

Reasoning with Knowledge Graph Visualizations

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A Mental Models Perspective

Eva Mayr¹, Johannes Liem¹, and Florian Windhager¹

¹Department for Arts & Cultural Studies,
Danube University Krems

1 Introduction

How do people reason with knowledge graphs and how can we support these reasoning activities? When working on questions like these, we propose to take into account a central theory of cognitive science, which states that knowledge is represented in the human mind as “mental models”, i.e. as structural and procedural internal representations of external phenomena (Johnson-Laird, 1983). For the construction of such mental models, multiple pieces of information are relationally interwoven by different kinds of inferential reasoning (Goodwin and Johnson-Laird, 2005). In this cognitive theory we see a clear similarity to the conception of knowledge graphs, which also model information structurally and relationally. While knowledge graph technologies primarily aim to make large data collections (up to the global web) more “readable”, understandable, and computable for machines regarding the semantic structuring of largely language-based data (Berners-Lee et al., 2001) they do create new challenges regarding human readability. In this paper we take a closer look at knowledge graph visualizations and how they can support reasoning on knowledge graphs from a mental models perspective. We illustrate this question by means of a current H2020 research and innovation project in the cultural heritage information domain, in which we construct a knowledge graph and aim to make it visually accessible for cultural heritage experts and laypeople.

2 Knowledge Graph Visualization

Complex graph structures are known to easily overwhelm human subjects due to their complexity and density of information. Designers of visual interfaces to such data thus are searching for representation techniques to make them more accessible and to avoid confusion and misconceptions due to the avoidable remediation of visual complexity and clutter (Nararatwong et al., 2020; Von Landesberger et al., 2011). A central problem for the visual representation of knowledge graphs is therefore the reduction of complexity on the interface side, as only a low number of data dimensions can be visually encoded (as defined by a finite number of visual variables; Munzner,

2014). In contrast, knowledge graphs tend to be high-dimensional constructs, which connect multiple types of nodes with multiple types of relations. To cope with the challenge of complexity for laypersons, but also for domain experts with low technical skills, Nararatwong et al. (2020) call for intuitive interfaces, which do not overwhelm users, reduce the number of available options and present the information in a way that reveals what is in for them quickly. To support graph comprehension and reasoning activities of experts and laypeople, different strategies and solutions have been developed by the visualization community.

3 Supporting Reasoning with Knowledge Graph Visualizations

Visualization research developed several options to represent multidimensional knowledge graphs. In the following, we present those which can support users in building up relations of entities within and between their mental models.

Reduction of data complexity: To reduce the cognitive load a visualization imposes to the user, Joseph et al. (2021) suggest to visualize only selected aspects of a knowledge graph so that users can gain a good first impression on selected dimensions of a knowledge graph. While this strategy frees cognitive resources for higher-order reasoning, any static implementation risks that users build up a mental model for this reduced knowledge graph only—and thereby also to restrict sensemaking processes only to pre-selected aspects of the knowledge graph. To cope with this risk of oversimplification, strategies of interactively accessing complexity layers are of central relevance. Such an approach equals the use of "advance organizers" (Ausubel, 1960) or of "overview first"-designs Shneiderman (1996), which are an omnipresent design strategy in complex knowledge communication contexts.

Incremental increase of complexity: To go beyond simple visual and mental models, knowledge graph visualization can utilize well-established techniques of incrementally increasing (visual) complexity. Such designs start from basic visualizations and allow users to blend in further data dimensions or adding further views step by step and on demand (Sarrafzadeh and Lank, 2017; Shneiderman, 1996). Such a procedure can help users build up a simpler mental model first and incrementally enrich it with further information (Windhager and Mayr, 2022). Research from cognitive science confirms that a progressive enrichment of an internal representation reduces the cognitive load required for the construction of a mental model.

Multiple coordinated views: Multidimensional knowledge graphs can be visualized as multiple juxtaposed views of different data dimensions (e.g., Ge et al., 2016). Coordinated interaction techniques establish links between the different views, by highlighting selected data or by filtering specific categories in all views. In theory, a huge number of views could be combined in such a way, but due to the limits of simultaneous processing, of human working memory, and due to the split attention effect, their cognitive integration is highly demanding (Windhager and Mayr, 2022). Therefore, it is recommended to keep the number of different views to a minimum, again to add further views step by step, or to let users configure and add different views on demand based on their information needs and interest.

Coherence techniques: A central characteristic of a mental model is its coher-

ence, i.e. how well the information elements are related and allow for reasoning and inferences (Tversky, 2020). We proposed the use of various visual coherence techniques (Windhager et al., 2020) which can support the construction of better integrated mental models—and thereby higher-dimensional reasoning with knowledge graphs. In a small experimental study, we observed that users can more easily draw multidimensional inferences (as an indicator of a multidimensional mental model), when these dimensions are represented in a synoptic fashion in one multidimensional view rather than as multiple views (Mayr et al., 2018).

Visual storytelling: The sequential chaining of information (just like in stories) offers another relevant sensemaking and reasoning technique—especially for laypersons (Windhager and Mayr, 2022): By visually walking users through a knowledge graph, they build up a (narrative) mental model which establishes narrative and causal relations between selected pieces of information (Battad et al., 2019).

All of the presented techniques have their strengths and limitations, which hampers generic design recommendations. We rather argue for their orchestrated use in close consideration of contextual realities (including data, user and tasks) and to weigh the expected benefits against possible drawbacks for each application case.

4 InTaVia: A Knowledge Graph on In/Tangible Cultural Heritage

The H2020 project InTaVia (2020-2023, <https://intavia.eu>) aims for the visual analysis, curation and communication of intangible and tangible cultural assets. On the data side of the project we are constructing a knowledge graph which connects entities from multiple national biography databases (intangible stories on the lives of cultural actors from Finland, the Netherlands, Austria, and Slovenia) and cultural object databases (tangible cultural artefacts from Europeana). On the user side, we are developing two visualization interfaces; one for the interaction with and analysis of the cultural knowledge graph (aka Visual analytics studio) and another one for the communication of this cultural information to the interested public (aka Visual storytelling Suite). These visual interfaces will combine visual support and reasoning strategies of all types (see section 3) to offer a plurality of coherent analytical perspectives for a wide variety of user types.

As a design strategy, we follow a user-centered mental models approach which helps us to cognitively ground the design, development, and evaluation of the novel visualizations. In the first project year, we conducted workshops with several cultural heritage practitioners and humanities experts to gain a better understanding of their mental models of the domain: We discussed their current procedures for the processing, analysis and communication of cultural heritage information, what data characteristics and dimensions they deem important, and which visualization techniques they regard as useful for their current research activities and work practices with tangible and / or intangible cultural assets. The results of these workshops were used to define user requirements and specify our development aims. They also lay the basis for the concrete planning of three evaluation cycles, which will help us to test the visual interfaces to the knowledge graph with our target users, gather their expert feedback, and refine the technologies to better align with their expectations and support the construction of mental models on the knowledge graph. To understand how the visualizations do

so, we will observe their sensemaking and reasoning with the visual interface to the knowledge graph by means of the think-aloud technique. The analysis of the think-aloud protocols will focus on relational inferences and the match of the mental models with the knowledge graph in the background.

Aside from this user-centered approach, our project team also involves several historians and cultural heritage experts, who continuously participate in project working session and give feedback. During the first year a gap became apparent between the technical definition of the data model for our knowledge graph on the backend side and the kind of queries and information envisioned by our humanities experts on the frontend side. To solve this problem, we developed two distinct data models—one for the backend and one for the frontend which matches the mental models of the humanities experts in a better way (their matching will happen on the backend side). These discussions also led the project team to develop ideas, how we can further support querying of the knowledge graph by users without technical knowledge with visual search interfaces, but also options of ad-hoc visual querying during the interactive visual exploration of the knowledge graph.

Though the project is only in an early phase and much of the reported work is still in progress, we already found the chosen mental models perspective to be of eminent value for the sensitive specification and refinement of our design requirements and for initiating and prioritizing technological developments.

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