

Natural Language-based User Guidance for Knowledge Graph Exploration: A User Study

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Keywords: User Guidance, Knowledge Graphs, Natural Language Interface.

Abstract: Large knowledge graphs hold the promise of helping knowledge workers in their tasks by answering simple and complex questions in specialised domains. However, searching and exploring knowledge graphs in current practice still requires knowledge of certain query languages such as SPARQL or Cypher, which many untrained end users do not possess. Approaches for more user-friendly exploration have been proposed and range from natural language querying over visual cues up to query-by-example mechanisms, often enhanced with recommendation mechanisms offering guidance. We observe, however, a lack of user studies indicating which of these approaches lead to a better user experience and optimal exploration outcomes. In this work, we make a step towards closing this gap by conducting a qualitative user study with a system that relies on formulating queries in natural language and providing answers in the form of subgraph visualisations. Our system is able to offer guidance via query recommendations based on a current context. The user study evaluates the impact of this guidance in terms of both efficiency and effectiveness (recall) of user sessions. We find that both aspects are improved, especially since query recommendations provide inspiration, leading to a larger number of insights discovered in roughly the same time.

1 INTRODUCTION

Knowledge graphs, i.e. networks of connected entities, constitute a flexible approach to integrating and storing information gathered from numerous heterogeneous sources. Their widespread adoption has led to an increased interest in exploration mechanisms (Lissandrini et al., 2020b): while knowledge graphs may hold vast amounts of potentially very useful information, accessing, exploring and understanding that information is a far from trivial task, especially for untrained end users.

When accessing a knowledge graph, users often have only a vague information need in mind (Witschel et al., 2020; Lissandrini et al., 2020a). They may be able to articulate certain aspects, however, that may then serve as a starting point for further exploration.

Moreover, many knowledge graphs require the use of structured query languages such as SPARQL (Pérez et al., 2009) or Cypher (Francis et al., 2018). Since most users do not have the technical know-how to use these, many researchers are advocating the use

of more user-friendly syntax, e.g. based on keyword search (Namaki et al., 2018). This of course poses new challenges since keyword queries are less precise than structured query languages (Yang et al., 2014).

Finally, users often do not know the graph schema, i.e. the available types of nodes/entities and the types of relationships between them. They are also unable to estimate the cardinalities of relationships and are hence often faced with either empty or overwhelmingly large result sets (Mohanty and Ramanath, 2019).

These challenges clearly suggest a need for user guidance, offering support e.g. via query suggestion or reformulation (Mohanty and Ramanath, 2019; Namaki et al., 2018) or via result previews (May et al., 2012).

1.1 Related Work

While the need for guidance seems obvious, there is a large number of even very basic design options along several dimensions:

The first dimension concerns the **query language** – here, choices range from structured query languages (Pérez et al., 2009; Francis et al., 2018) over keyword-

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based queries (Namaki et al., 2018) in the tradition of *information retrieval* systems and questions in natural language (Tong et al., 2019) from the area of *question answering* (QA) up to the construction of subgraphs as a means to perform *query-by-example* (Jayaram et al., 2015; Yi et al., 2017).

A second dimension concerns the **display of results**: while QA systems such as (Tong et al., 2019) generate a textual response, graph exploration studies prefer to visualize subgraphs (Gladisch et al., 2013; May et al., 2012). Here, some studies propose to return single graphs that a user iteratively explores (Gladisch et al., 2013; Witschel et al., 2020), others assume that multiple subgraphs should be provided as results (Jayaram et al., 2015), whereas a third category of approaches aims at graph summaries instead of full subgraphs (Wu et al., 2013; Yang et al., 2014).

Finally, in a third dimension, one can distinguish different forms of **interaction**: while many approaches concentrate on the refinement of user queries (Mohanty and Ramanath, 2019; Namaki et al., 2018; Bhowmick et al., 2013), be it via auto-completion, suggestion of alternative or additional keywords or queries, others work with a notion of context that allows for e.g. the recommendation of further directions (May et al., 2012) or “navigation cues” including a certain kind of preview (Gladisch et al., 2013). In the area of QA, the notion of “Sequential Question Answering” addresses the need of users to iteratively refine queries to address their (evolving) information need (Saha et al., 2018; Witschel et al., 2020).

Although each of these possibilities results in a quite different user experience, there is a surprising lack of user-based evaluations that would indicate the relative utility of the given approaches from an end user perspective: studies in classical question answering evaluate the effectiveness of their approaches with datasets comprising the “correct” answers to questions and thus serving as gold standards (e.g. (Tong et al., 2019; Saha et al., 2018)). The *exploration* of graphs via Sequential Question Answering has led to the creation of datasets containing *dialogs* between a user and a knowledge graph-based QA system (Saha et al., 2018).

In the area of visual graph exploration, many studies such as (Mohanty and Ramanath, 2019; Namaki et al., 2018; Pienta et al., 2017; Gladisch et al., 2013; Bhowmick et al., 2013) provide “demonstrations” of their approach, but there is no user-based evaluation. Others also use datasets as gold standards and make assumptions about ground truths (Jayaram et al., 2015; Yogev et al., 2012) or user efforts for query construction (Lissandrini et al., 2020a),

whereas still others focus on efficiency and user waiting times (Jin et al., 2012; Mottin et al., 2015).

None of these studies have involved actual end users in the evaluation of their approaches. (Gladisch et al., 2013) are aware of this drawback and mention the need for user-based evaluation as a “pressing issue”. In (May et al., 2012), a user study is reported focusing on the efficiency of participants to solve a task with or without navigation support. Somewhat similarly (but not applied to knowledge graphs), (Yi et al., 2017) measures the number of clicks that can be saved in the construction of subgraph queries when applying query autocomplete. While the results are interesting, we believe that much more insight is needed, in particular – as discussed in the next subsection – to understand not only gains in efficiency, but also the effectiveness of entire user sessions.

1.2 Contribution

We aim at addressing also effectiveness issues: we first describe a further development of our graph-based sequential question answering system (Witschel et al., 2020), which we enhance with a context-aware query recommendation mechanism. Based on this, we aim to answer the following two research questions with a user experiment:

- Do query recommendations make knowledge graph exploration more efficient, i.e. do users find relevant answers faster than without that support?
- Does the query recommendation result in a more effective search, especially in terms of recall, i.e. do users find more answers / derive more insights than without it?

Especially the second question is a novel one in the area of knowledge graph exploration. In our study, we consider the effectiveness of an entire user session devoted to the exploration of a larger group of themes, i.e. not limited to a specific detailed query or discovery task and not constrained by a narrow set of expected outcomes. We strongly believe that a broad and relatively unconstrained setting is important to evaluate the effects of user guidance in *exploratory* settings.

The system that we have developed can be seen as our “best guess” regarding an optimised user experience w.r.t. the above-mentioned research questions. We will provide arguments for that approach and a detailed description in Section 2. Section 3 describes the setup and results of our experimental user study, from which we draw some conclusions and further directions in Section 4.

2 CONTEXT-BASED QUERY RECOMMENDATION

2.1 Knowledge Graph Exploration via Sequential Question Answering

Our approach to knowledge graph exploration is based on a paradigm of interactive question-answer steps as described in (Witschel et al., 2020).

In a nutshell, the approach works as follows:

- In step 0, a user finds an entry point into a knowledge graph $G = (V, E)$ via keyword search (see Figure 1, “Step 0”), which returns all nodes $v \in V$ whose string properties contain (a subset of) the entered keywords. The retrieved nodes are initially disconnected. The search can be constrained by node type filters on the left side.
- In each step i , the user sees a certain subgraph $G_i \subset G$. The user can select a set of nodes N_{G_i} that serves as a *context*. In the example in Figure 1, the user selected both blue nodes as a step 1a. Then, the user can ask a question about the chosen context in natural language – the example question “Which diseases cause these symptoms” is shown at the bottom (step 1b). The system parses the question, translates it into the query language Cypher¹ and displays the result as a new subgraph G_{i+1} .

Thus, the system is a hybrid QA system, accepting questions in natural language and giving answers in the form of subgraph visualisations. In our small user study in (Witschel et al., 2020), we have been able a) to confirm the user-friendliness of natural language as a query language, b) to show that visualisation of subgraphs supports users in quickly understanding patterns even in complex answers and c) to prove the intuitiveness of alternating context selection and querying as a means of iterative refinement and exploration.

2.2 Recommendations: User Perspective

However, when users are faced with the challenge to use a knowledge graph to satisfy an initially vague and fuzzy information need, there are still two main obstacles:

- The user might be overwhelmed with the large number of possibilities for querying (Gladisch et al., 2013). This fact is aggravated by the

fact that users are initially unaware of the graph schema (Yi et al., 2017).

- Although natural language is user-friendly, it is ambiguous and its parsing is hence error-prone (Shekarpour et al., 2017).

Therefore, we extend our interaction concept by query recommendations displayed to users when they select a set of nodes N_{G_i} as a context. An example is shown in Figure 2, where the user has selected the node “pneumonia” (of type disease) and now receives query suggestions for further exploration.

The recommendations solve both of the above-mentioned problems since a) they provide guidance and inspiration by implicitly informing the user about relationships and adjacent node types and b) they are automatically generated and hence guaranteed to be parsed correctly.

2.3 Recommendation Heuristics

Our query recommendation algorithm is based on a number of intuitions: there are three main types of queries that are recommended, namely

- **Relation queries**, ask for nodes that are related to nodes in the current context N_{G_i} , e.g. “Which **treatments** treat *this disease*?”. Here, the **bold** font indicates the type of nodes that are to be retrieved (we will call it the “return type”), the *italic* font indicates the current context.
- **Similarity queries** ask for nodes that are of the same type as those in N_{G_i} and share many adjacent nodes, e.g. “Which **diseases** are similar to *this one*? ”
- **Filter queries**, ask for a subset of currently selected nodes that fulfil a certain condition, e.g. “Which of these **diseases** have a *contraindication*? ”

We have consciously limited the choice of available query types to these simple alternatives since we believe that the sequential exploration process supported by our interaction paradigm allows to satisfy also very complex information needs, even if the queries applied in that process are fairly simple.

To understand how queries are generated, let $C = N_{G_i}$ be the set of currently selected nodes (the current context). Further, let N be the set of currently visible nodes (i.e. all nodes in the currently displayed graph G_i) and N' the set of all nodes that were visible in the previous step, i.e. in G_{i-1} .

The main question to answer by our heuristics is: where would the user like to go next? To answer this question, the following considerations can be helpful:

¹<https://neo4j.com/>

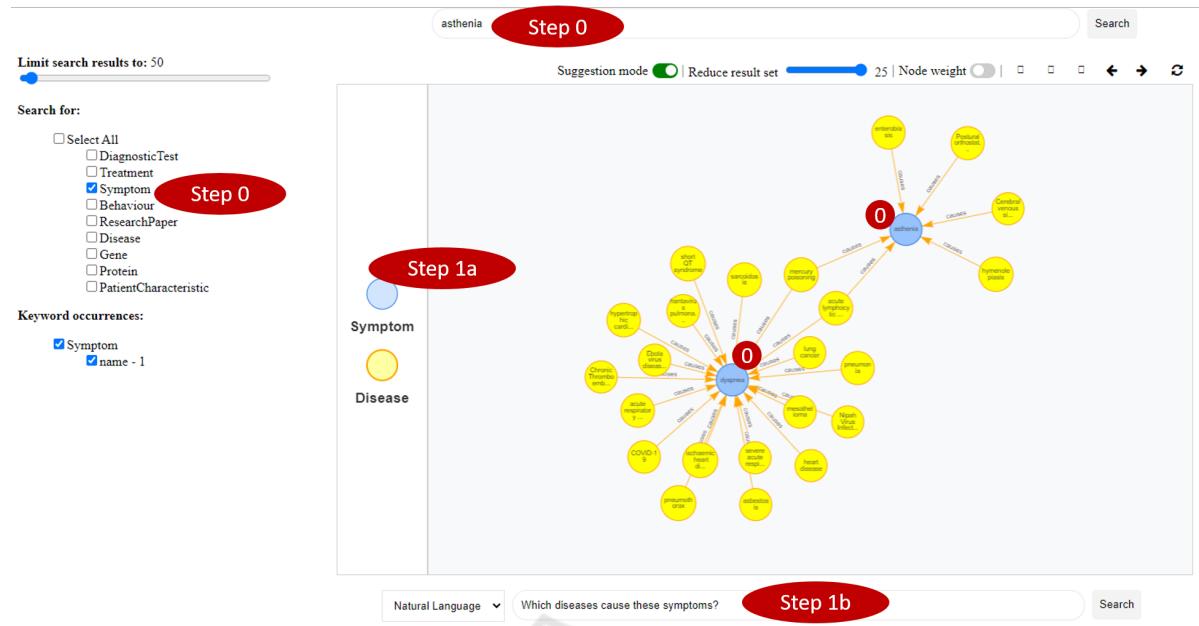


Figure 1: The knowledge graph exploration interface.

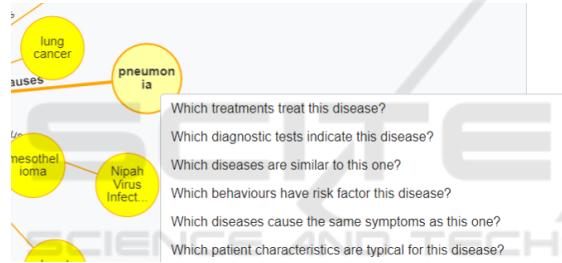


Figure 2: Queries recommended when choosing the node “pneumonia”.

- If the context C consists of a large number of nodes, the user is more likely to be interested in asking a filter query. Conversely, similarity queries are more probable when only one node is selected.
- Otherwise, relation queries are generally very common. Since one usually wants to explore new entities, asking for node types that are currently displayed or have been displayed in the step before is less likely.
- The probability of asking for a certain node type (return type) depends on its connectedness in the schema graph – i.e. node types that have relations to many other node types can be expected to be more common and hence more likely to be queried for.
- Queries involving node types or relationships with names consisting of several words are considered as “complex” and hence less probable – the length

of a query in words can be used as a simple approximation of its general complexity.

Given these intuitions, we implemented our query generation algorithm as follows:

1. Generate candidate queries q_i for each node type, including relation, similarity and filter queries. This is done by using the names of node types as subjects and objects and the names of relationships as verbs. For instance, for a given return type $\langle x \rangle$ and a context of nodes of type $\langle c \rangle$, which are connected by a relationship $\langle r \rangle$ pointing from $\langle c \rangle$ to $\langle x \rangle$, a relation query has the general form “Which $\langle x \rangle \langle r \rangle$ these $\langle c \rangle$?", e.g. “Which $\langle \text{diseases} \rangle \langle \text{cause} \rangle$ these $\langle \text{symptoms} \rangle$?”. Any context consisting of type c nodes will trigger the same query recommendations.
2. For each node type in the graph G , compute a score based on C , N and N' , see Section 2.4 below.
3. Each query candidate q_i from step 1 is initially scored by the score of its return type. In a final step, these scores are multiplied by a length weight that reflects the complexity of the query and is given by $\frac{1}{1+d^2}$ where $d = |q_i| - \min_j |q_j|$ is the difference between q_i 's length in words and the length of the shortest query candidate.
4. Rank candidate queries by their score and display the top k queries to the user.

2.4 Pre-scoring of Node Types

Pre-scoring of node types makes use of both the current view C and N of the search and the very recent history N' . For the below definitions, let N_t be the set of nodes $n \in N$ and N'_t the nodes $n' \in N'$ of type t .

For node types t that are currently on display ($|N_t| > 0$) or were on display in the previous step ($|N'_t| > 0$), we assign fixed probabilities, depending on whether they are assumed to be the result of a filter query ($|N_t| > 0$ and $|N'_t| > 0$, but $|N_t| < |N'_t|$, low probability), a “new” node type ($|N_t| > |N'_t| = 0$, also improbable) or “abandoned” node types ($|N'_t| > |N_t| = 0$, slightly more probable).

For node types t that have not been on display in either the current or previous step, i.e. for which $|N_t| = |N'_t| = 0$, we apply the intuition that their probability depends on how easily they can be reached from N within the schema graph (see above). We have implemented this intuition by applying a biased random walk, using PageRank with priors (White and Smyth, 2003) on the schema graph – where we initialise by assigning some non-zero uniform prior weights to all $n \in N$ and some slightly higher uniform weights to all $n \in C$.

3 EXPERIMENTS

3.1 Experimental Setup and Methodology

For our user study, we set up a large medical knowledge graph by gathering data from a number of sources, see (Riesen, 2020).

We then recruited 10 persons (2 female) studying in a Master program of “Medical Informatics”. All of them had a very basic background in medicine, some had more advanced medical knowledge from specific work experiences. However, none of them had a deeper knowledge in medical diagnosis and treatment. We can therefore assume that our test persons can take the role of a very inexperienced junior doctor who is in need of medical knowledge when handling a new patient case. We prepared a corresponding case, consisting of some minimal information about a patient’s demographics (age and gender) and symptoms.

We divided test persons into a test and a control group such that both groups had to solve the task using our system – the control group working only with the basic approach described in Section 2.1 and the test group additionally with query recommendations

as described in Section 2.2. Despite our small sample size – which prohibits any quantitative experimental evaluation – we believe that this setup helps to avoid the bias and learning effects that would result when having all test persons work with both setups. The assignment of participants to test and control group was randomized.

All participants received the same introduction to the tool, demonstrating the general interaction paradigm of sequential question answering with some example queries which were unrelated to their task. Test group participants additionally got a demo of query recommendations as shown in Figure 2. All participants were then introduced to the task (see above) and asked to solve it with the help of the knowledge graph. They were encouraged to think out loud while doing so.

All sessions were video-recorded and later annotated with the help of the video annotation tool ANVIL² by the authors of this paper. In line with our two research questions defined in Section 1.2, we annotated and then measured two things for each participant:

- We annotated different kinds of **activities** that participants were performing while solving the task and measured the **time spent** on each. These activities were: strategising (i.e. figuring out what to do next to get closer to the solution), studying suggestions (i.e. reading recommended queries before choosing one), interpreting results (i.e. discussing how a returned subgraph would help to solve the task) and struggling (i.e. trying to figure out how to use tool functionalities to accomplish a goal). We also annotated struggling activities with an inductively derived set of sub-categories, i.e. different ways of struggling. These measurements will help us to judge the efficiency of solving the task. The time spent with struggling also gives an indication of *precision* of e.g. suggested queries.
- We annotated situations where participants retrieved a result as “insights”. Given our task, we formulated some expected insights, e.g. to find diseases causing the described symptoms, to find further symptoms to use for differentiation, to find out for which patient groups retrieved diseases are typical, which treatments to apply etc. Besides these, we also annotated insights retrieved by participants that went beyond these expectations. All retrieved and annotated insights bear some relevance w.r.t. the task. Thus, the **number of insights** derived during a session gives an indication

²<https://www.anvil-software.org/>

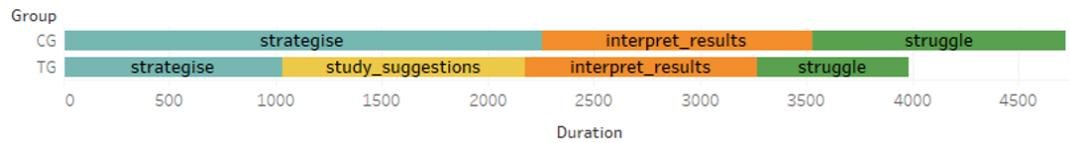


Figure 3: Total duration of user activities within sessions.

about the effectiveness of the exploration, in particular its recall.

In addition to these annotations, we also conducted a small interview directly after each session, asking participants to both rate and comment on the following aspects:

- The general ease or difficulty of finding one's way through the knowledge graph
- the perceived efficiency of completing their task
- their confidence of having discovered all relevant insights contained in the graph

Although we asked for a rating (from 1 to 5) on each aspect, the ratings are not reported here – as we expected, they depend very much on the personality of participants. Instead, we focused on their explanations and comments to gain qualitative insights.

3.2 Results and Discussion

3.2.1 Efficiency

The upper part of Figure 3 shows the total duration (in seconds) of activities within the user sessions. Since we did not cut off the sessions, their duration varied slightly – control group (CG) sessions took overall more time. The time spent on interpreting results was comparable in both groups. While test group (TG) participants spent much less time on pure strategising, a significant share of their time went into studying query recommendations – which can be seen as a system-supported way of strategising. Thus, regarding the planning of next steps, the overall time difference between both groups was minimal. From a qualitative point of view, we observed that all test group participants pondered the recommended queries very carefully. Often, the time for doing so was prolonged by strange or less useful recommendations in the list, causing confusion – which indicates that the quality of recommendations (which we are not evaluating here) plays a role for the efficiency of solving the task. With the current implementation, it seems at first glance that there is no significant efficiency gain from query recommendations as far as the planning of next steps is concerned. However, as we will see in Section 3.2.2 below, test group participants do achieve a larger number of insights in the given time – which does suggest efficiency gains.

There was a notable difference in struggling with the tool functionalities, on which test group participants spent only roughly an average of 2.4 minutes whereas control group participants wasted an average of almost 4 minutes on it. A significant portion of this extra time was spent with query formulation – a problem that test group participants could avoid almost entirely by using the recommended queries. On the other hand, test group participants were more prone to the mistake of failing to select multiple nodes as a context when this was required (e.g. selecting both symptoms before asking which diseases cause them). An explanation for this – backed also by our observations – is that query recommendations pop up immediately when clicking on an individual node. Test group participants were thus tempted to fire off these queries without caring enough about a proper context selection. The problem of context selection was already observed in our first study (Witschel et al., 2020) – where we could however also show that users need a bit of time to get used to it, but then pick it up rather quickly. All in all, we can carefully conclude that query recommendations slightly increase the ease of use of our tool.

A last interesting finding was that users had false expectations regarding the node type filters on the left side of the user interface (see Figure 1): while these are only meant to help narrow down initial keyword searches – and are not meant to be used in subsequent steps – participants understood that they revealed information about the graph schema (all available node types). In the control group, all participants tried to select node types to constrain results in a subsequent query result at least once (marked “wanted_to_use_checkboxes” in the lower part of Figure 3). Since query recommendations also contain some hints about the graph schema, test group participants were less likely to fall into that trap.

When discussing about this problem, some participants (from both groups equally) stated that natural language queries are intuitive, but sometimes just selecting a node type and then expanding a context by retrieving all nodes of the chosen type connected to that context would be a useful feature. This implies that natural language queries may not be the most user-friendly navigation aid for all users in all situations.

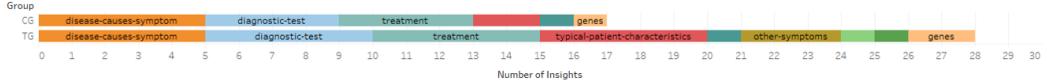


Figure 4: Insights derived in user sessions.

3.2.2 Effectiveness/Recall

As explained above, our main indicator of effectiveness was the number of insights covered in a given session. As shown in Figure 4, test group users discovered an average of 5.4 insights whereas control group users found only 3.4. More precisely, the number of insights in the test group sessions were (4, 5, 5, 6, 7); in the control group the distribution was (3, 1, 3, 7, 3). This shows that results in the control group depend more heavily on the creativity and previous knowledge of participants, whereas query recommendations seem to achieve a higher and more reliable number of insights in the test group. This leads us to the conclusion that query recommendations can increase recall by providing not only guidance regarding the graph schema, but also providing inspiration for further insights.

If we consider that test group participants have discovered a larger number of insights and that test group sessions were on average slightly shorter (see Figure 3, top), we can slightly revise our conclusions regarding efficiency: since more results are achieved in the same timeframe, query recommendations do seem to have a positive effect on efficiency, too.

3.2.3 Post-test Interview Results

The answers of participants in the post-test interviews showed quite little differences between control and test group regarding the ease of use/navigation. All participants of both groups found the tool either easy to use or easy to get used to (in line with our findings in (Witschel et al., 2020)), pointing out a few usability issues.

Similarly, participants in both groups rated the efficiency as high, some of them mentioned that a lack of knowledge slowed them down, but that the tool helped them. While control group members mainly mention that they got used to the paradigm quickly, test group participants refer notably more often to being “guided” or “helped to find a way”. Finally, neither of the two groups are very confident regarding the recall of their search.

All in all, perceptions in both groups seem to be very similar. As a single notable difference, test group members were more likely to refer to the guidance that the tool offered them and its help in finding a good strategy.

4 CONCLUSIONS

In this study, our goal was to investigate the extent to which user guidance mechanisms, in particular query recommendations, can boost the efficiency and effectiveness of knowledge graph exploration. We have developed a simple iterative exploration mechanism of alternating context selection and querying and enriched it with heuristics-based query recommendation. We then conducted a qualitative user study to understand the impact of the recommendations on efficiency and effectiveness.

The findings of our user study suggest that recommendations provide some gains in efficiency, especially when considering how much time is needed per discovered insight – although participants in both test and control group spent about the same time planning and strategising, we observed that test group participants discovered a significantly higher number of insights, i.e. they achieve more “output” in the same time. Furthermore, we conclude that recommendations seem to have an “inspiring” effect, leading to an increased recall. This guiding effect was also subjectively perceived by test group members who stated that the recommendations helped them in defining their strategy for solving the task.

Since our findings also showed that suboptimal query recommendations can slow down knowledge graph exploration quite significantly, checking the effectiveness of our recommendation heuristics in more detail, as well as working on more sophisticated recommendation mechanisms is an obvious focus of future work. Such work may be based on collection of (training) data from user sessions, applying machine learning techniques to predict the best queries based on past user decisions, eventually replacing our simple heuristics.

Another direction for future work could be to work on easy-to-use guidance mechanisms that allow quick navigation without the use of natural language queries – which a user currently has to either type or read through. We expect that a combination of such simple graphical and click-based mechanisms with natural language queries might be better than each of these alone.

ACKNOWLEDGEMENTS

Supported by Innosuisse Project Nr. 26281.2 PFES-ES.

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