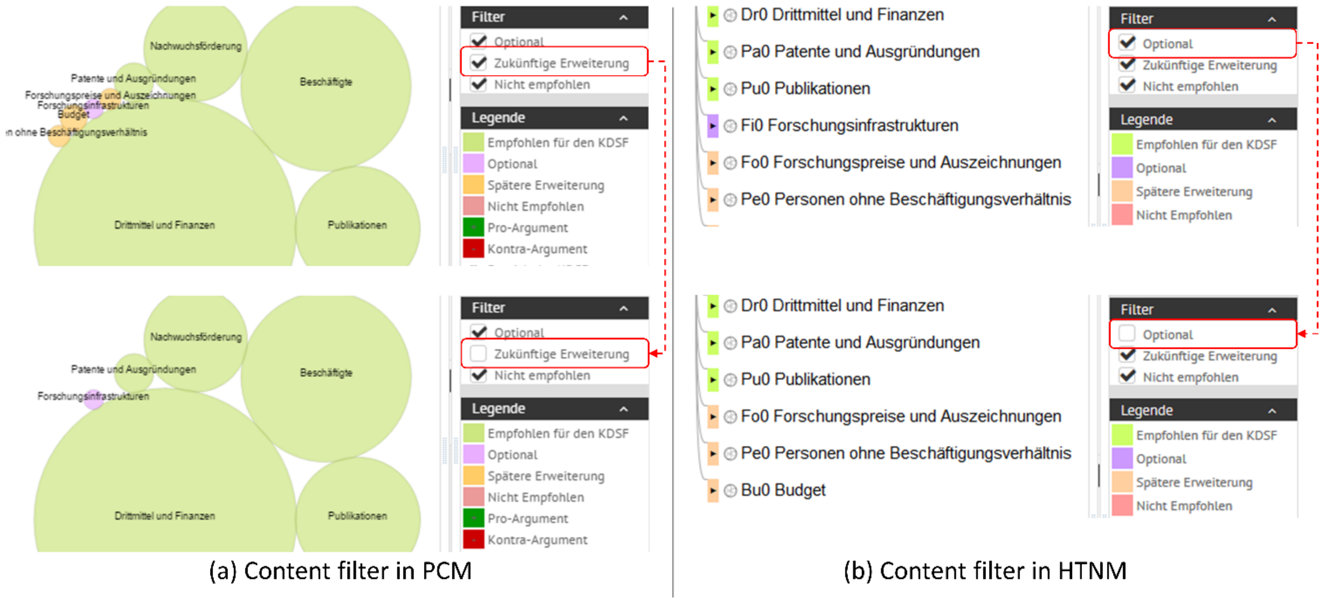

Figure 6: Filtering in PCM (a) and HTNM (b)

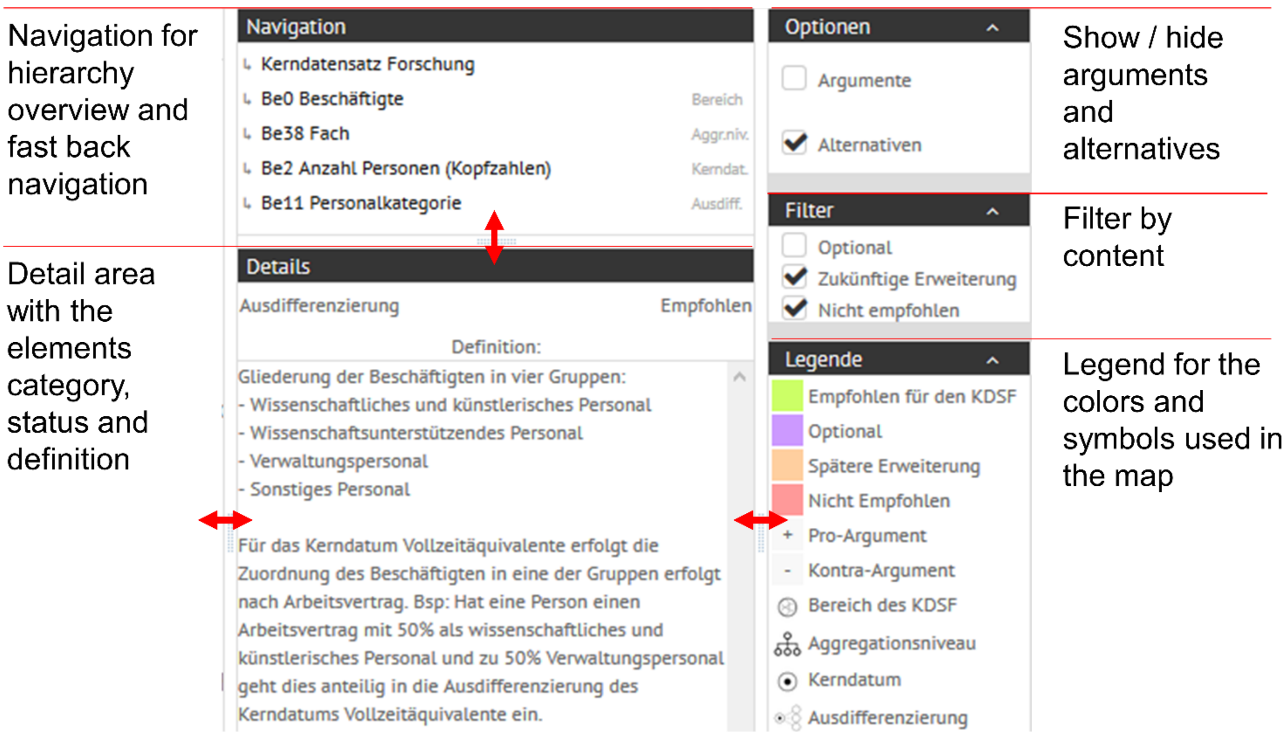

Figure 7: Details menu with navigation, details, options, filter and legend sub-menus

Details-on-demand: Select an item or group and get details when needed: The details-on-demand functionality is implemented with three concepts.

Firstly, the node focus can be changed by clicking on a node's sub-node or a node which is visible in parallel (see Figure 5). This is possible in Compendium Web Maps as well, but our implementation allows for dynamic hierarchy level transitions without the need to manage multiple windows. This is of particular importance if there are a high number of hierarchy levels. Both HTNM and PCM show visually which hierarchy depth is being focused on.

Secondly, detailed information about the focused element is accessible with a context menu on the right screen side (shown in Figure 7).

Because we use clicking for changing the focus, we expect that the user wants information about the clicked element. If detailed information is desired, then only displaying the context information once a user has clicked on the element results in the necessity to click on each element (similar to Compendium Web Maps). Providing detailed information when hovering over a node significantly reduces the number of clicks required to provide information, but conflicts with the click-and-focus logic above. We therefore developed a two-step focus concept, to integrate both advantages (Figure 8). After clicking on an element, the focus is set on that element (state (i)). In this state, only the detailed information of the clicked element is displayed in the detail area, even if the user hovers over other elements. If another element is clicked on from here, the focus is set to the next clicked element in state (i). If the same element is clicked on again, the element is set to status (ii). Now, the hovering information is activated and detailed information about other (not clicked) elements can be obtained much faster. Using this approach, both clicking information and hovering information can be provided with minimal user interaction.

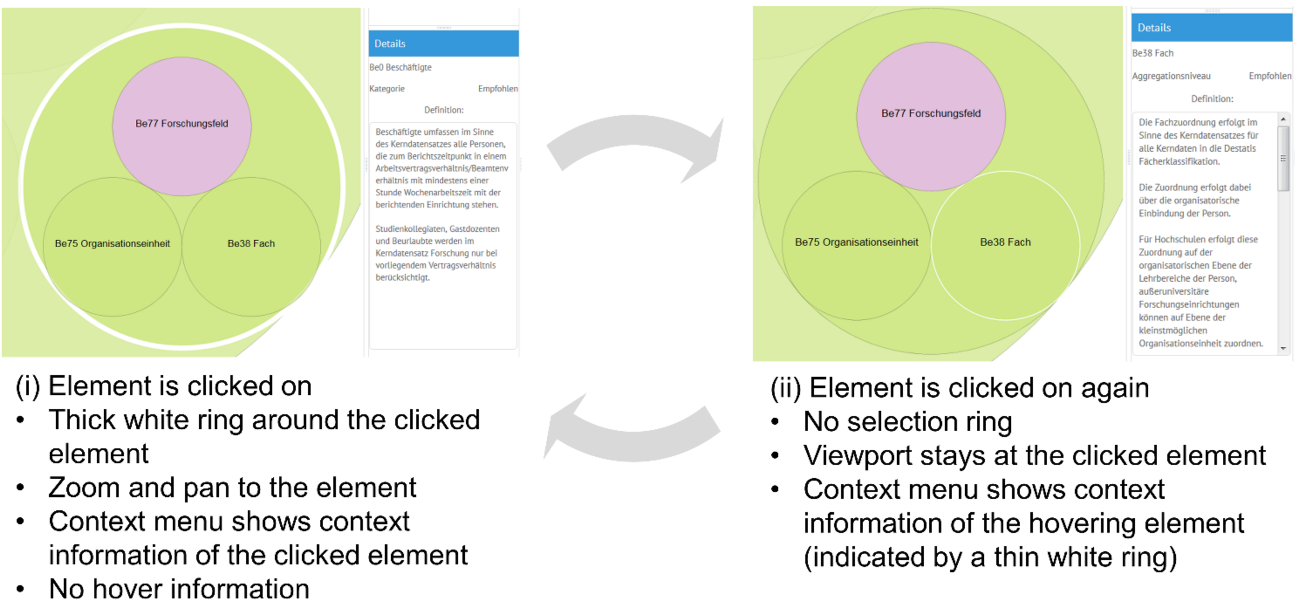

Figure 8: Focus concept with two states to integrate click and hover detail information

Thirdly and most importantly for argumentation maps, we fade in alternatives and arguments when an element has been clicked on in PCM. This information is already accessible in the detailed menu, but a visual representation in the map is more present and allows for further interaction. Figure 9 shows the implementation of the alternatives (represented by circles around the focused element) and arguments (represented by circle segments around each element). After the second click on the focused element, information about the alternatives and arguments is provided by the hover information, significantly reducing the number of clicks required (see focus concept in Figure 8). Note that the number of arguments determines the number of circle segments. For the element 'Be38c' (on the left), no arguments were documented.

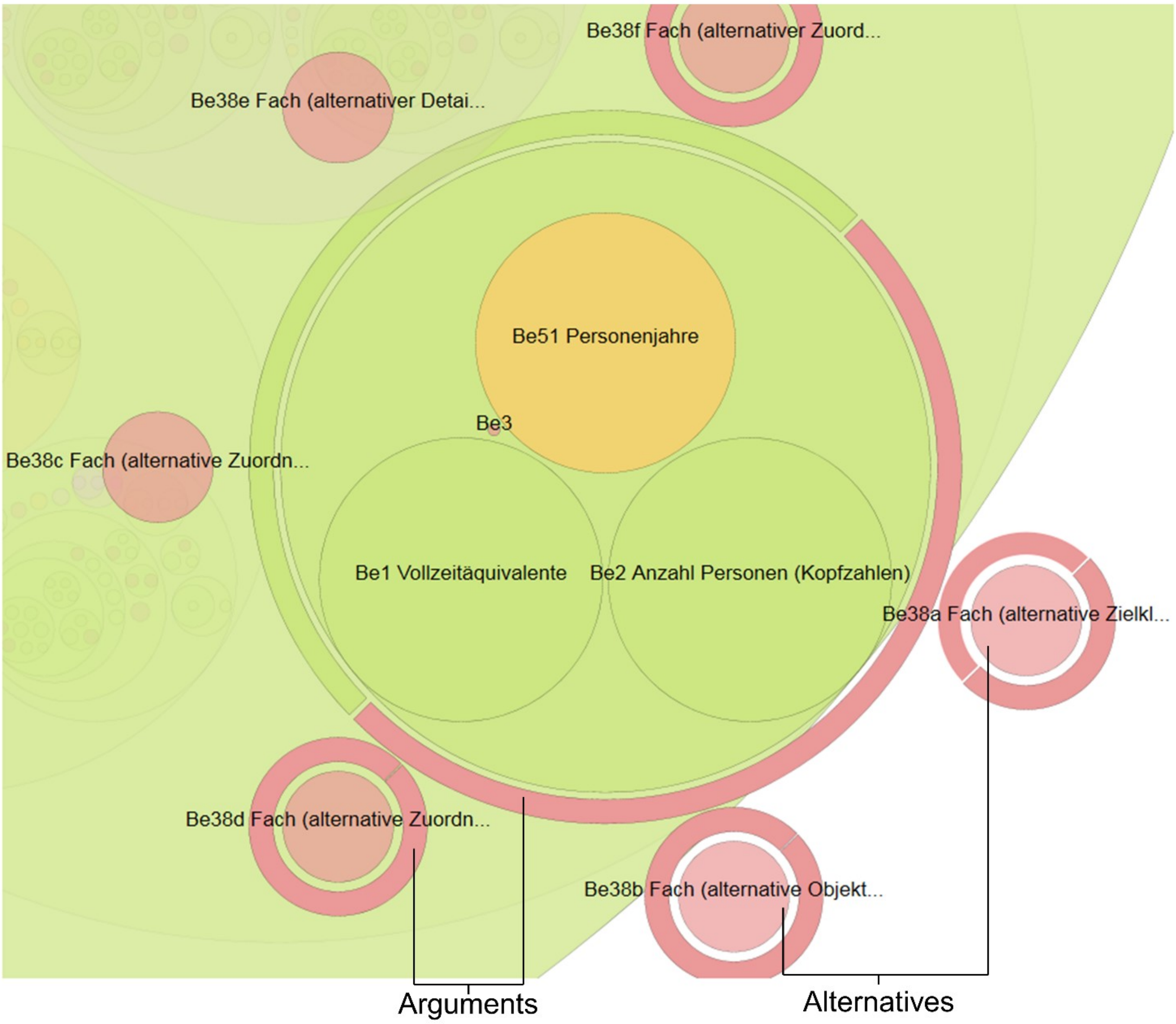

Figure 9: Alternatives (circles around the focused element) and arguments (circle segments around each element) in PCM

The implementation of alternatives and arguments in the HTNM is shown in Figure 10.

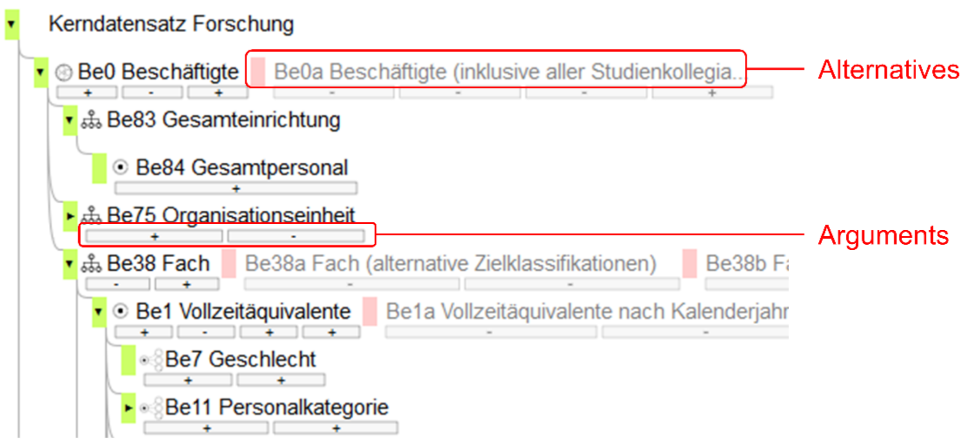

Figure 10: Alternatives and arguments in HTNM

Relate: View relationships among items: As organizing multiple levels in a window for each Compendium sub-map confused our project group members rather than enhancing the overview, we decided that all information should be organized in a single tree. This allows all hierarchy and cross-hierarchy dependencies to be presented without the window barriers seen in Compendium Web Maps. Additionally, it is much easier for the user to get her bearings.

6 Prototype Evaluation

To get a multi-perspective view of the prototype's visual quality, we split the evaluation into three parts: First, we qualitatively analyse the prototype's perception among a group of experts in the project. In this part, the number of statements for or against the visual representations regarding the evaluation criteria is analysed. This means that one interviewee can provide multiple reasons why a representation might be of benefit regarding the same criteria. This part of the evaluation is referred to as **content-oriented evaluation** in the following sections. In the second part, we compare the final preference for a representation of those experts with a quantitative evaluation using an online questionnaire for professors affected by the contents presented. Here, only one of the representations can be chosen by the interviewee. Therefore, the second part of the evaluation is **preference-oriented**. As in the last part, the quantitative preference results are compared with the evaluation of the Compendium Web Map.

6.1 Evaluation Method

Content-oriented evaluation of HTNM and PCM
The evaluation of the visual representations is conducted with semi-structured questions based on the requirements identified in Section 5.1. We examined the intuitiveness, information presentation and coding, and information depth of the visual representations.
The sampling of the ten interviewees covers experts participating in the policy development process (4 interviewees) and non-participating concerned parties (6). Further criteria were the type of expertise: practical expertise (7) and theoretical visualization expertise (3). Finally, the employment level was considered: management (6) and operational (4). None of the interviewees had seen the prototypes before the interviews. The coding procedure included two coders working in parallel and independently from one another. After a short introduction and explanation of the two representations (5 interviews starting with PCM, 5 starting with HTNM), all attendees were asked to decide which of the visual representations (PCM or HTNM) they preferred for all the sub-questions and to explain why they chose a particular representation. The results were transcribed and coded with MaxQDA.

Preference-oriented evaluation of HTNM and PCM
For the second part of the evaluation, we analysed which representation was chosen as the final preference of the interviewee. This used the same transcribed interviews from the last part. Again, the answers were coded but this time only one preference for one visual representation was allowed per interviewee and sub-question.
To test these results against a larger user group, we had to remove some questions which were found to be hard to explain in a standardized quantitative interview without additional explanations. Therefore, we used the questions which were found to be understandable without additional explanation in a standardized questionnaire phase. For that part, a random sample of 4314 German professors were invited by email to evaluate the development representations PCM, HTNM and Compendium WebMap. Out of them, 1917 saw the PCM and HTNM combination. In total, 52 (2.7 %) completed the questionnaire after exploring both PCM and HTNM representations. As the representation shows discussion contents that will change the way researchers' output is documented, they are indirectly affected by the discussion results. The order in which the representations were shown was randomised. Both representations were

introduced by an interactive tutorial, explaining the goal and functionality of the representations. The average viewing time of one representation was 4.57 minutes, while the qualitative expert interviews lasted an average of 42 minutes.

Comparison HTNM, PCM and Compendium Web Map

Out of the 4314 invitations in the quantitative part of the evaluation, 316 professors (7.3 %) completed the questionnaire. Each interviewee was shown two randomly selected visual representations and asked to specify their preferred representation in terms of the quantitative criteria for visual quality. Again, the order in which the representations were shown was randomised.

6.2 Evaluation Results

Content-oriented evaluation of HTNM and PCM

Figure 11 shows the number of statements for and against the representation for each sub-question on the left. Those statements are aggregated on the right. The bottom aggregation sums up the statements found for and against the visual representations.

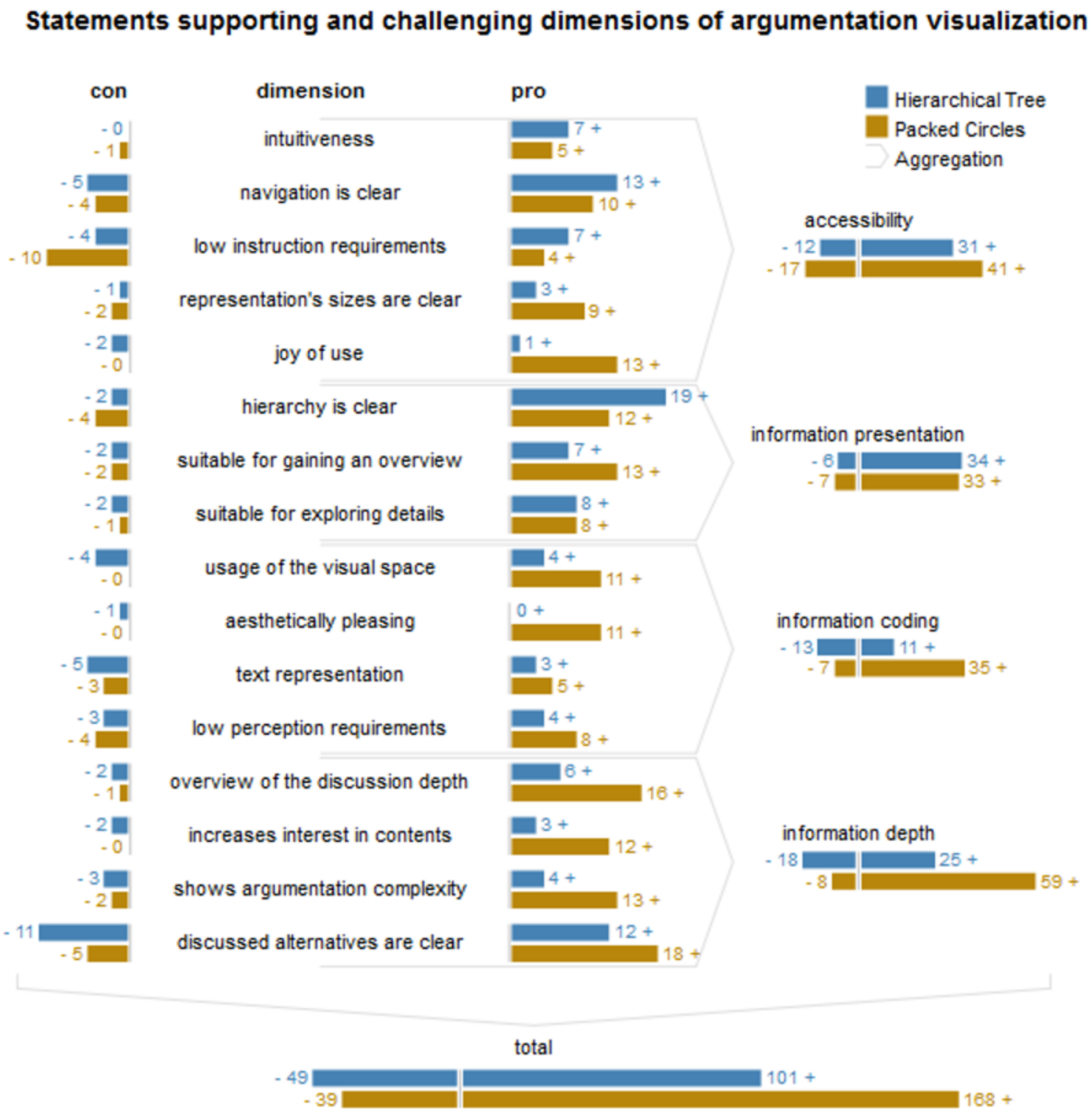

Figure 11: Qualitative evaluation using the inductively found categories during the development process

In total, the PCM was evaluated positively in 168 statements, with 39 statements against, meaning 81 % of statements where positive in nature. Based on this evaluation, its main weakness lies in the higher instruction requirements. It seems to be better suited to providing an overview and is more visually appealing.
The HTNM was referred to less by the stakeholders (150 HTNM vs. 207 PCM statements). Furthermore, 67 % (as opposed to 81 %) of the statements were positive in nature. Its main strengths seem to lie in the structural perception, clearer navigation, and low instruction requirements.

Preference-oriented evaluation of HTNM and PCM
Figure 12 shows the decisions of the 10 interviewees for each sub-question on the left. Comparing the decisions of the qualitative phase (n=10) with the questionnaire phase (n=52), we can confirm that PCM was perceived as aesthetically more pleasing in both evaluations. Furthermore, the joy of use was perceived to be higher in the PCM in both evaluations. The intuitiveness was perceived as being much better in the larger sample than in the small sample. Differences in the evaluations were the clearness of the hierarchy (this is much more evenly distributed in the larger sample), the perception of the suitability for exploring details (the larger sample favours HTMN for this more strongly).

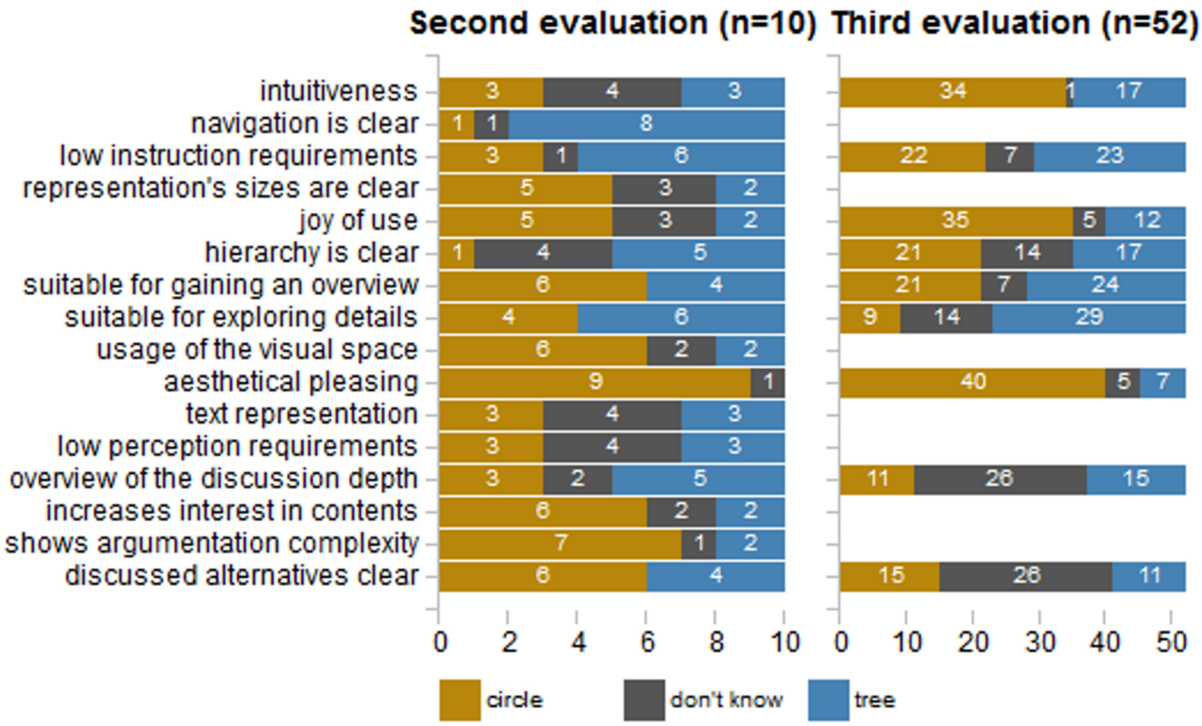

Figure 12: Decision evaluation with a qualitative (n=10, expert interviews) and a quantitative round (n=52, online questionnaire)

Comparison HTNM, PCM and Compendium Web Map
Finally, we compared how the HTNM and PCM were perceived in comparison to the original representation in Compendium Web Map (CWM). The CWM shows all nodes, their connections and arguments modelled in Compendium as a navigable, searchable and interactive interface. Table 1 shows the number of times a representation was chosen out of the total times it was shown. As the representations were shown randomly, they differ slightly regarding the number shown (105 vs. 106 times). On the right the table shows the percentage of how often the representation was shown (of the respective total). As can be seen, the PCM and the HTNM representation were chosen much more frequently in all criteria except for details. Here CWM was chosen slightly more often than PCM.

Table 1: Number of times and percentage the circle, tree and Compendium representation were chosen

criteria \ representation	Number of times chosen				Percentage of chosen/shown		
	none	PCM	HTNM	CWM	%PCM (n=105)	%HTNM (n=105)	%CWM (n=106)
intuitiveness	6	77	59	16	0.73	0.56	0.15
low instruction requirements	24	59	58	17	0.56	0.55	0.16
joy of use	31	67	40	20	0.64	0.38	0.19
hierarchy is clear	38	48	53	19	0.46	0.5	0.18
suitable for gaining an overview	18	58	65	17	0.55	0.62	0.16
suitable for exploring details	32	28	63	35	0.27	0.6	0.33
aesthetical pleasing	17	84	40	17	0.8	0.38	0.16
overview of the discussion depth	67	33	36	22	0.31	0.34	0.21
discussed alternatives clear	67	37	31	23	0.35	0.3	0.22
total average	33.3	54.6	49.4	20.7	0.52	0.47	0.20

6.3 Discussion

In the following, we discuss the findings of part 1 of the evaluation – the content-oriented evaluation – as well as of part 2 – the preference-oriented evaluation – based on the requirements identified in Section 5.1. As both HTNM and PCM were strongly preferred over the Compendium representation, we focus on both of them in the following discussion.

6.3.1 R1: include functionality to reduce the visual complexity of the argumentation visualization

Both visual representations PCM and HTNM use the same techniques to reduce visual complexity. In both representations, the argumentation network is displayed as a navigable tree structure, with only the top levels being shown initially as an overview. Both use zoom and pan functions to facilitate navigation. Both provide detailed information as requested by the user. Both implement the same filter functionalities. The only difference between the representations is the way the information is presented visually, and consequently the mode of navigation (HTNM: pan vs. PCM: zoom).

Table 2 shows the results of the evaluation. On the left, the number of pro and contra statements is shown. All the statements are given from the ten experts in the qualitative evaluation phase. The cells are highlighted orange or blue if a representation tends to be evaluated better in terms of a particular dimension. If the distribution is even or similar, the cells are not highlighted. On the right side, the results of the two phases of the preference-oriented evaluation are shown.

Gaining an overview: The content-oriented evaluation (COE) indicates that PCM is better suited to gaining an overview. It was stated that it is clearer “which contents belong together” and which “information is of interest at this level”. By contrast, the preference-oriented evaluation (DOE) indicates that it is possible to gain an overview with both representations. Although the experts provided considerably more single statements in favour of the PCM, when looking at final preferences decisions, the result is fairly balanced and even slightly in favour of the HTNM. As the third evaluation (n=52) was without human interaction, this may hint at the need for more training so that the potential benefits of the PCM will convince more experts to choose this representation.

Table 2: Evaluation of functionality to reduce the complexity of the argumentation visualization

Evaluation phase / Evaluation type / criteria	Evaluation 1				Evaluation 2		Evaluation 3	
	content-oriented evaluation (COE)				preference-oriented evaluation (DOE)			
	PCM		HTNM		PCM	HTNM	PCM	HTNM
	pro	con	Pro	con	n=10		n=52	
gaining an overview	13+	2-	7+	2-	6	4	21	24
exploring details	8+	1-	8+	2-	4	6	9	29
navigation is clear	10+	4-	13+	5-	1	8	-	-
Total	31+	7-	28+	9-	11/30	18/30	30/104	53/104

Exploring details: In the COE, both of them seem to be equally suited. In the DOE, we find a clear preference for the tree structure, especially in the unsupervised situation. Again we expect this to be caused by the fact that users are much more familiar with the tree structure (as it is similar to the Windows Explorer, for example).
The ***navigation*** is slightly clearer in the hierarchical tree structure in the COE. It might be possible to address this through more training, since two experts stated that they would "prefer the circle layout if they were more used to it". At the same time, experts stated that they expect the instruction requirements to be higher in the PCM. When choosing one of the representations in the DOE, the experts clearly favoured the tree.
Summing the evaluation of this requirement up, we found that all functions received considerably more pro than contra statements. We therefore consider the functions to be of value for reducing visual complexity. For all of the functions, we found the pattern that the tree structure was the favoured representation in an unsupervised evaluation situation, although the circle structure received more pro statements when the interviewees could ask questions directly. For the overview in particular, there were considerably more pro statements. One viable approach for exploiting these potential benefits, could involve addressing the familiarity gap with an improved introduction, training and help system.

6.3.2 R2: higher accessibility of the argumentation visualization than Compendium Web Maps

Based on the inductive category building of the qualitative development, we analysed intuitiveness, navigation, low instruction requirements, the clearness of representation sizes and joy of use for accessibility. Table 3 shows the number of pro and contra statements for COE and the number of decisions. The rows are highlighted in each evaluation cell in the colour of the dominant visual representation.

Intuitiveness is perceived similarly among both representations in the content-oriented evaluation (COE). Both the PCM and the HTNM received far more pro than contra statements. In the PCM, the ability to see a fast visual representation of the sub-contents was reported to feel natural. For HTNM, the possibility of going deeper into the structure without losing the overview was reported as very intuitive. In phase two of the evaluation (DOE), the experts' decision was again balanced, but in the third phase we found a strong preference for the PCM among the interviewees. This is rather surprising, as HTNM seemed to be closer to what the interviewees were used to.

Table 3: Evaluation of the accessibility of the argumentation visualization

Evaluation phase	Evaluation 1				Evaluation 2		Evaluation 3	
Evaluation type	content-oriented evaluation (COE)				preference-oriented evaluation (DOE)			
	PCM		HTNM		PCM	HTNM	PCM	HTNM
criteria	Pro	con	pro	con	n=10		n=52	
Intuitiveness	5+	1-	7+	0-	3	3	34	17
navigation is clear	10+	4-	13+	5-	1	8	-	-
low instruction requirements	4+	10-	7+	4-	3	6	22	23
representation sizes are clear	9+	2-	3+	1-	5	2	-	-
joy of use	13+	0-	1+	2-	5	2	35	12
Total	41+	17-	31+	12-	20/50	21/50	91/156	52/156

Navigation: As stated in the discussion of R1, the ***navigation*** is slightly clearer in the hierarchical tree structure in the COE. When choosing one of the representations in the DOE, the experts clearly favour the tree.
Low instruction requirements: In the COE and in evaluation 1 of the DOE, the experts stated that they expected HTNM to have lower instruction requirements. For the PCM, the navigation structure was reported to be unusual, which results in the need for training. Additionally, the positioning of the circle elements inside larger circles was reported as requiring explanation. In contrast to this, the instruction requirements were evaluated similarly in the third evaluation of the DOE. One reason for this may be that we showed a short tutorial explaining the structure for both representations in the non-supervised setting. This may hint at the possibility of reducing this perception substantially via this short tutorial.
Representation sizes are clear: Both in the COE and DOE, experts favoured the PCM over the HTNM. In the PCM, experts stated that they favoured the possibility of adding additional information in the circle size, which is not feasible in the HTNM. Additionally, the experts liked the visual "weighting" of the sizes.
Joy of use: The experts strongly favoured the PCM in all three evaluations. The experts stated that exploring the data was more fun when navigating inside circles than the more common tree structure.
In total, the experts reported considerably more pro statements (PCM: 41; HTNM: 31) than contra statements (PCM: 17; HTNM: 12). We therefore consider this requirement to be met. When looking at the decisions, both representations were chosen equally in evaluation 2 (DOE), but PCM clearly dominated the third evaluation with an unsupervised setting. It seems that the tutorial provided helped people to overcome the higher perceived instruction requirements.

6.3.3 R3: improve information presentation and coding compared to Compendium Web Maps

We analysed usage of the visual space, aesthetics, text representation, and low perception requirements for information presentation. Furthermore, we analysed hierarchy perception, overview and detail suitability for information coding. Table 4 shows the number of pro and contra statements for COE and the number of decisions. In each evaluation cell, the rows are highlighted in the colour of the dominant visual representation.

Table 4: Evaluation of the information coding and information presentation of the argumentation visualization

Evaluation phase	Evaluation 1				Evaluation 2		Evaluation 3	
Evaluation type	content-oriented evaluation (COE)				preference-oriented evaluation (DOE)			
	PCM		HTNM		PCM	HTNM	PCM	HTNM
criteria	pro	con	pro	con	n=10		n=52	
usage of the visual space	11+	0-	4+	4-	6	2	-	-
aesthetical pleasing	11+	0-	0+	1-	9	0	40	7
text representation	5+	3-	3+	5-	3	3	-	-
low perception requirements	8+	4-	4+	3-	3	3	-	-
total information coding	35+	7-	11+	13-	21/40	8/40	40/52	7/52
hierarchy is clear	12+	4-	19+	2-	1	5	21	17
suitable for gaining an overview	13+	2-	7+	2-	6	4	21	24
suitable for exploring details	8+	1-	8+	2-	4	6	9	29
total information presentation	33+	7-	34+	6-	11/30	15/30	51/156	70/156
Total	68+	14-	45+	19-	32/70	23/70	91/208	77/208

Usage of the visual space is clearly perceived as better for the PCM in both evaluation 1 and 2. The experts stated that the circles allowed more information to be displayed compared to a tree structure.
Aesthetics is strongly perceived to be a strength of the PCM in all three evaluations.
Text representation: The experts provided slightly more statements in favour of the PCM in the COE. In both representations, displaying very long element names was reported to be an issue. However, the PCM deals better with displaying the text of multiple alternatives (which have to be cut off in the HTNM). In the second evaluation (DOE), both representations were chosen equally.

Lower perception requirements: Regarding the lower perception requirements, the experts favoured the PCM in the first evaluation (COE). It was reported that the PCM made it easier to focus on information on the same level. By contrast, both representations were evaluated similarly in the second evaluation (DOE).
Total information coding: In total, information coding seems to be better in the PCM. While the PCM received significantly more pro than contra statements (35+ vs. 7-), the HTNM received more contra than pro statements (11+ vs. 13-). When users had to choose a representation (DOE), we also found that most experts preferred PCM in terms of information coding criteria.
Hierarchy is clear: The hierarchy was perceived more clearly with the HTNM representation in the first (COE) and second (DOE) evaluations. By contrast, we found a higher preference for the PCM in an unsupervised setting. This change may be influenced by the tutorial which was shown in the third evaluation, while evaluations 1 and 2 only involved the interviewer explaining the representations.
Suitable for gaining an overview: As stated in the discussion of requirement 1, PCM was perceived as more suitable for providing an overview in the first (COE) and second (DOE) evaluations. It is perceived similarly in the third evaluation (DOE).
Suitable for exploring details: As stated in the discussion of requirement 1, PCM and HTNM were perceived similarly for exploring details in the first evaluation (COE). In the third evaluation (DOE), the experts favoured the HTNM.

Total information presentation: Regarding the number of statements in the COE, both representations were perceived similarly positively. However, in the DOE the experts leaned slightly towards HTNM – in both a supervised and unsupervised setting.
In total, the PCM was viewed more positively than the HTNM (PCM: 68+ vs. 14-; HTNM: 45+ vs. 19-) in the first evaluation (COE); as such, we consider this requirement to be met. In the second and third evaluations (DOE), PCM also performed better according to the experts.

6.3.4 R4: provide the same depth of information as in Compendium Web Maps

We analysed the overview of the discussion depth, increase of interest, argumentation complexity and clearness of alternatives for information depth. The number of pro and contra statements for COE and the number of decisions are provided in Table 5. In each evaluation cell, the rows are highlighted in the colour of the dominant visual representation.

Table 5: Evaluation of the information depth of the argumentation visualization

Evaluation phase	Evaluation 1				Evaluation 2		Evaluation 3	
Evaluation type	content-oriented evaluation (COE)				preference-oriented evaluation (DOE)			
	PCM		HTNM		PCM	HTNM	PCM	HTNM
criteria	pro	con	pro	con	n=10		n=52	
overview over the discussion depth	16+	1-	6+	2-	3	5	11	15
increases the interest in contents	12+	0-	3+	2-	6	2	-	-
shows argumentation complexity	13+	2-	4+	3-	7	2	-	-
discussed alternatives are clear	18+	5-	12+	11-	6	4	15	11
total	59+	8-	25+	18-	22/40	13/40	26/104	26/104

Overview of the discussion depth: The experts provided substantially more statements for the PCM in the first evaluation (COE). One main difference was that the circle does provide information about the total number of alternatives and arguments faster. However, in the DOE we found a slight preference for the HTNM. We believe this to be influenced by familiarity with the interaction concept in HTNM.
Increases the interest in the contents: In the first (COE) and second (DOE) evaluations, the experts clearly favoured the PCM. The main difference to the tree structure was reported as being the PCM's option of showing substructures in the circle before clicking.
Shows argumentation complexity: In the first (COE) and second (DOE) evaluations, the experts clearly favoured the PCM. The experts stated that the form of visual representation made it clearer that pro and contra arguments exist.
Discussed alternatives are clear: The PCM outperformed the HTNM in all evaluations (COE and DOE). For example, the experts stated that it was easier to perceive the total number of alternatives (as they are all shown as circles around the focused circle), while in HTNM they have to be shortened or even hidden when the number of alternatives is too high.
Overall, the experts stated a clear preference for PCM in the first (COE) and second (DOE) evaluations in terms of information depth. In the DOE evaluation, however, we see that experts chose equally among the two visual representations of the questions that could be asked. This may be skewed a little by leaving out two questions in which PCM is clearly favoured.

6.4 Limitations

The evaluation of the qualitative phases with 10 experts focused on providing detailed insights into the reasoning for and against the visual representations. Because of the small number of participants, the results should be interpreted with caution. For the quantitative phase, we had to remove some questions which were found to be hard to explain in a standardized quantitative interview without additional explanations. This means that not all dimensions of the criteria were tested both qualitatively and quantitatively. The quantitative phase incorporated a larger number (52) of interviewees, but because of the low participation rate (1 %) it is questionable whether the results can be generalized to other fields without further research. The results do permit the conclusion that both PCM and HTNM are perceived much better than the original Compendium Web Maps in this context. To apply these results to other fields of application, further studies with a larger quantitative sample are necessary.

7 Conclusion and Outlook

The two newly developed visual representations PCM and HTNM both outperform the existing Compendium Web Maps in terms of all requirements analysed in our project. Our qualitative and quantitative evaluation shows that PCM is better suited to increasing accessibility, information presentation and coding as well as information depth. The HTNM is perceived as being slightly stronger when it comes to reducing complexity. Regarding the specific sub-dimensions, we found highly varying perceptions although the presented content was consistent across all representations. These insights pave the way for a more empirical-based usage of visual representations in development processes with a high number of stakeholders. While argumentation modelling should still be performed using tools like Compendium, the visual representation of results should be provided in the developed visualizations, whose focus is customised based on the goal of the visualization.
As a further research step, we plan to expand the application of both visual representations to other use cases than the standardization case. Furthermore, extending the evaluation to a larger quantitative study with more participants will allow for a higher generalizability of the results.

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Improving Argumentation Visualization of Multi-Stakeholder Development – A Prototyping Case

A shared understanding of development argumentation is crucial for a wide range of development processes (such as requirements engineering, change management, eGovernment and eParticipation, public policy) and central to prevent the failure of IT and development projects. Computer-Supported Argumentation Visualization (CSAV) has been used to model and represent discourse information for about 35 years. Although modelling tools have significantly matured and continue to evolve, the visual representation of existing tools does not scale ideally with increasing model complexity. For large-scale argumentation models, existing visualization approaches from argumentation visualization are reported as being too complex for target stakeholders. This prevents them from gaining insights into the development process and may ultimately contribute to the rejection of the development result, causing severe costs for both public and private organizations. In this paper, we employ the 'design science' methodology to incrementally develop two interactive visual representations for argumentation visualization, incorporating best practices from information visualization research. The prototypes are implemented and evaluated in the setting of the project "Research Core Dataset", a nation-wide project involving all major stakeholder groups of the German science system in order to develop harmonized definitions for research information. In our evaluation, both of the visual representations developed are perceived as being much better at providing insights into complex development processes with a high number of stakeholders.

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