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Master thesis

Visualisation of Collective Spatial Keyword Queries and their Usability

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Visualisation of Collective Spatial Keyword Queries and their Usability

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master thesis entitled:

Visualisation of Collective Spatial Keyword Queries and their Usability

I have fully referenced the ideas and work of others, whether published or unpublished.
Literal or analogous citations are clearly marked as such.

Munich, 08.09.2020 Jonas Sebastian Beinder

Für Rio

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
— T.S. Eliot, Four Quartets

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Abstract

A collective spatial keyword query is a keyword query that returns geo-textual data in such a way that the result consists of items that cover the keywords collectively, but do not necessarily belong to the same category. The subject of collective spatial keyword querying has seen an increasing scientific interest over the last few years, but efforts have heavily concentrated on the algorithmic side of the problem rather than the visual. This thesis proposes a detailed concept for visualising collective queries on a map and evaluates this concept's usability and usefulness.

A methodology involving all steps from requesting keywords to rendering the results on a map is proposed. Core features are a novel type of collective query called TYPE2a Query, a center-point semantic where the first given keyword denotes a central point for finding matches of the other keywords, typified markers for lower zoom levels and routing between the individual items.

To test the hypothesis that collective queries have a higher usability for certain scenarios than current commercial mapping applications without this feature, a prototype called CoSKQVis (Collective Spatial Keyword Query Visualisation) was implemented and a user test was conducted. Participants were randomly divided between two groups and had to solve a task that involved finding a satisfactory set of five points of interest (PoIs) in an unknown environment with and without the feature of collective querying. They were then asked for their experience regarding different aspects of usability like efficiency, learnability, ease of use, subjective satisfaction and accuracy. The results support the hypothesis insofar that the prototype was rated significantly better in several of those aspects than the commercial alternative in the given target group and for the given task. Also usefulness was confirmed by the users for specific scenarios. However, many users in both groups had problems with executing the task entirely correctly and finding a set of five PoIs.

It has been shown that there is a need and interest for research in this matter. This thesis introduces the subject of visualising collective keyword queries, paving the way for future research to create an impact on search efficiency in the long term.

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List of Abbreviations

API	Application Programming Interface
CoSKQ	Collective Spatial Keyword Query
CoSKQVis	Collective Spatial Keyword Query Visualisation
GIR	Geographical Information Retrieval
GPM	Graph Pattern Matching
JSON	JavaScript Object Notation
LkT	Location-aware Top-k Text Retrieval (Cong, Jensen & Wu, 2009)
minSK	Minimum Spatial Keyword Cover (Choi, Pei & Lin, 2016)
mSKQ	m-closest Keyword Query (Zhang, Chee, Mondal, Tung & Kitsuregawa, 2009)
NLP	Natural Language Processing
OSM	OpenStreetMap
OSRM	Open Source Routing Machine (Luxen & Vetter, 2011)
PoI	Point of Interest
SERP	Search Engine Result Page
SGK Query	Spatial Group Keyword Query
SK-Cover	Spatial Keyword Cover (Choi et al., 2016)
SKQ	Spatial Keyword Query
SPM	Spatial Pattern Matching (Fang, Cheng, Cong, Mamoulis & Li, 2018)
UI	User Interface
UX	User Experience
WGS	World Geodetic System

1 Introduction

1.1 Research Problem and Motivation

Searching for Points of Interest (PoIs) is one of the central tasks for a mobile map application like Google Maps[1], Bing Maps[2] or HERE WeGo[3] as well as navigation software such as TomTom[4], Waze[5] or OsmAnd[6]. Whether finding the nearest gas station or a restaurant in the vicinity of your workplace, asking an app on your smartphone is nowadays usually the way to go.

Searches for PoIs in a spatio-textual manner using a set of keywords and a target area are called *Spatial Keyword Queries*. Such a spatial keyword query typically takes a location and one or more keywords and tries to find one or multiple objects that satisfy all arguments in or around the target area (Cong & Jensen, 2016).

But one could think of scenarios where a query cannot be satisfied by just one type of PoIs. This kind of query is called *Collective Spatial Keyword Query* or *Spatial Group Keyword Query* (Cao, Cong, Jensen & Ooi, 2011). Here a set of keywords is matched by a (heterogeneous) group of multiple PoIs.

1.1.1 Problem Statement

An example of current interest for a collective spatial keyword query is a driver of an electric car who might want to spend the time needed to recharge their car's batteries with a fun or useful activity, like eating lunch or visiting a library. They might therefore look out for an electric charger that has a restaurant or a library nearby using their navigation app. But, as O'Beirne (2017) puts it, currently "there's [..] no easy way to search for a combination of places, say Restaurants *and* Hotels *and* Gas Stations, together."

So how can such a combination of places be found, considering the need for proximity between the electric charger and the desired activity, ideally near the user's position or along their planned route? Or, in general terms, how does a map user find places of *category x* that are close to places of *category y*, in their current or future vicinity?

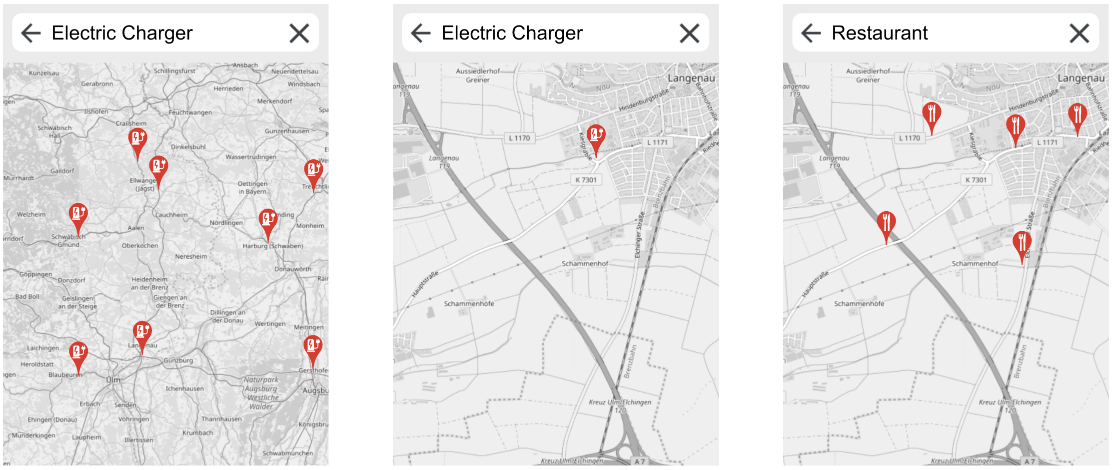
[1]https://www.google.com/maps
[2]https://www.bing.com/maps
[3]https://wego.here.com
[4]https://www.tomtom.com/
[5]https://www.waze.com/
[6]https://osmand.net

Questions like these can be found in different contexts, e. g. when a user wants to combine two or more activities successively or simultaneously. Examples of such activities include the following:

- "I want to go out tonight. How do I find a bar that is close to a discotheque?"
- "I am hungry and tired. How do I find a hotel that is close to a restaurant?"
- "I want to eat something and go for a nice walk while my electric car recharges."
- "Where is a laundry service where I can go shopping while waiting for my clothing to dry?"
- "I have a meeting in city X, I need a hotel and a dry cleaner near a bus station."
- "Give me places where I can eat, sleep and go shopping close to each other."

1.1.2 Current Workaround

Currently, formulating such queries is not possible with popular mapping apps like Google Maps, Bing Maps or OpenStreetMap[7]. To tackle such a problem with one of these services, the user first has to search for *category x* (e. g. electric charging stations, see Figure 1.1a), focus on one result at a time (see Figure 1.1b) and then search separately for *category y* (e. g. restaurants) around each result (see Figure 1.1c). But this leads to a new search result, discarding the results of the previous query, making it difficult to estimate distances between the two search results.



(a) Step 1: Finding electric chargers in the vicinity or along a route

(b) Step 2: Focusing on one charger at a time to find activities nearby

(c) Step 3: Searching for the desired activity, but the results of the previous query are gone

Figure 1.1: Current workaround to find spatially related points of interest using a web mapping platform

When the user has found a set of PoIs in close vicinity, they furthermore need another request to the application to find routes to navigate between the found PoIs. Because of this complexity

[7] https://www.openstreetmap.org/

and the time-consuming nature, the user will probably never consider all suitable places and most likely not find the optimal place either, nor be satisfied with their selection.

Herein lies a strong potential for improvement. Collective queries can add a whole new dimension of usefulness and usability to the search for points of interest. Enabling mapping or navigation applications to accept and subsequently visualise such queries might increase their benefit immensely. This benefit could be even greater if the visualisation provided direct routing between the found elements.

1.2 Research Identification

Users of mobile navigation applications make up the majority of smartphone users (77%, Panko (2018)), and Google Maps alone claims to have more than 1 billion users (Glasgow, 2020). For this user group, the ability to easily formulate questions on more than one category of interest can greatly enhance the usefulness of these applications. Also providers of such services can profit from simplifications in formulation of complex queries, as this means customers are more satisfied and productive and thus more likely to return to their service.

This thesis evaluates the possibility to use collective queries in the context of current mapping applications.

1.2.1 Research Objectives

The main objective of this thesis is therefore to **propose a visualisation of such collective spatial keyword queries**.

This overall objective can be subdivided into three separate sub-objectives and dependent research questions.

Objective 1. Provide a useful visual concept that supports collective spatial keyword queries in such a way that allows users to search for PoIs of different categories simultaneously.

Objective 2. Provide a useful visual concept that displays the results of collective spatial keyword queries on a map.

Objective 3. Test whether this suggested concept is an improvement over existing systems for the targeted audience.

What this research explicitly excludes is the algorithm and data storage aspects of finding and managing geospatial web objects, as there has been plenty of research dealing with these aspects (e. g. Cao, Chen et al., 2012; Cao et al., 2011; Chen, Cong, Jensen & Wu, 2013; De Felipe, Hristidis & Rishe, 2008). These works provide a comprehensive overview of the domain of spatial data structures, like R-trees and their various variants, and efficient retrieval of spatio-textual data.

1.2.2 Research Questions

Three research questions are formulated to reach the research objectives, each consisting of several sub-questions.

RQ1. How can an appropriate visual concept look and behave to provide the possibility to search for more than one PoI category?

- What are the characteristics of a spatial query?
- How does querying for more than one PoI category change the context of spatial search?
- How does the ordering of keywords affect a query result?
- Which UI elements are needed on a screen to enable such searches?

RQ2. How can an appropriate visual concept look and behave to visualise results of such queries on a map?

- What information needs to be represented visually within a query result?
- How can a collective query with multiple results be visualised on a map?
- How can routing information be integrated into the visualisation of results?
- How does a good query match differ visually from a bad match within a result set?

RQ3. Is a system that enables queries for more than one PoI category superior in terms of usability to current commercial systems, e. g. Google Maps?

- How to measure the usability of the proposed framework?
- Is the visual representation an improvement in terms of usability?
- Have there been misunderstandings in the semantics of the results?
- Is the system actually useful in certain scenarios?
- What features are missing in the system?

1.2.3 Hypothesis

The overall hypothesis guiding this research is that the possibility to search for multiple PoIs simultaneously has advantages over the current commercial state of the art in certain scenarios. Such advantages can be in terms of satisfaction, usefulness, ease of use, learnability or accuracy.

1.3 Thesis Structure

This thesis is organised as follows:

Chapter 1 – Introduction

This introduction presents the topic and context of this thesis' research. Here the problem is described and a number of real-world examples are given. The current workaround is sketched and the potential for improvement is laid out. The chapter is wrapped up with the statement of the research objectives and research questions this thesis deals with.

Chapter 2 – Background and Related Research

To place this work within the existing research, this chapter gives a thorough overview of the state of the art, separated into two chapters covering spatial keyword queries and user interfaces for spatial search. First, standard and collective spatial keyword queries are introduced and several kinds thereof are described and characterised. Collective queries are distinguished between those with and those without a query location, and notable scientific projects that visualise different types of spatial keyword queries are introduced.

Afterwards, user interfaces for spatial search, namely text-based and map-based interfaces, are described. Text-based queries using structured and unstructured form and their respective processing are characterised. Afterwards map-based interfaces are discussed, especially map markers. Marker icons and their iconicity, as well as an overview of visual variables are given. Finally, generalisation techniques are assessed and typification as the most suitable technique is discussed in particular.

Chapter 3 – Methodology

To create a sound visual concept for collective queries a number of considerations must be made. This chapter presents questions and possible solutions towards a visual concept for collective queries. The different components of the concept and their interplay are introduced in such a way that a sound image is created.

Chapter 4 – Case Study

The case study consists of two parts: first, the implementation of the methodology in the form of a prototype named CoSKQVis, and second, the testing of the usability of the prototype in a user test. This chapter elaborates on the development and structure of the prototype, its UI elements and their realisation in a usable client-server application. Thereafter the user test is explained, detailing on the target user group, attributes of usability that need to be raised, and its general structure.

Chapter 5 – Results

This chapter shows the procedure, evaluation and results of the user study. Erroneous submissions are analysed, before detailing the demography and web map product usage of the remaining users. The mastering of the task is examined, and the answers regarding five different aspects of usability are listed and investigated. The chapter closes with the results and analysis of questions directed towards particular features contained in CoSKQVis.

Chapter 6 – Discussion

The discussion chapter revisits the research questions stated in Chapter 1 and elaborates on related findings from the preceding chapters. Furthermore, limitations of the methodology and the user study that were encountered in the course of this thesis are discussed.

Chapter 7 – Conclusion and Outlook

Lastly, the key findings from the thesis are stated and their impact on the field of spatial querying is estimated. The thesis concludes with an outlook on future research that may be useful for continuing work on this subject.

2 Background and Related Research

The research of this thesis covers two main areas in the field of geo-visualisation: spatial querying and its technical principles, and user interface design. This chapter gives a thorough overview of both areas to an equal extent.

First it provides a comprehensive review of different kinds of spatial keyword queries, especially collective spatial keyword queries, and states their features and exemplary use. An overview of existing projects to visualise such queries is included. Afterwards a review of user interface principles in the context of spatial and non-spatial search is presented, with a focus on symbol design to support the development of a suitable symbology in Chapter 3.

2.1 Spatial Keyword Queries

This section explains what spatial keyword queries are and characterises the different types of standard and collective queries. Collective queries are distinguished between those with and without explicit query location. Finally, an overview of the state of the art to visualise such queries is given.

Any web content that is enriched by a location is called *geo-textual* or *spatial-textual data* (Cong et al., 2009), or alternatively *spatial web objects* or *places* (Cao, Chen et al., 2012). Examples of such geo-textual content include geotagged blog or news entries, tweets from Twitter[1] or photos on platforms like Instagram[2] or flickr[3] that contain a location component, as well as representations of real world places like those found on Foursquare[4], TripAdvisor[5] or Google Places[6].

2.1.1 Standard Queries

The omnipresence of geotagged data has led to the need for efficient searching thereof in a spatial or spatio-textual way. Standard *spatial keyword queries (SKQ)* take a location and one or more keywords and return the best object or a set of similar objects matching the parameters supplied (Cong & Jensen, 2016).

[1] http://www.twitter.com
[2] http://www.instagram.com
[3] http://www.flickr.com
[4] http://www.foursquare.com
[5] http://www.tripadvisor.com
[6] http://places.google.com

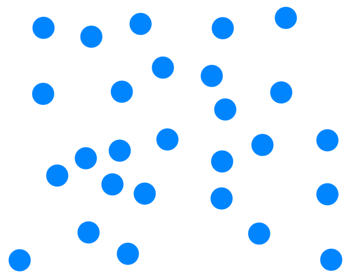
To accomplish this a spatially enabled database is simultaneously tested for spatial closeness and text similarity. When it comes to the spatial component, *range queries* return every object in a certain area, while *nearest neighbor searches* return the k closest results to a location (*kNN queries*). Textual queries can be either *Boolean queries* that search for exact matches, or *rank based queries* that measure the similarity of the given keywords.

From these categories four general types of queries can be derived (Cao, Chen et al., 2012):

1. *Boolean Range Queries* $q = \langle \rho, \psi \rangle$ take a spatial region ρ and a set of keywords ψ, returning all objects that lie inside the region ρ and contain the keywords ψ (see Table 2.1 row 1).
2. *Top-k Range Queries* $q = \langle \rho, \psi, k \rangle$ take a region ρ, a set of keywords ψ and a number k, retrieving k places inside the query region ρ, ranked according to their textual relevance to the keywords ψ (see Table 2.1 row 2).
3. *Boolean kNN Queries* $q = \langle \lambda, \psi, k \rangle$ take a spatial point λ, a set of keywords ψ and a number k, returning the k results closest to the point λ containing the keywords ψ (see Table 2.1 row 3).
4. *Top-k kNN Queries* $q = \langle \lambda, \psi, k \rangle$ return k places ranked according to a calculated score incorporating the closeness to the point λ and the textual similarity to the keywords ψ (see Table 2.1 row 4).

The naming of these queries follows the schema of Cao, Chen et al. (2012) and Chen et al. (2013). Queries may be named differently in other literature, e. g. Top-k kNN Queries may be called *Top-k Spatial Keyword Queries* (Rocha-Junior, Gkorgkas, Jonassen & Nørvåg, 2011), *Location-aware Top-k Text Retrieval (LkT) Queries* (Cong et al., 2009) or *Top-k Spatial Text Retrieval Queries* (Wu, Cong & Jensen, 2012).

The following Table 2.1 gives a general overview of such simple spatial queries. The first two rows give general information: the first row shows the whole search space containing all (relevant and irrelevant) items, and the second reduces the search space to show only those objects matching the hypothetical keywords. Afterwards, the four types of queries working on this search space are outlined with a description and a simplified schematic visualisation.

Name	Description	Schematic Image
Search Space	All items in the search space are marked blue	

Continued on next page

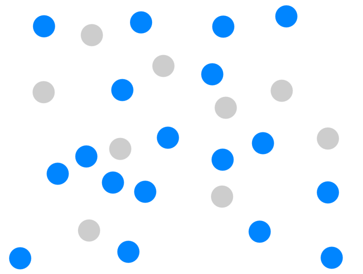
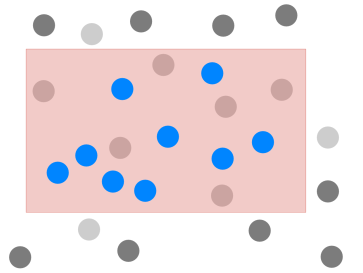
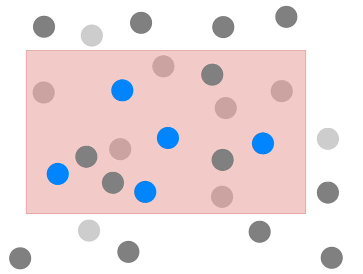
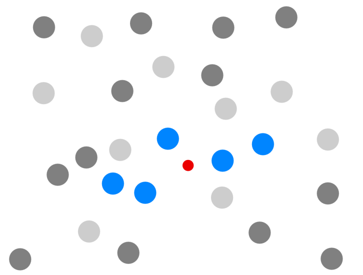
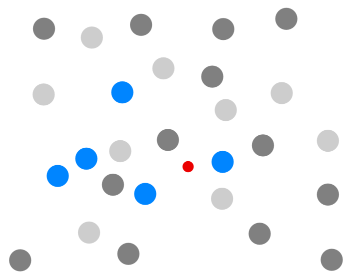
	Name	Description	Schematic Image
	Keyword matches	All items from the search space that match the keywords are marked blue, non-hits are marked grey	
1	**Boolean Range Query**	All items that match the keywords and fall into the query region (red) are returned (blue)	
2	**Top-k Range Query**	Here: k = 5 The best 5 matches ranked according to their textual relevance inside the query region (red) are returned (blue)	
3	**Boolean kNN Query**	Here: k = 5 The best 5 matches ranked according to the closeness to the query point (red) are returned (blue)	
4	**Top-k kNN Query**	Here: k = 5 The best 5 matches ranked according to a calculated score incorporating the closeness to the query point (red) and the textual relevance are returned (blue)	

Table 2.1: Description and visualisation of standard spatial queries

The above standard queries have in common that they return a homogeneous set of similar objects, e. g. hotels with the requested keywords. But it is easy to think of queries that no single object can satisfy, but a set of places in close vicinity collectively can. For example, a query for fueling a car, dining, and shopping can rarely be satisfied by a single place, but possibly by a combination of three separate places. Such queries are called *Collective Spatial Keyword Queries (CoSKQ)* (Long, Wong, Wang & Fu, 2013) or *Spatial Group Keyword (SGK) Queries* (Cao et al., 2011), and will be explained in the next chapter.

2.1.2 Collective Queries

So far a distinction between range queries and kNN queries has been made. For CoSKQ, a similar differentiation can be carried out: an algorithm can either work on the full search space (or a subset thereof), creating something like a range query, or the user supplies a query location, effectively building a kNN query.

But unlike the differentiation between Boolean and top-k queries, where the user receives either all or up to k results, research in CoSKQ usually only considers one – the best – result. However, not much imagination is necessary to picture top-k and Boolean CoSKQ; the difference lies only in the number of results.

There are different kinds of collective queries: some work without a query location, others rely on the supplement of a query location. Separate from these two techniques is spatial pattern matching, as it does not employ a cost function but rather works with graph matching algorithms. These three categories will be explained in detail in the following chapter. Table 2.2 lists all described CoSKQ types with a small description and a simplified schematic image.

Collective Queries without Query Location

When it comes to collective queries that do not rely on a given query location but use the whole search space, the most simple approach is the *m-closest Keyword Query (mSKQ)* (Zhang et al., 2009). A result set χ is deemed optimal for a collective query, when the diameter of the set is minimal, i. e. the cost is the maximum distance between any two objects in the set:

$$\text{Cost}(\chi) = \max_{r_1, r_2 \in \chi} \big(\text{Dist}(r_1, r_2)\big)$$

This kind of query is useful for someone who is not committed to a certain location, but rather needs short distances between the individual objects (see Table 2.2, row 1).

An improvement on this approach is presented by Choi et al. (2016). They propose a query type called *Spatial Keyword Cover (SK-Cover)*, also referred to as *minSK* (Fang, Cheng, Wang et al., 2018). It is shown here that the minimal diameter does not always return the best result, and a cost function is introduced that also tries to minimise the number of results:

$$\text{Cost}(\chi) = (|\chi| - 1) \cdot \max_{r_1, r_2 \in \chi} \big(\text{Dist}(r_1, r_2)\big)$$

with $|\chi|$ denoting the number of objects in the result set. The query takes into account that some items do not just belong to one category, e. g. a bakery can also be a café. With the supplied formula, the number of individual locations a user needs to consider in order to visit all PoIs can be reduced (see Table 2.2, row 2).

Collective Queries with Query Location

In order to retrieve object groups using a query location Cao et al. (2011) state three criteria to find the optimal result set. A group of places satisfies such a query, if:

1. the union of all objects' keywords cover all keywords of the query
2. the objects are as close to each other as possible and
3. all objects are as close to the query location as possible

With these criteria in mind Cao et al. (2011) present two different methods for finding appropriate object groups. A group of places χ is considered fit for the query $q = \langle \lambda, \psi \rangle$, if

1. χ covers the keywords ψ in such a way that the sum of distances to the query location λ is minimised (*TYPE1 query*).
2. χ covers the keywords ψ in such a way that the sum of the maximum distance between an object and λ and the maximum distance between two objects is minimised (*TYPE2 query*).

TYPE1 SGK (see Table 2.2, row 3) queries are used when it is necessary to consider the distance between the query location and the query results, e. g. when there is a central meeting point to return to (Cao, Cong et al., 2012) or the finding of consortium partners for a joint project (Cao et al., 2011).

The cost function representing this type of SGK queries is the sum of the distances between each object in χ and the query location λ:

$$\mathrm{Cost}(q, \chi) = \sum_{r \in \chi} \big(\mathrm{Dist}(r, \lambda)\big)$$

TYPE2 SGK (see Table 2.2, row 4) queries may serve cases where tourists want to visit several places sequentially, without necessarily returning to the query location (Cao, Cong et al., 2012). The cost function for this type consists of two parts: the distance between any object in χ and the query location λ, and the maximum distance between two objects in χ (the diameter of the result):

$$\mathrm{Cost}(q, \chi) = \max_{r \in \chi} \big(\mathrm{Dist}(r, \lambda)\big) + \max_{r_1, r_2 \in \chi} \big(\mathrm{Dist}(r_1, r_2)\big)$$

Both parts of this function can be preceded by parameters to individually weigh their influence on the overall result (Cao et al., 2011).

Long et al. (2013) call this TYPE2 kind of collective query *MaxSum-CoSKQ* (maximum sum cost function collective spatial keyword query) and propose another kind of collective spatial keyword query: *Dia-CoSKQ* (diameter cost function collective spatial keyword query, see Table 2.2, row 5).

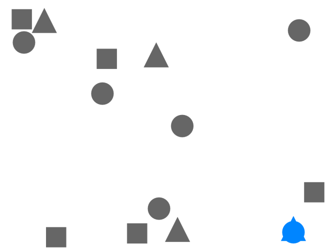
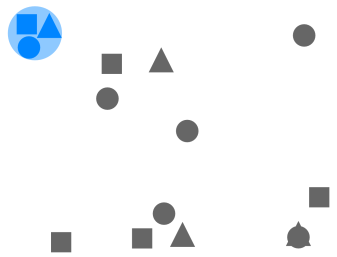
Here the fitness of the result set is determined solely by its spatial diameter including the query location, i. e.

$$\mathrm{Cost}(q, \chi) = \max_{r_1, r_2 \in \chi \cup \lambda} \left(\mathrm{Dist}(r1, r2)\right)$$

Spatial Pattern Matching

Another type of Collective Queries called *Spatial Pattern Matching (SPM)* queries is introduced by Fang, Cheng, Cong et al. (2018). The specialty here is that the objects inside the result set are not necessarily close to each other, but lie inside minimum and maximum distances that can be determined by the user (see Table 2.2, row 6). For example, a user might want to purchase a house that has a school in a distance between 0.2 and 0.5 km, a station between 0.2 and 0.4 km, and a park not further away than 0.2 km. The nature of these kinds of queries is resembled by a graph whose vertices are labeled with keywords and edges denominate the distance between the vertices. By using optimised graph pattern matching (GPM) algorithms SPM finds all suitable subgraphs inside the object graph that match the query graph.

All CoSKQ types introduced in this chapter are summarised and visualised with a schematic illustration in the following Table 2.2:

	Name	Description	Schematic Image
	Search Space	Items in the search space belong to one of three categories symbolized by three different symbols; One symbol (marked blue) belongs to two categories (important for query type *SK-Cover*)	
1	**m-closest Keyword Query (mSKQ)**	The PoI group with the smallest diameter in the whole search space is returned (blue)	

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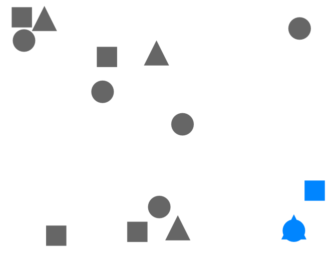
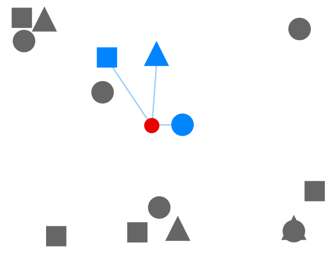
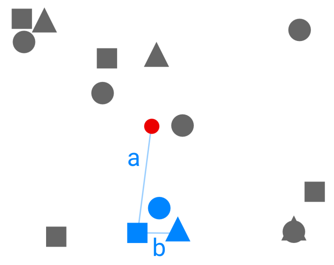
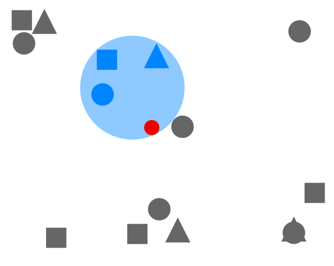
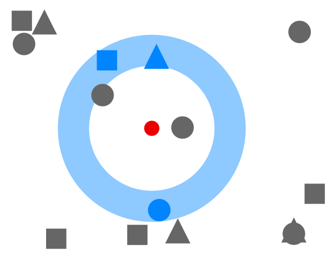
	Name	Description	Schematic Image
2	**Spatial Keyword Cover (SK-Cover)**	The PoI group with the smallest diameter containing the fewest individual elements is returned (blue)	
3	**TYPE1 SGK Query**	The PoI group where each element has the smallest distance to the query location (red) is returned (blue)	
4	**TYPE2 SGK Query**	The PoI group having (a) the smallest maximum distance to the query location (red) and (b) the smallest inter-object distance is returned (blue)	
5	**Diameter Cost Function (Dia-CoSKQ)**	The PoI group having the smallest diameter, including the query location (red), is returned (blue)	
6	**Spatial Pattern Matching (SPM)**	Unlike the other types, SPM works by building a graph of all objects in the search space and matching a query graph against it. This way users can query for spatial patterns, e.g. objects that lie inside a certain distance range (blue) to a query location (red).	

Table 2.2: Description and visualisation of collective spatial queries

2.1.3 Visualisation of Spatial Keyword Queries

While keyword querying is one of the basic functions of many commercial web mapping services like Google Maps[7] or Bing Maps[8], scientific efforts have been made to create visualisations of keyword queries that exceed the current commercial state of the art, for example:

- GroupFinder (Bøgh, Skovsgaard & Jensen, 2013) is a platform that facilitates users to find locally dense groups of PoIs of the same type in order to explore different options before making a choice.
- SOPS (Chen, Cui, Cong & Cao, 2014) provides the possibility to subscribe to spatio-temporal keyword streams (e. g. Twitter) to retrieve the most relevant objects over time.
- YASK (Chen, Xu, Jensen & Li, 2016) is a visualisation of spatial keyword top-k queries that is capable of answering why-not questions, that is, why a certain item has not been included in a result set.
- RISE (Feng, Zhao, Liu & Cong, 2016) is a system optimised for spatio-temporal region search and region exploration.

The possibility to explore CoSKQ in a visual way has been a focus in these two projects:

SWORS (Cao, Cong et al., 2012) is an open web-based platform that allows users to retrieve spatial web objects using top-k kNN queries as well as TYPE1 and TYPE2 SKG queries. Retrieval of the best result can be done by an exact algorithm (slower) or by approximation (faster). The visualisation of the query results seems to be using standard markers on a very simple interface using Google Maps (see Figure 2.1), but there is no information showing the actual result of a SGK query, since the application is not to be found online.

SpaceKey (Fang, Cheng, Wang et al., 2018) is the system with the closest ties to this thesis' research. Here users can issue SGK and SPM queries that are visualised with vertices and edges, showing the distances between the individual items and displaying which node satisfies which keyword. Notable is the possibility to compare different algorithms and the possibility to extend the system with future algorithms.

Due to the extensive capabilities of the app, the interface is relatively complex, having a sidebar, popup windows, and several main windows for different functions. Query results are displayed in the map window, using bold text on simple red markers. When using the SPM query, these are connected with red lines representing the edges of the graph (see Figure 2.2). The system is not limited to retrieving only one result per query, so it is possible to cycle through the results one by one, but not to have the whole result set visualised at once.

A discussion of the similarities and differences between SpaceKey and this thesis' research results can be read in Section 6.5.

[7] https://www.google.com/maps
[8] https://www.bing.com/maps

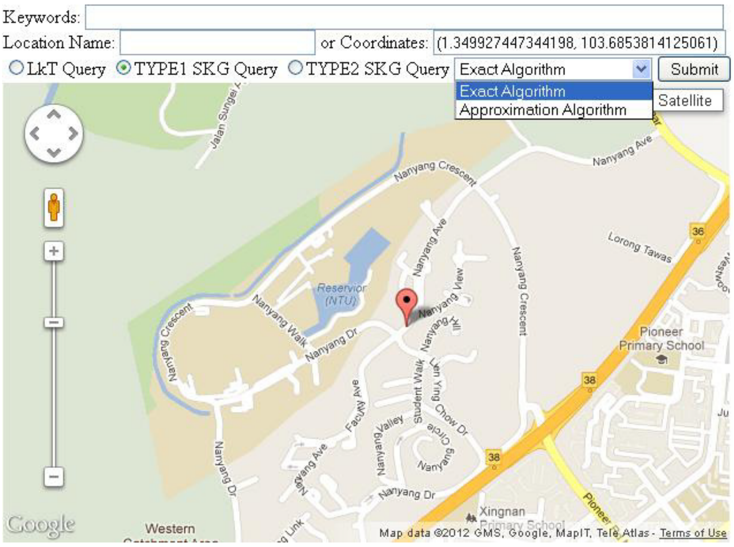


Figure 2.1: Interface of SWORS, taken from Cao, Cong et al. (2012)

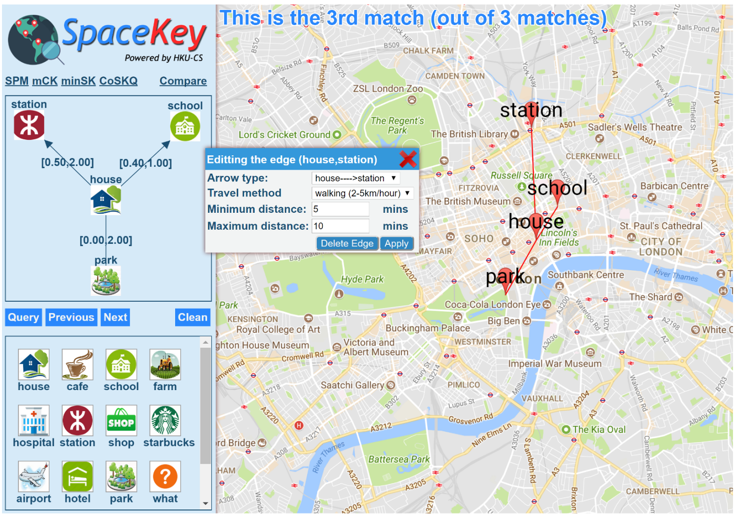


Figure 2.2: Interface of SpaceKey, taken from Fang, Cheng, Wang et al. (2018)

2.1.4 Conclusion

This section has introduced the discipline of spatial keyword querying, classified into two groups: standard queries and collective queries. While standard queries (Section 2.1.1) return homogeneous result sets with each item satisfying all keywords, collective queries (Section 2.1.2) result in heterogeneous item sets that jointly cover all keywords in question. For both categories a number of different query types have been outlined, and a distinction between collective queries with and without query location, as well as spatial pattern matching has been carried out. Section 2.1.3

has shown scientific efforts that exceed the capabilities of commercial applications and focused on two projects that visualise collective queries.

2.2 User Interface Design for Spatial Search

User interfaces (UI) and *user experience (UX)* are closely connected terms that Roth et al. (2017) describe as “a set of concepts, guidelines and workflows for [..] the design and use of an interactive product, map-based or otherwise”. Together they shape the communication between the user and system. In this context manipulation of underlying data and control of the behaviour of the system is done with the help of user interfaces.

A user interface within a *geographical information retrieval (GIR)* system enables the user to formulate a search query consisting of a textual and a spatial component. The textual part is usually entered in one or more search fields, while the spatial constraints are specified either textually (“north of”, “near”) or with the help of a map component. Both parts are matched against a database evaluating the *spatial* and *thematic relevance* of each object in the context of the query (Bucher, Clough, Joho, Purves & Syed, 2005).

This section presents existing research that addresses user interfaces in the context of spatial and also non-spatial search, since many principles apply to both. The focus is laid on the two most important UI elements in the context of spatial search: search interfaces and their characteristics, and the symbolic presentation of the results on a map. Both play an important role in the novel CoSKQ visualisation presented in Chapter 3.

2.2.1 Text-based Search Interfaces

Purves, Clough, Jones, Hall and Murdock (2018) state that the first interaction a user with an information need usually undertakes is to enter their query into a search bar before executing the search by pressing a “search” button.

Advanced and Simple Search Forms

There seem to be two general approaches when it comes to search forms: either the form is complex with several inputs, dropdown fields and checkboxes, giving the user a wide range of possible search parameters to consider (for an example see Figure 2.3), but often limiting them to the available options. This approach is called *Advanced Search* and came with the advent of “form filling” using graphical user interfaces in the late 1980s (Wilson, 2011). Advanced search facilities can often be found in library interfaces, although attempts have been made to provide single-input interfaces instead (Lown, Sierra & Boyer, 2013; McKay & Buchanan, 2013).

But instead of providing a high number of specialised search inputs, search engines nowadays rely on the other extreme: one search bar (also “search box”) for everything (see Figure 2.4), allowing users to freely express their desire, be it using keywords, terms, sentences or questions.

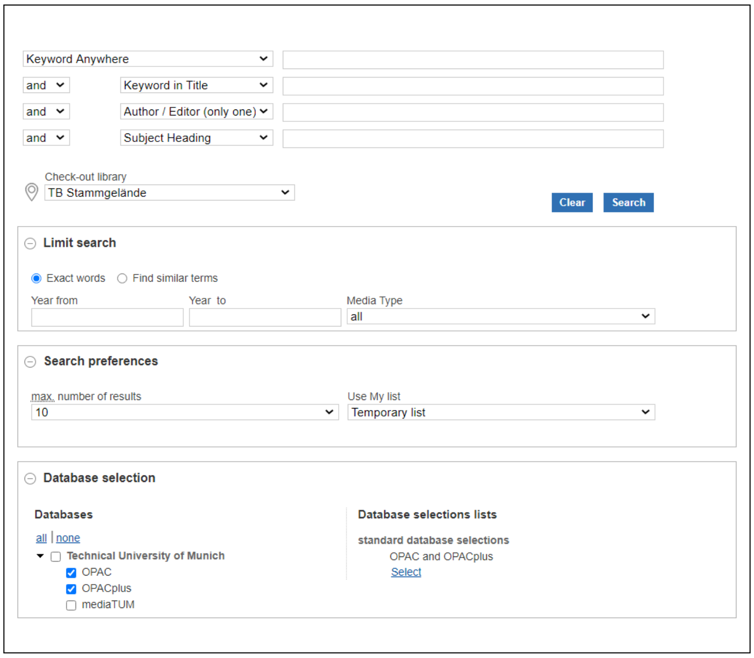


Figure 2.3: TUM OPAC search interface, taken from https://www.ub.tum.de/tum-opac

Such simple search forms are often accompanied with an auto-complete feature to guide users towards queries that are likely to work (Wilson, 2011) and the possibility to use operators like "OR", "AND" (to combine terms), and "NOT" (to exclude terms from the search), and advanced keywords like "site:" (a term to show only results from a certain domain). Often, search interfaces that allow the query to be manipulated with operators and keywords offer an alternative search via an advanced form that provides all possible options as separate inputs, e. g. Google Advanced Search[9].

Structures and Unstructured Queries

In general, the difference between free-form and advanced interfaces is one of structured and unstructured queries. Structured queries rely on the data having a well-structured form. Therefore advanced forms often provide only valid parameters to the user, e. g. in dropdown fields or by using an autocomplete feature. Free-form input is often not processed before comparing it to a database, making slight deviations in user input critical. Unstructured queries in contrast need to be refined by a natural language processor (NLP) or a similar function to recognize relevant entities, and to create structured from unstructured data.

Both strategies have their advantages and disadvantages – while unstructured queries allow users to express their desire in their native language, the analysis of input and distinction of important terms from irrelevant filler words is difficult and error-prone. Structured queries, however, can be

[9] https://www.google.com/advanced_search

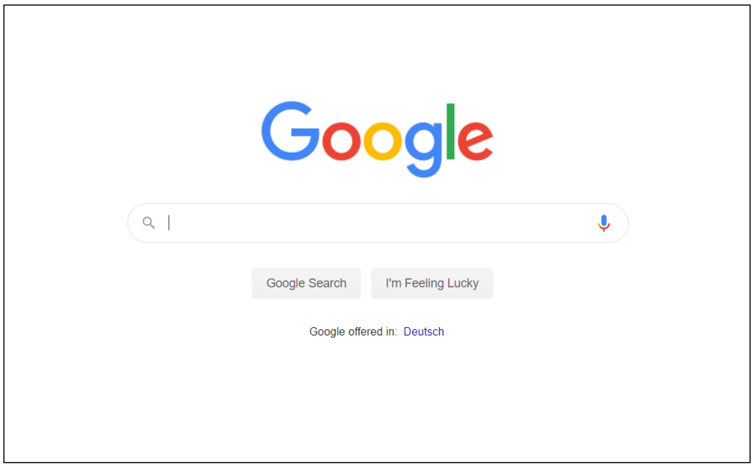


Figure 2.4: Google search interface, taken from http://www.google.com

easily matched against the underlying data that is often structured itself (e. g. place names), but the user needs to handle complex forms in order to state a question.

While the specification of query strings is non-spatial in nature, there are several options to access the spatial aspect of geo-textual data. To constrain a search to a certain spatial area a user can supply a georeference, i. e. geographical coordinates or toponyms (e. g. “Munich”) specifying the target area, or with a more complex directional specification such as “north of the Danube”, in a structured or an unstructured manner.

Structured geo-queries having a well-defined form consist of a theme (the “what”) and a location (the “where”), and either an implicit spatial relationship (`<theme><location>`, e. g. castles, Scotland) or an explicit (`<theme><relationship><location>`, e. g. lakes north of Munich) (Bucher et al., 2005).

Unstructured queries in contrast allow the user to specify spatial declarations in any way the user likes, e. g. “places in southern Bavaria, that have a stadium”, and the NLP needs to extract the theme, the relationship and the location from it.

2.2.2 Map-based Search Interfaces

While textual supply of the spatial component is a valid option, most modern mapping applications (exclusively or additionally) offer a map-based query interface, which is useful for cases where the user may not know the name of the place searched for or that place is not easily specified.

Spatial queries can be restricted here by zooming and panning a map interface to the desired region. Either the whole shown area is then used as the query region or the user can confine it more by drawing a bounding box or polygon on the map.

Additionally, *exploratory search* is a concept that aims not to answer well-defined questions, but rather to leverage broad curiosity, learning, decision making and other open-ended activities

(R. W. White & Roth, 2009). Users can state a query and then zoom and pan the map interface to discover relevant entries in different parts of the world. This exploration process is done by reinterpreting the thematic query every time the map has been zoomed or panned.

Marker Symbols for Search Interfaces

As soon as the request has been sent by the user, interpreted by the system and the relevant data has been retrieved from the geodatabase, the results must be reported back to the user. This is usually done in one of two ways: either the interface shows a list containing the results in the form of a *search engine result page (SERP)*, whole or paginated, or by displaying it graphically on a map. Many GIRs combine a map-based and a list-based interface and show exactly those markers on the map that are listed in the SERP (Purves et al., 2018).

List-based SERPs are usually simple to implement and easy to understand, but they lack the spatial aspect of the result set. This is why map-based visualisations of spatial query results are quite common nowadays. Here results are rendered dynamically on a map interface, using the three vector primitives: points, lines and polygons, based on the nature of the represented feature and the zoom level. Point features have no spatial extents and simply denote locations of items, without further specifying their size. Lines represent one-dimensional features like roads, train tracks or river centerlines. Lastly, polygons are used for two-dimensional features that occupy larger areas, such as parks, forests and water bodies.

The proposed visualisation in Chapter 3 presents query results using point features to denote the locations of found PoIs, and line features, to account for routes between them.

Point features are often symbolised with so-called markers, which give further information about the requested result upon click. While many map markers are generic, such as circles, pins, or upside-down teardrops, it is common to show icons to communicate the nature of the marked place. Map marker icons generally fall into one of three typological categories – they are either pictorial, associative or geometric (MacEachren, 1995 via Bell, 2020):

- **Pictorial icons** display the object or place they resemble. A symbol for a camping place for example may show an icon of a tent, a traffic light might be shown as just that.
- **Associative icons** are similar, but they show a close association to the resembled place. Examples are a tree for a forest, a book for a library or a slide for a playground.
- **Geometric icons** are abstract and bear little to no similarity to the represented place, such as circles for cities or squares for buildings. (Bell, 2020)

MacEachren (1995) ranks these icons along an axis from mimetic (imitating reality) or iconic (having a high recognition factor) to arbitrary (no resemblance to reality): geometric icons are usually very arbitrary, while pictorial and associative icons can be rather iconic (see Figure 2.5). On the other hand, geometric icons lose less significance when resized, so there is a trade-off between accommodation of more symbols or more easily comprehensible icons (Stevens, Robinson & MacEachren, 2013).

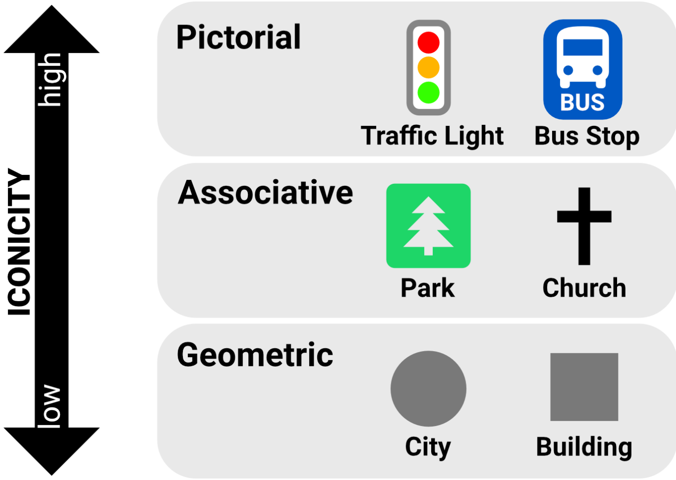


Figure 2.5: Typological categories of map icons, ranked according to their iconicity

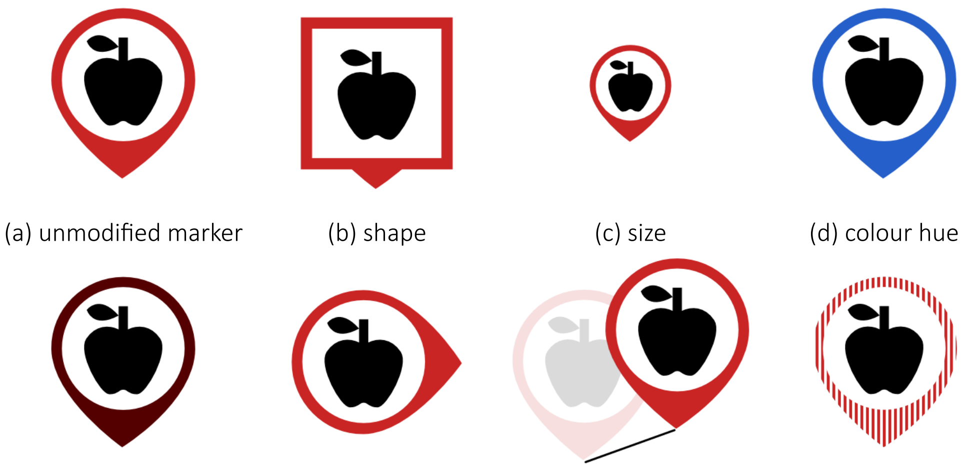
Visual Variables for Marker Symbols

While map marker icons are in general only used to communicate different categories of places, it is possible to describe other high-level information, like importance or uncertainty, using *visual variables*. Visual variables are regarded as the basic building blocks of maps or other visualisations, and are processed pre-attentively, i. e. at the sensory level of the perception apparatus (Roth, 2017).

Bertin (1983) describes seven different visual variables: position, shape, size, colour hue, colour value, orientation and texture. Morrison (1974) (via MacEachren et al., 2012) adds colour saturation and arrangement, and MacEachren (1992) further suggests crispness (also called clarity or fuzziness), resolution and transparency for visualisation of uncertainty. More variables can be derived, when time (animation) or non-visual aspects (sound, touch, smell) are considered (T. White, 2017).

Of the original seven variables, the following five are usually employed with map markers to transport differences in value: shape, size, colour hue, colour value and orientation (Bell, 2020). The two remaining are rarely used for this purpose, since **position** (Figure 2.6g) is usually fixed by the underlying data (although displacement is a common technique that uses variations in position, see later this chapter), and **texture** (Figure 2.6h) is rather used with areal symbols, not point symbols.

- **Shape** (Figure 2.6b) describes the general appearance of a symbol, e. g. circles, squares, triangles. Changes in shape usually denote differences in qualitative data, e. g. categories.
- **Size** (Figure 2.6c) is the area a symbol occupies and is best used for numerical measurements.
- **Colour Hue** (Figure 2.6d) denotes the colour of a symbol, and can be used for all kinds of data, but hues need to be logically ordered to be used for quantitative data.



(a) unmodified marker (b) shape (c) size (d) colour hue

(e) colour value (f) orientation (g) position (h) texture

Figure 2.6: Visual variables for map markers

- **Colour Value** (Figure 2.6e) is the term for the lightness or darkness of a symbol in a certain hue, e. g. light red or dark red. Changes in colour value are usually used for different quantitative values.
- **Orientation** (Figure 2.6f) is the direction a symbol faces in the map plane, and can be used for either qualitative or quantitative data.

These variables are often combined to create redundant symbolisation (T. White, 2017), e. g. large red symbols for high values and small grey symbols for low values.

Further information about the effectiveness of each variable can be found in Slocum, McMaster, Kessler and Howard (2009) (for Bertin's original seven and Morrison's two additional variables). T. White (2017) improves on this categorisation and also ranks non-visual variables.

Besides their importance for encoding of information and general aesthetic decisions, visual variables are also relevant when it comes to *salience* of maps. Visual salience is a term that refers to the perceptual quality of a visual element in a complex scene that makes it stand out from the rest, leading to the guidance of attention of the user (Itti, 2007). An important characteristic of map symbols is their separation from the background, i. e. their *figure-ground distinction*. Each visual variable has its own effect on the salience and figure-ground relation of the respective symbol. Some variations, such as centered positions, large sizes, dark symbols on bright maps and vice versa, or red colour hues tend to make the symbol rise to the foreground, while their opposites, peripheral positions, small sizes, similar brightness levels between symbol and map, or blue hues rather send a feature to the ground (Roth, 2017).

Generalisation of Map Symbols

One problem mapmakers are often confronted with is the visualisation of large amounts of point data. A commonly used term for the number of objects or grade of detail a map at a certain scale can support is called *map capacity* (Ratajski, 1967 via Edwardes, Burghardt & Weibel, 2005). To determine this number an often used solution is the so-called *Radical Law* by Töpfer and Pillewizer (1966), which gives an empirically estimated number of objects that can be shown based on the scales of the source and the target map, and the number of objects in the source material.

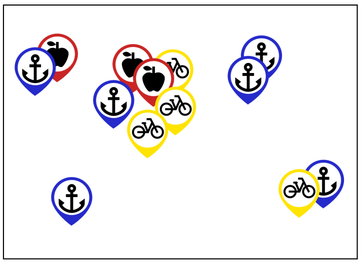
On small-scale or interactive maps markers quickly overlay one another and occlude parts of the data. Occlusion of data is called *clutter*, and the prevention or reduction thereof is a topic prominent in both information visualisation (Ellis & Dix, 2007) and cartography (Burigat & Chittaro, 2008).

Clutter reduction is a relevant topic for this research, because results of CoSKQ usually consist of a densely packed set of items that is prone to overlaying each other, at least on smaller scales. To avoid this, an automated process to generalise the point symbols of these items is needed.

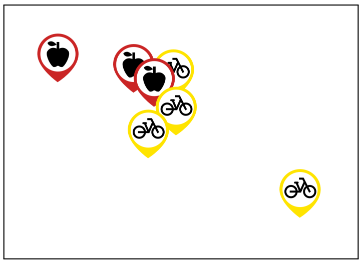
In cartography clutter reduction is basically congruent with *generalisation*, the technique of reducing the complexity of maps. This is commonly necessary for the creation of different scale maps from the same data or automatic reduction of details, e. g. in interactive maps. Many generalisation techniques are well established, but do not fit in this research, because they cannot be applied to point data (e. g. simplification of features or smoothing of lines, see McMaster & Shea, 1992).

Korpi and Ahonen-Rainio (2013) have compiled a list of eight clutter reduction techniques from different sources that they consider applicable for point data on maps:

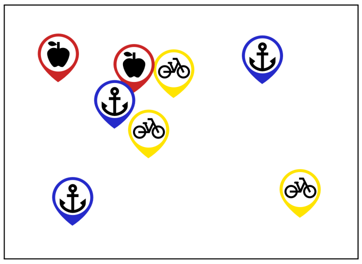
- **Selection** (Figure 2.7b) is the filtering of the data based on a criterion, e. g. global or local importance or relevance
- **Refinement** or **sampling** (Figure 2.7c) reduces the amount of visualised symbols by randomly selecting a subset of points, while preserving spatial patterns
- **Displacement** (Figure 2.7d) moves individual symbols away from their natural position to prevent overlay
- **Aggregation** (Figure 2.7e) is a **clustering** technique that groups semantically similar items by replacing them with a single item, e. g. a number, their bounding box or a Voronoi polygon
- **Typification** (Figure 2.7f) also belongs to the clustering methods, but combines aggregation and displacement in such a way that item are combined according to a category, and moved to not hide one another afterwards
- **Symbolisation** (Figure 2.7g) replaces icons with other icons that are less prone to clutter, e. g. smaller or more transparent
- **Spatial Distortion** (Figure 2.7h) does not change the items themselves, but rather stretches the background to create more space
- **Animation** (Figure 2.7i) can be used in digital maps to alternate between symbols and thus reduce the amount of items shown at the same time



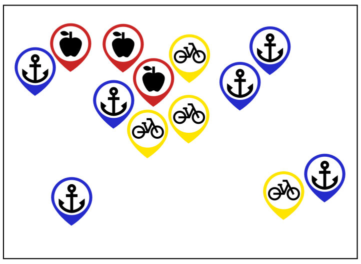
(a) Cluttered map



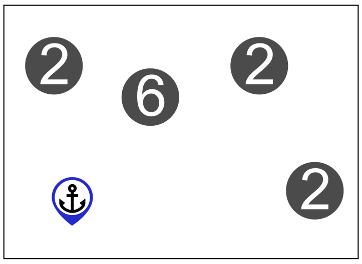
(b) Selection



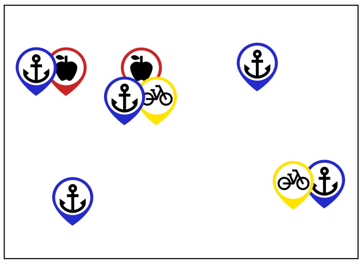
(c) Sampling



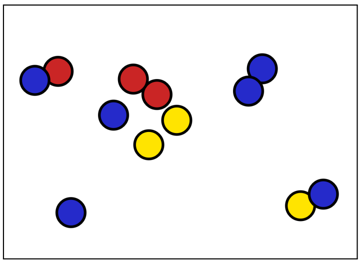
(d) Displacement



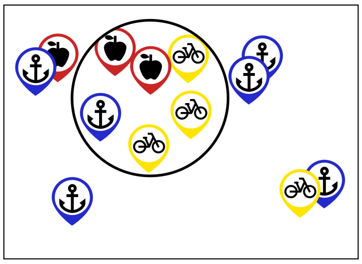
(e) Aggregation



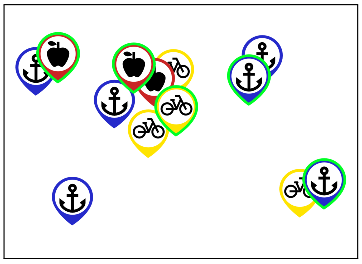
(f) Typification



(g) Symbolisation



(h) Distortion (magnifying lens centered to the most cluttered area)



(i) Animation (overlapping markers change order, currently highlighted markers with green outline)

Figure 2.7: Clutter reduction mechanisms for point markers

Korpi and Ahonen-Rainio (2013) also present ten different criteria to evaluate these techniques against, e. g. whether they reduce the visual complexity, avoid the hiding of symbols, or keep spatial information. An overview of all ten criteria is shown in Table 2.3, accompanied by an assessment regarding the relevancy towards this thesis' research, conducted by the author. Hereby the importance of criteria is categorised into the three levels "high", "medium" and "low" according to the main goals of this measure: to reduce visual clutter while keeping attributes visible.

Criterion	Importance	Comment
reduces complexity	high	CoSKQ results should be easily comprehensible to a user
avoids hidden symbols	high	this is the main reason for generalisation in this research
keeps spatial information	low	for small scales keeping the exact position is not important; for large scales, there should be no need for generalisation, as all items need to be visible
can be localised	low	each result is to be generalised independent of the others, so there are no clusters
is scalable	medium	the method should work for any amount of items in a result
is controllable	low	at the beginning, generalisation interaction is negligible
can show attribute values	high	for each result, the place type should still be discernible
can access individual symbols	medium	at least after unpacking a combined symbol, there should be access to the individual items
improves aesthetic quality	medium	good aesthetics are part of good UX
keeps logical hierarchy	low	there are no items that are more important than others

Table 2.3: Assessment of criteria from Korpi and Ahonen-Rainio (2013) against the requirements of this thesis' research

When considering the mentioned goals, only one technique is feasible: typification. Displacement is also a possibility, but does not really reduce visual clutter, while aggregation has the disadvantage of not maintaining attributes on display. In Chapter 3.3 typification is used as a basis for the visualisation proposal of this thesis.

Typification as a Generalisation Mechanism

Typification is a technique that is often used to reduce the level of detail in the process of creating larger scale maps from smaller scales, especially when it comes to line features (e. g. Touya & Girres, 2014) or buildings (e. g. Burghardt & Cecconi, 2007). For point symbols typification works on locally dense clusters of items and replaces them with new phenomena using an arrangement composed of a reduced number of features (Edwardes et al., 2005), or, as this thesis promotes, a dynamically created symbol that represents all contained items (e. g. Pombinho, Carmo & Afonso, 2009).

Edwardes et al. (2005) give three general criteria on the creation of symbol groups:

- each symbol must be individually recognizable
- smaller symbols should be arranged on top of larger ones
- the shape of the new group should represent the original shape of the symbols

For the generation of dynamic symbols the author is not aware of any research in this field, and considers the previously stated rules not fully applicable. Therefore a new set of rules is introduced in Section 3.3.1.

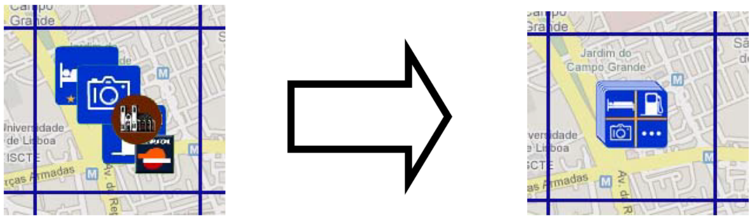


Figure 2.8: Typification operator used by Pombinho et al. (2009)

One user study has been found that contains the evaluation of a dynamically combined symbol. Pombinho et al. (2009) let the users solve different tasks using their map application that shows PoIs in smaller scales using typification (see Figure 2.8), aggregation and displacement mechanisms. One task is the search for a restaurant that has a gas station nearby, and they conclude that "[..] users found both aggregation and typification operators very helpful in creating a less confusing visualization."

2.2.3 Conclusion

This chapter presented principles of user interfaces relevant for spatial search. Text-based search interfaces (Section 2.2.1), either consisting of an advanced or a simple search form, enable users to request spatio-textual information by making structured or unstructured geo-queries.

Map-based search interfaces (Section 2.2.2) supplement this by giving the opportunity to specify the spatial component via a map interface. Map markers are used to pin locations of results on a map component, and often include marker icons to symbolize different categories of results. The resemblance an icon has to the marked place is described by their iconicity.

To describe higher levels of information, visual variables like size, shape or colour can be used. To reduce clutter among point symbols generalisation techniques are employed, of which typification shows the highest feasibility in the context of this research.

3 A Visualisation Concept for Collective Spatial Keyword Queries

To create a visually and functionally sound visual concept for collective queries as introduced in Chapter 2, a number of aspects have to be addressed. Therefore this chapter presents challenges and considerations that play a role in such a visualisation, and proposes a methodology for how the components for a novel collective spatial keyword query visualisation may look and feel. The focus is thereby directed towards a working interplay between the algorithmic and the visual part.

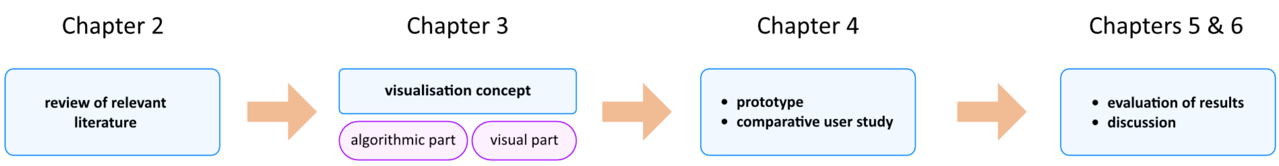


Figure 3.1: Research workflow

Figure 3.1 shows the workflow of this thesis' research. After having conducted the literature review and stated the background of the research, this chapter explains the general visualisation concept, before the user study and the prototype are presented in the next chapter. Afterwards, the results from the user study are evaluated, presented and discussed.

3.1 Collective Querying

A query that is sent by the user is expected to return a number of results. However, the way these results are obtained from the geodatabase depends on a number of decisions, most of all, which metric is being applied to distinguish good from bad results. This section presents considerations concerning the creation of a result set, first by introducing a variation of the TYPE2 SGK Query and a corresponding cost function, and second by discussing the relativity and transitivity of nearness and the conclusions that follow.

3.1.1 The TYPE2a Query

In Section 2.1.2 a number of different collective spatial keyword queries have been presented. Each of those fulfils different affordances and has its strengths in different scenarios. One of these is the TYPE2 SGK Query as shown in row 3 in Table 2.2. It is useful in finding result sets that have a small distance from the query location to the furthest query result and a small inter-result diameter. This leads to result sets that have a dense cluster of results in relative proximity to the query location, implying that this query location is the place where the user starts their excursion(s).

But what if the user does not have a fixed location? For example when they still need to figure out which hotel or other central location is located best for their needs.

Therefore this research proposes a variation of the TYPE2 SGK Query by Cao et al. (2011): the *TYPE2a SGK Query*. Instead of searching a result set with a minimal diameter this query separates the first keyword and treats it as a denominator for a "*center point*" as close to the query location as possible. From there all other keywords are searched in their immediate vicinity. In this scenario the query location works more as a general descriptor of the area of interest than a fixed location with significance to the user.

This separation grants one advantage: returning more than one result set is natural now. Whereas a TYPE2 query is designed to return just one, the best, result set, TYPE2a queries return a set for every item of the first keyword type.

3.1.2 The TYPE2a Cost Function

The central goal of a collective query is to find a set of PoIs that satisfy all keywords and are located near each other, possibly including a user-specified query location. But whether two points are in fact spatially near to each other depends entirely on the context. As Purves et al. (2018) explain, the term *near* "will have a different definition when the reference and location change." That is, the queries for "airports near Hamburg" and "bars near the Hilton" inevitably lead to completely different definitions of nearness.

This relativity of nearness makes it mandatory to find a metric for the fitness of result sets, depicting how near the found points are to each other and to the query location. Based on that metric only a subset of the whole data set is to be considered, while results that exceed a certain threshold can be discarded.

In the case of the proposed TYPE2a spatial keyword query, fitness is determined by the following cost function:

$$\mathrm{Cost}(q, \chi) = \mathrm{Dist}(r_0, \lambda) + \sum_{r_n \in \chi} \mathrm{Dist}(r_0, r_n)$$

This function can be understood as the sum of two parts: first, the distance from the query location to the center point r_0 (a match of the first keyword), and second, the sum of all distances from this center point to the other keyword matches. The lower the resulting value, the smaller are the distances between all contained PoIs and the better is the result.

A simple schematic of this query applied to the search space from Chapter 2 (see Table 2.2) can be found in Table 3.1.

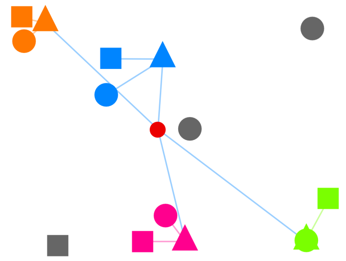
Name	Description	Schematic Image
TYPE2a SGK Query	Assuming the triangle represents the first keyword; each result in the set has its own color	

Table 3.1: Description and visualisation of the TYPE2a SGK Query

To determine those results that are included in a result set based on this fitness function, two variables need to be defined in advance: n is the maximum number of results a result set should contain before it becomes too large, and a, with $a > 1$ is the factor by which a result may deviate from the best result in the set. For example, if the best match has a cost of x, then the worst match may have a maximum cost of $a \cdot x$, at least as long the result set does not exceed n items.

3.1.3 Keyword Ordering

When seeking out suitable combinations of points, the relative nearness of results in relation to each other is not the only relevant factor. It can be easily seen that transitivity is not given when it comes to nearness of results, however "near" might be defined in this context: consider a point **A**, that is close to a point **B**, which in turn is close to a point **C**. It is clear that point **A** is not necessarily near point **C**.

In combination with the "center point" semantic explained in Section 3.1.1 these considerations imply that order matters when searching for multiple PoIs, unlike for all CoSKQ algorithms presented in Section 2.1.2. This can be regarded as an advantage, since it enables querying for more than one result, as well as a disadvantage, since the user may not be aware of this fact and could be confused by different results for different keyword orderings.

3.1.4 Querying Multiple Results

When querying for, and displaying, more than one result at a time, one problem arises: often results are not clearly distinct from each other. That is, a result contains items that are also part of another result, creating overlaps that are hard to visualise on a map without misunderstandings and clutter. Therefore it is proposed that results should avoid overlapping items, and items should only be assigned to one result per set. This leads to results that are distinct from each other and less prone to occupy the same area on the map. On the other hand this leads on average to a deterioration in the quality of all results except the best.

3.1.5 Scalability

It is expected that this kind of query is well scalable. The number of PoIs is not really relevant as long as database structure and access is implemented properly. The prototype detailed in Section 4.1 deals with over 300 000 PoIs without significant speed loss. All parts of the methodology can of course be applied to other, especially larger data sets identically.

Of course, the number of returned results, depending on the variables a and n, needs to stay in a reasonable range as not to clutter the map too much and to avoid overlaps as much as possible.

3.1.6 Conclusion

This section laid out some theoretical considerations for developing a methodology for the creation of a profound visual concept. Therefore first a new type of collective spatial keyword query, called TYPE2a SGK Query was introduced (Section 3.1.1), which builds on the TYPE2 query shown in Chapter 2. A novel "center point" semantic, the corresponding cost function (Section 3.1.2) and a metric for choosing valid results from the database were proposed. The importance of the order of keywords (Section 3.1.3) and the necessity to avoid including items in multiple results (Section 3.1.4) were described.

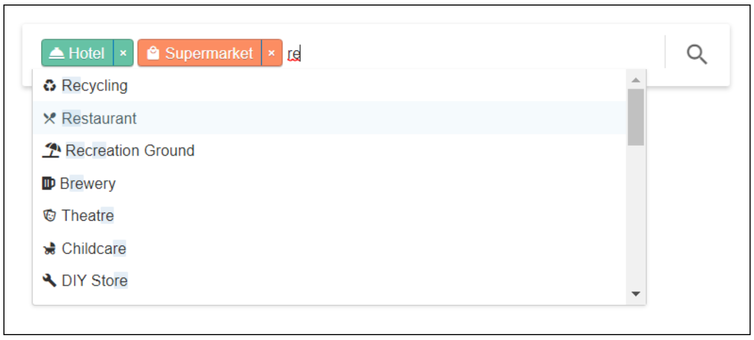
3.2 Search Interface

A search interface consists of a combination of different user interface components, as explained in Section 2.2. To enable the user to query for multiple PoIs simultaneously this proposal introduces a set of elements that in combination make collective spatial keyword queries in a practical environment possible: a search bar with an auto-complete feature, a button to set the query location, and a map component that displays the found results. All of this is imagined in a client-server environment, i. e. a web site that can be used with a browser.

3.2.1 Search Bar

The characteristic of a collective query is that it takes more than one keyword, otherwise it would degenerate into a standard query.

To account for that the search bar needs to support the input of more than one keyword. In this thesis this is accounted for by having the search bar auto-complete typed text. A list of all available keywords is searched as the user types (Figure 3.2a) and upon selection of a list entry the corresponding keyword is added to the list of keywords (Figure 3.2b). This way a user can collect all needed keywords before sending the query to the geodatabase. This is helpful to disambiguate terms that consist of more than one word, e. g. "dog park", "arts center", "food court" or "bicycle parking". Allowing the user to accept suggestions before having them typed out is also a comfort feature that saves time spent typing and prevents the user from trying to find PoI categories that may not be provided by the system.



(a) Search bar with two selected items and autocomplete suggestions

(b) Search bar after selection of the item "restaurant"

Figure 3.2: Search bar with autocomplete feature

3.2.2 Defining the Query Location

Since the introduced TYPE2a query is dependent on a query location, there needs to be a way to set this query location. This can be done explicitly, e. g. by dragging a marker to the preferred location, or implicitly, e. g. by assuming that the center of the visible screen is the query location. Setting the location via textual input, e. g. via textual spatial constraints ("near") is also possible.

3.2.3 The Map Component

The map component takes up the most area on the screen. After the query location has been set and the keywords have been sent to the geodatabase, results are visualised here for the user and can be interacted with.

In general the map component consists of a base map (background) and a number of information layers (foreground) to hold information like markers, routes or textual information. To create a high figure-ground contrast between these, the base map should be generally inconspicuous, and the information layers either need to use colours not present in the base map or must provide shadows for every item.

3.2.4 Conclusion

In this chapter the visual components of the concept were outlined: a search bar (Section 3.2.1) with an autocomplete feature, a means to set the query location (Section 3.2.2) and the map component to display search results (Section 3.2.3).

3.3 Visualisation of Query Results

Since maps that display point data often have to deal with clutter problems, strategies have to be defined that work against this clutter. This chapter presents a visualisation of results that uses typification as an anti-clutter mechanism, and is tailored to the previously introduced TYPE2a query and their characteristics.

3.3.1 Typification in Interactive Maps

A result set that is to be visualised on a map can consist of a large number of individual items. Section 3.1 introduces the number n representing the number of results in a result set. A collective query can in theory support any number of keywords, but in practice there has to be a limit before queries become too complicated and take too long to finish or are too unlikely to return a (feasible) result. Let this limit be k_{max}, then a result set consists of up to $n \cdot k_{max}$ individual items that have to be displayed on the map.

As seen in Section 2.2.2, an evaluation of anti-clutter mechanisms leads to the decision to employ typification as primary method against overcrowding the map interface. However, the aggregation of items is only necessary when items are densely packed or highly clustered, which is usually dependent on the zoom level. The higher the zoom level, the more dispersed are the items, and the more relevant is the actual location of the PoI. Thus there has to be a break point or threshold in the zoom level, which determines when items are being displayed as combined, “typified” symbols and when as individual markers. This break point may be dependent on the degree of clustering that is present in the data set or on the number of individual items.

Above this threshold items are typified according to a certain set of rules. The rules stated by Edwardes et al. (2005), and rephrased in Section 2.1.2, are in the author’s opinion not entirely applicable, as they were designed with static maps in mind. A new set of rules, updated for interactive maps, is proposed here:

- each contained symbol needs to be individually recognizable, or the typified marker should show the individual symbols upon interaction
- the location of the symbol should relate to the location of the typified group
- characteristics of the group can be encoded in the symbol using visual variables

3.3.2 Typification for Collective Queries

When creating a visualisation for collective queries, where one result set contains a number of independent results, it is important to aggregate markers not simply by location, but primarily by their result association. This means that markers of different results are never combined into a typified symbol, but rather only items of the same result.

Collective queries have the characteristic that each result contains up to one item per keyword. For example, if a user searches for a hotel, a restaurant and a bar, a result may contain three items, one for each keyword. However, it is also possible that a restaurant within a hotel is featured, so only two PoIs are in the result, or even just one, if a hotel has a restaurant and a bar. If a result set contains results with less PoIs than keywords, some typified symbols may be composed of a smaller number of components than others. However, such symbols are potentially confusing to the user, since they might assume that the result set does not properly contain all keywords. Thus a place matching multiple keywords should not be represented by its main keyword, but rather by a combination of all matched keywords. This again is best implemented with a typified visualisation.

The same problem may arise when aggregating only a subset of items of a result. A user encountering an incomplete symbol will probably not be aware of the remainder of items that may be represented in a different symbol or as individual items. It is thus reasonable to either combine all items of a result or none. When taking the previously mentioned zoom threshold into account, it can be concluded that each result of a collective query is best represented by either one combined symbol, containing one component for each queried keyword, or by individual markers, depending on the amount of clutter and overlap contained in the result set.

3.3.3 Symbolisation of Typified Results

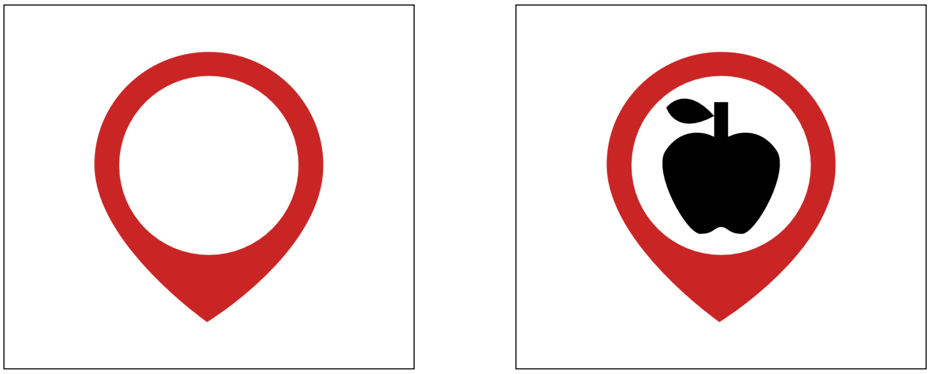
This section presents a proposal for the visualisation of query results on a map component, according to the previously stated observations and rules. As explained, there are two different states a visualised result can adopt: either every contained PoI is represented by an individual marker, depicting its exact location, or by a typified, combined symbol that uses all contained keywords as components.

Individual Markers

The proposed markers for individual representation of PoIs can be seen in Figure 3.3a. They consist of two basic components: first, the outline of an upside-down tear gives the marker its general shape, and second, a white circle offers space for an icon. The resulting marker symbol is both simple and functional.

The most important information about a PoI to be conveyed to the user is the keyword this PoI matches, which in many cases corresponds with the PoI category. Therefore an icon that represents the matched keyword can be placed in the white area of the marker (see Figure 3.3b).

Another visual variable can be used to signify categorical membership: by using the same colour for a keyword in the search bar and the marker matching this keyword a direct association between these two can be established (see Figure 3.4). Harrower and Brewer (2003) for example provide several qualitative colour schemes suitable for this purpose.



(a) Individual marker without icon (b) Individual marker with icon

Figure 3.3: Individual markers without and with icon

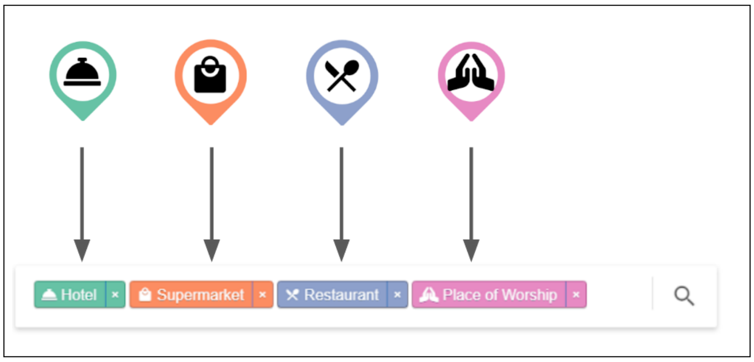


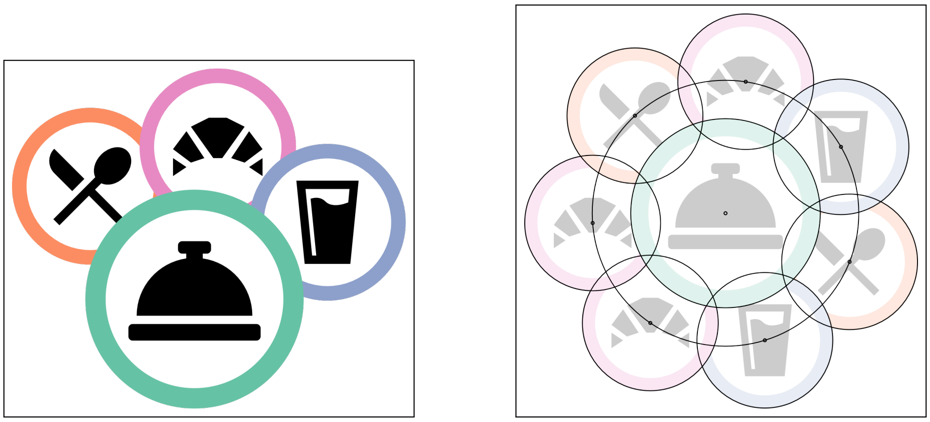
Figure 3.4: Colour (and icon) match between markers and search bar

Combined Markers

To create the combined markers, it is possible to build on the design of the individual markers. A similar look and feel creates optical consistency and helps the user in the understanding of the marker semantics.

The visualisation proposal of this thesis uses circles as components and composes a combined icon based on the individual markers contained. Considering the "center point" semantic explained in Section 3.1.1 there are two different circles: a larger one that represents the center point, and several smaller ones for all peripheral PoIs that are part of the same result cluster. The circles again consist of a coloured outline and white center, in which an icon can be placed. The smaller circles are placed in a radius around the larger circle so that they appear behind it, but only so far that the icon is not covered (see Figure 3.5a).

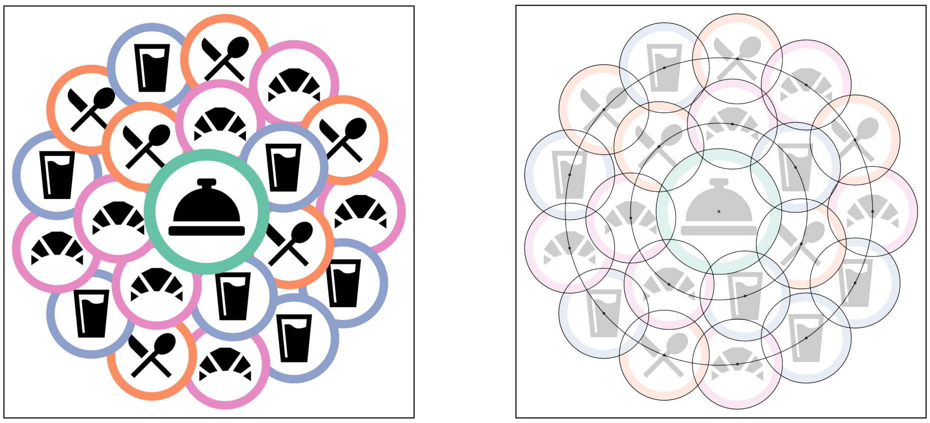
In case the result contains more PoIs than can be placed side by side, additional radii can be added (see Figure 3.6b), but this quickly leads to over-complex icons that are difficult to digest. It is thus recommended to keep the number of keywords small enough to fit all results on one radius.



(a) Combined marker with four components

(b) Components placed on one radius

Figure 3.5: Combined marker with one radius



(a) Combined marker with 21 components

(b) Components placed on two radii

Figure 3.6: Combined marker with two radii

The combined marker is supposed to be placed in the center of the result, in accordance with the second rule for typification of interactive maps (see Section 3.3.1). This not only helps the user to grasp the general location of a result, but also supports the encoding of information as shown below.

Since combined markers represent a whole result and aggregate all items contained, characteristic properties of this result can be used for their visualisation. Examples may be the fitness of the result, or information about the spatial distribution of the markers. The visualisation proposal presented in this thesis uses the visual variables size and orientation to encode these to properties into the combined marker.

A result set containing several results may consist of results with higher and lower fitness, depending on the cost function presented in Section 3.1.1. The general understanding of the fitness is that results with a high fitness have a higher probability to be the result the user is looking for. So it might be useful to encode the fitness of the result into the visualisation of the combined marker. By scaling the combined marker to match the relative fitness of the result, the user can quickly focus on the higher ranked results. An example for this scaling can be found in Figure 3.7.

Figure 3.7: A good and a bad result, represented as a large and a small marker

Another bit of information can be encoded into the result marker: if the radius for placement of smaller circles is not fully occupied, it is possible to use the smaller circles' orientation to encode the position of the individual markers in relation to the combined marker. Since the combined marker is placed in the center of the result, the individual PoIs are most likely spread out into different directions. These directions are then used for the placement of the smaller circles on the fixed radius. For example, a PoI that is located directly in the south of the combined marker may thus be represented by a small circle on the bottom of the larger circle (see Figure 3.8). This way users see at a glance whether there is one PoI that is in a completely different direction than the others, or whether they are spread out equally in all directions. This also aids in a smoother transition between individual and combined markers while zooming the map. Of course, if this causes the smaller circles to overlap, they need to be displaced as far as necessary so that they do not occlude each other.

Routing

The center point semantic leads to another feature: since it is assumed that users want to travel from the first PoI (the center point) to all others, routes between this first PoI to the others can be easily calculated and displayed, without having to decide on an ideal route between all PoIs. Of course display of routes is only relevant when individual markers are shown, not in the context of the combined markers.

Figure 3.8: Orientation of components indicating the direction of markers

3.4 Evaluation of the Concept

To quantify the usefulness of this concept, a comparative user study was conducted. Participants were divided into one of two groups: one group needed to solve a task that included searching for multiple close PoIs using a prototype that implements the preceding concepts, while the other group solved the same task with a commercial alternative that does not support simultaneous searching for multiple keywords. Users were then asked for their assessment regarding their subjective satisfaction, perceived ease of usage, learnability, accuracy and efficiency. The two groups were then be compared to be able to make a statement regarding these attributes of usability.

3.5 Conclusion

This chapter proposed a visualisation of query results. Typification was named as the primary clutter reduction mechanism, and three rules for typification in interactive maps were created (Section 3.3.1). Considerations about the typification of results were presented in Section 3.3.2. These were then used to symbolise the results as individual and combined markers (Section 3.3.3). Visual variables like colour, size and orientation were used to encode additional information.

Building on this methodology the next chapter presents a case study, based upon a prototype of this visualisation concept and a comparative study for evaluation of its usability.

4 Visualisation of CoSK Queries and their Usability on the Example of Bavaria

To be able to evaluate the concepts introduced in Chapter 3 a comparative user study was conducted. Therefore a prototype called **CoSKQVis** (Collective Spatial Keyword Query Visualisation) was implemented, and tested against the commercial state of the art mapping platform Google Maps.

This chapter describes the development of the prototype and the design of the user study.

4.1 Implementation of a Prototype

For the implementation of the concept a prototype was developed. Its general design was that of a web application, using a geodatabase, server-side scripts for retrieval of data and client-side scripts for interaction with the user. The prototype was named "CoSKQVis" (spoken "cos-quiz") and is available under https://beinder.net/coskqvis at the time of publication of this thesis. This section explains its principles, features and characteristics.

4.1.1 Server-side Data

The prototype was to operate on openly available PoI data. For this purpose a data excerpt from OpenStreetMap (OSM) was downloaded from Geofabrik[1]. The region of Bavaria was chosen for proving the feasibility of the concept as it contains several clusters of PoIs in the larger cities and regions with lower density, but is small enough to keep processing times feasible and users can keep the overview easily.

Size of Dataset

At the time of downloading the Bavarian excerpt consisted of 1.987.289 point features, 2 875 659 line features and 5 857 429 polygon features. By importing the dataset into a PostGIS database using Osmosis[2], an OSM data processing tool, it was possible to operate efficiently on the data, e. g. extract a subset of PoIs useful for the research.

[1] https://download.geofabrik.de/
[2] https://github.com/openstreetmap/osmosis

OpenStreetMap data is tagged with different values for a number of keys to denominate features of certain types. For example, a hotel may have the key-value combination `tourism=hotel`, a supermarket `shop=supermarket` and a cafe `amenity=cafe`. From these tags a set of 118 key-value pairs that describe common PoI categories like schools, pharmacies or bars was chosen. This led to a total of 326 252 PoIs all over Bavaria available in the prototype. A complete list of PoI categories and the respective number of PoIs can be found in appendix A.1.

API

A simple application programming interface (API) was built in the server-side language PHP that connects to the database and retrieves relevant PoIs, wraps them in result objects and encodes the whole result set as JSON (Javascript Object Notation) upon request. Any client connecting to the API needs to supply an array of keywords and a query location in WGS 84 format. Those are expected as GET-Parameters, so a typical request with three keywords and a location might look as follows:
https://<domain>/api.php?keywords=hotel,supermarket,bar&lat=48.137154&lon=11.576124

Due to the center point semantic of the TYPE2a SGK Query introduced in Section 3.1.1 the algorithm separates the first supplied keyword and queries for results near to the query location. Upon retrieval of the results for this keyword, for each match all other keywords are searched for in the vicinity. To keep search speed high and visual complexity reasonable, the maximum number of keywords a user can search for in the prototype has been limited to 5.

All aerial line distances, from the first PoI to the query location, and from all other PoIs to the first PoI, are summed up. This results in an accumulated value that acts as an estimation for the fitness of the result.

Now, all results are sorted by this fitness value, while results that include PoIs that are already part of a better result are removed from the result set. Section 3.1.2 introduces the variables n for the maximum of results in a result set, and a for the factor that the fitness of a result must not exceed. While developing CoSKQVis it turned out that $n = 6$ seems to be a reasonable number for this database size and density: result sets with more results were often harder to understand, while six results were mostly still quite well understandable. For a the value 3 was chosen – results that exceeded this summed distance factor in relation to the best result were often too poor to be considered real matches. In the end this leads to result sets of up to 6 results whose fitness lies in between f and $3f$, with f being the fitness of the best result.

4.1.2 Client-side Interface

The application was created with a server-client architecture in mind: the user interface is a web application running in all modern browsers and in almost any screen size, built with HTML, CSS and JavaScript. For the purpose of building a versatile application, only open source or self made components were used.

Javascript Libraries

The general JavaScript framework used was chosen to be *Leaflet*[3], a client-only open source library used to build web mapping applications. For the combined icons an addon called *Leaflet.markercluster*[4] was included and customised. Other Leaflet plugins used were *Leaflet Custom Searchbox*[5], *Leaflet.encoded*[6], *Leaflet.Spin*[7], and *leaflet-control-window*[8].
For different purposes, e. g. event handling or requesting and processing results and routes, the libraries *jQuery*[9] and *jQuery UI*[10] were adopted.
To accomplish selection of multiple items in the search bar, a library named *selectize.js*[11] was included. For the selection and display of icons in search and map markers two icon fonts were used: *Material Design Icons*[12] and *FontAwesome*[13].

UI elements

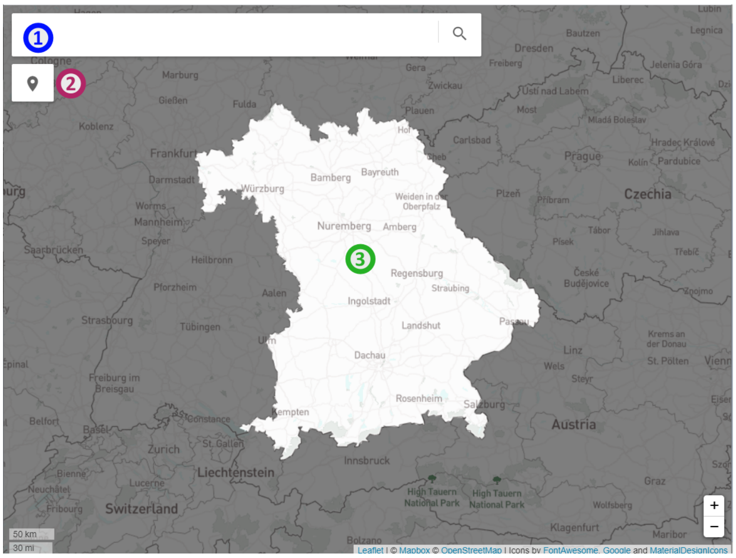


Figure 4.1: General structure of the prototype: search bar (1), query location button (2), base map (3)

[3] https://leafletjs.com/
[4] https://github.com/Leaflet/Leaflet.markercluster
[5] https://github.com/8to5Developer/leaflet-custom-searchbox
[6] https://github.com/jieter/Leaflet.encoded
[7] https://github.com/makinacorpus/Leaflet.Spin
[8] https://github.com/mapshakers/leaflet-control-window
[9] https://jquery.com/
[10] https://jqueryui.com/
[11] https://selectize.github.io/selectize.js/
[12] https://materialdesignicons.com/
[13] https://fontawesome.com/

Three UI elements had to be designed for the prototype, as implied by the methodology: a search bar (1), a query location button (2) and the map component (3). The application was designed to have the map cover the entire page, with the search bar and the button as interactive elements overlaying it (see Figure 4.1).

The base map was designed with Mapbox Studio[14], by customizing the supplied preset "Basic" in the variation "Spring". The resulting style has the characteristics that it is very unobtrusive, uses light and achromatic colour hues as well as modern fonts, and focuses on roads, water bodies and green spaces. It was deemed suitable as a base map for the prototype, as map markers in bolder colours set themselves sufficiently apart (figure-ground contrast) and do not clash with features on the map. A semi-transparent layer was placed upon the map, only sparing out the contours of Bavaria, depicting the area the application supports. Further elements that can be found on the map are a scale (bottom left corner), a zoom control and attribution information (both bottom right corner).

To have the user specify their preferred location they can click the query location button, which will make a yellow marker appear in the center of the screen (see Figure 4.2). This marker can be moved around freely by dragging and dropping. Another click of the button would reset the query location marker to the center of the map. If the user has not yet set a query location when submitting their query, the marker is displayed in the center of the currently visible map section. A specification of the query location via the search input is not part of this version of the prototype.

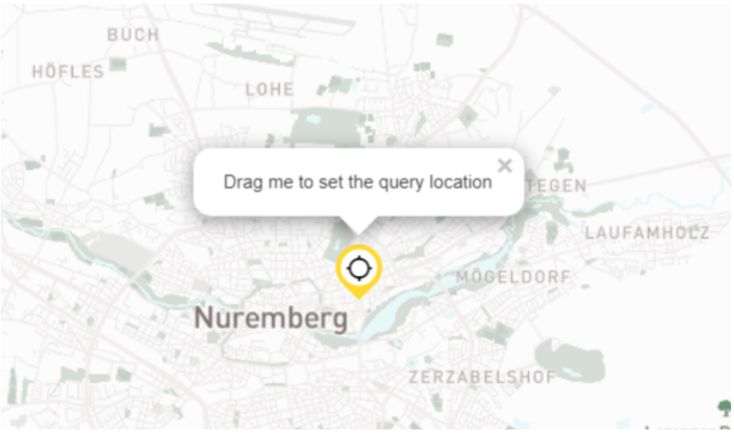


Figure 4.2: Query location marker

The search bar is the most complex UI element: it consists of an input field where the user can type their keywords, an autocomplete feature that suggests possible PoI categories, and a search button that submits the query (Figure 4.3).

A user searching for PoIs can enter their keywords into the input field (1). When they start to type, a dropdown opens displaying all matches found in the list of possible categories (2). The user is required to select one of the matches, using pointer, keyboard or touch, whereupon the selected match is accepted into the list of keywords (3).

[14]https://www.mapbox.com/mapbox-studio

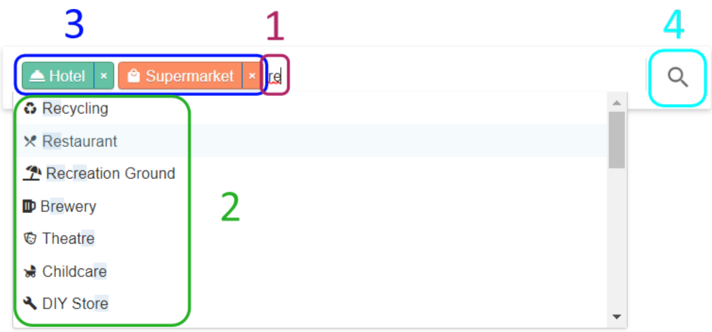


Figure 4.3: Structure of the search bar

Selected keywords are shown inside the input field as distinct elements (Figure 4.4), with the possibility to rearrange their order using drag and drop. Deletion of a keyword can be done with a small button (3) or by using the backspace key on the keyboard. Furthermore, a keyword item shows an icon (1) and the name of the selected PoI category (2). Each item gets a different colour that corresponds with the marker colour on the map. The prototype currently supports the selection of up to five keywords.

Figure 4.4: Structure of a selected keyword

Search Results

After submission of the query by clicking the search button in the search bar (4, Figure 4.3) or pressing the Enter key, the API collects appropriate results according to the selection rules presented in Section 3.1 and returns them to the client in JSON format. Every result contained is then visualised on the map.

As described in Section 3.3.3, a result can assume two different states: either each PoI is represented by a single marker or the whole result is aggregated to a combined marker. This aggregation process was handled using custom CSS markers and the Leaflet.markercluster plugin. Some adjustments had to be made to the threshold when clustering is appropriate, since it was crucial that results are clustered completely or not at all, and all at the same time.

Both individual and combined markers were designed according to the visualisation proposal in Section 3.3.3. colour and icons were used to establish a connection between the keyword item in the search bar and the PoI marker or marker component on the map. It was attempted to choose icons with large iconicity as their size would be fixed and users should be able to establish a connection between the icon and the resembled PoI.

A list of all used icons can be found in Table A.1 in the Annex. Icons were chosen from three different sources: the majority was taken from Material Design Icons[15], which also includes all icons released by Google as part of their material design kit material.io[16]. The remainder of icons was taken from FontAwesome[17] and OpenStreetMap icons[18]. All icons are used under their respective licenses.

Routes

Search results also include routes from the center point to all other PoIs. Therefore an OSRM server was set up. OSRM (Luxen & Vetter, 2011) is a small routing server that operates on OSM data and can be queried using simple GET requests. A query for a route between two points may look like this: https://<domain>/router/route/v1/<profile>/48.374477,10.907223;48.149673,11.568773.

The string `<profile>` needs to be replaced by the name of a profile that is installed in the server software, e. g. foot, bike or car. Unfortunately the instance installed on the prototype server could not be made to return routes for any profile but cars.

The resulting answer consists of a polyline from the first to the second point (if possible according to the routing data) that can easily be added to the map, and some metadata, like reasonable information about the length and duration of the route. This length information was summed up to inform the user about the total distance they might have to travel.

For this purpose, and to have a better distinction between individual results, a mouse hover effect was created: when the user moves their mouse pointer over any element of a result, the whole result is highlighted subtly, so that all corresponding PoIs and routes are clearly identifiable. Additionally, when hovering over a PoI marker, a tooltip with the name of the PoI, or, if there is no clear name, a combination of the category and unique ID of the PoI, is displayed. When hovering over a route, the summed up information about the total length of all routes is displayed.

4.2 User Study

Purves et al. (2018) write: “Having designed a system capable of responding to queries with geographic content, an important research task is to demonstrate that a given system offers advantages over previously published work, through a thorough and reproducible evaluation.”

[15] https://materialdesignicons.com/
[16] https://material.io/resources/icons/
[17] https://fontawesome.com/
[18] https://github.com/openstreetmap/map-icons

To determine whether this advantage over previously published work, in this case the market-leading commercial mapping application Google Maps, exists, at least in certain scenarios, was the task for the comparative user study that ran from 17.07.2020 to 31.07.2020.

4.2.1 General Information

The study was created with the web application *SoSci Survey*[19] that offers a large toolbox to create questionnaires for all kinds of purposes. The questionnaire contained a mixture of questions with qualitative and quantitative nature. Qualitative questions were mainly asked as free text. Most quantitative questions that required an estimation from the user were presented in the form of a 5-point Likert scale, ranging from “very much” over “neutral” to “not at all”.

Target Group

Since the application is considered to be helpful mainly in complex use cases, the target group for it is expected to be at least advanced users of mapping or navigation software. The questionnaire was therefore mainly distributed where such users were expected: facebook groups for the geo scene, mailing lists of cartographers, students of the Cartography MSc. course and tech-savvy friends and acquaintances of the author.

Attributes of Usability

To assess the usability of a user interface Nielsen (1994) (via Purves et al., 2018) gives five attributes of usability that can be measured in a user test: learnability, memorability, efficiency, errors (accuracy) and subjective satisfaction.

For this study, memorability was considered of low importance, since users were supposed to be tested only once, and remembering the application’s functionality is not of high priority, as long as the users find their way into the application easily. Therefore memorability was replaced by the attribute “ease of usage” and questions were asked towards the collection of this variable.

4.2.2 Structure of the Study

Users participating in the study were to fill an online questionnaire consisting of five sections – introduction and consent, introductory questions, task, attribute questions and demographic questions – and a task that had to be conducted using either the prototype or Google Maps. Users were assigned to these two groups by the application with the maxim to have an equal number of fully answered questionnaires in both groups.

The full questionnaire can be found in Appendix A.2.

[19] https://www.soscisurvey.de/

Introduction and Consent

The first section was set up to give the user an idea of the topic of the study, to assure the user that their participation is voluntary, anonymous and secure, and to receive their consent to start the questionnaire. Only by clicking "Yes, I agree" users were able to move on to the second section.

Introductory Questions

The second section questioned the user for their frequency of use of web mapping applications to search for PoIs (Q1) and for navigation (Q3), and the use of car bound navigation systems (Q4). When the user answered positively to the question regarding PoI search, they were asked for web mapping platforms that they use for that purpose (Q2). Lastly, users were asked whether they ever had the need to search for multiple PoIs simultaneously (Q5), and if so, whether the task felt easy or not (Q6).

Several indicators for the research questions can be derived from the answers, e. g. whether advanced users can use the application intuitively, which mapping platforms are state of the art, and whether demand for such an application actually exists.

Task

The third section gave the user the main task: they were asked to find a set of PoIs using either CoSKQVis or Google Maps, based on the group they were assigned to. The full task was phrased as follows:

*Imagine you want to go to Nuremberg (German: Nürnberg, a city in northern Bavaria) with your nephew. To sleep, you need a **hotel**. For cash, you want a **bank** nearby. And for your activities, it would be good to know the closest **playground**, **cinema** and **zoo**.*

Task: find exactly this set of the five points of interest (PoIs) that appear suitable for your trip (a hotel, a bank, a playground, a cinema and a zoo). Each of the five categories should be represented once in your result. Please write down the names of the five found PoIs before returning to this questionnaire.

Users were expected to pan the map to the area of Nuremberg and look for the five PoI categories either by typing them one after the other into the search bar (CoSKQVis), or searching them one by one (Google Maps). In the end they were supposed to have a set of five PoIs, one per category, that are not too far apart.

This task is the main tool to examine the usability of the methodology. In working with the prototype users are able to test the features and characteristics hands-on. Only by using the system can errors, misunderstandings and difficulties be detected.

To be able to move on to the next section, users also had to answer the question of whether they lived in Nuremberg (Q7), currently or in the past. This was necessary to try to exclude users who might be inclined to answer the task from memory instead of the assigned application.

Attribute Questions

Section four presented a large set of questions regarding the task. First of all, the names of the five PoIs were asked (Q8), in order to be able to reproduce the set of PoIs the user had found. In the end, it also proved useful to determine whether the user understood and solved the task correctly.

Afterwards the users were asked in free form whether errors or inconsistencies were present (Q9). Eight questions followed to investigate the variables ease of use, learnability, efficiency and subjective satisfaction, each represented by two questions. Ease of use was determined by asking "How easy was the process to find a set of PoIs?" (Q10) and "How intuitive was the process to find a set of PoIs?" (Q14). Learnability was represented by the questions "How easy to learn was the process to find a set of PoIs?" (Q12) and "How user friendly was the process to find a set of PoIs?" (Q16). Q11 ("How efficient was the process to find a set of PoIs?") and Q13 ("How helpful was the search in solving the task?") were used to indicate efficiency, while Q15 ("Did you enjoy working with the web mapping platform?") and Q17 ("Would you rate the retrieved PoIs as satisfactory?") were part of the satisfaction variable.

Another question (Q18) aimed for the user's certainty to have found a good set of PoIs: "How confident are you that you found the selection of PoIs that has the smallest distances between each other?".

The remainder of questions in this section only appeared when the user was using the CoSKQVis prototype: they were asked for the usability of the search bar (Q19: "How quickly did you find the items you were looking for in the search box?"), attractivity of the markers (Q20: "Are the marker symbols an attractive solution?"), and for the understandability of the three visual variables used: color (Q21: "The colors of the marker symbols correspond with the colors in the search bar. How intuitive do you think this is?"), orientation (Q22: "The orientation of the smaller marker symbols correspond with their approximate orientation in the map space. How intuitive do you think this is?") and size (Q23: "The size of the combined marker symbols correspond with how appropriate the algorithm thinks the result is. How intuitive do you think this is?"). Each of these questions was accompanied with an image of how the visual variable was used in the prototype.

Lastly, users were asked for their opinion on whether they think this kind of query may be useful for certain tasks (Q24), and, if they answered "yes", what tasks they could think of (Q25).

Demographic Questions

The last section asked for demographic data of the user: gender (Q26), age group (Q27) and education (Q28). Finally, users were asked whether they had any remarks on the questionnaire (Q30).

4.2.3 Pretest

A pretest of the questionnaire was conducted ahead of the publication with four users from the Chair of Cartography of the TU Munich and one user from the Research Division Cartography of the TU Vienna. After examining the remarks of these test users, a number of changes were carried out:

- a short definition of web mapping and web mapping applications was added to the beginning of the second section in order to communicate the subject of the following questions
- for the same reason examples for PoIs were added to question 1
- images detailing the visual variables color, orientation and size in the context of the prototype were added to questions 21, 22 and 23 to explain the subject in case users did not notice
- a text field especially for program errors and unexpected behaviour was inserted in the third section
- naming was standardised, instead of using “places” in some questions, the term “PoI” was used throughout the questionnaire

4.3 Conclusion

This chapter detailed how the case study was conducted. First, the implementation of a prototype using the methodology presented in Chapter 3 was outlined. The prototype is a web-based client-server application accessible with a browser that contains three main elements: a search bar, a query location button and the base map. The search bar supports the selection of up to five keywords from the suggestion list. The underlying data is queried through an API that accesses a database with over 300 000 PoIs in over 100 categories. Results are displayed as either combined or individual markers, each using an icon to denominate the category. Routes are shown between individual markers using an OSRM server.

The second part of the chapter dealt with the subsequent user test. The target group was specified to be advanced users of navigation and web mapping systems. Attributes of usability collected in the user study were listed as learnability, efficiency, errors / accuracy, ease of usage and subjective satisfaction. The five sections of the questionnaire – introduction and consent, introductory questions, task, attribute questions and demographic questions – were listed and explained.

5 Evaluation of Results from the User Test

The study detailed in Section 4.2 ran for two weeks, from 17.07.2020 to 31.07.2020. In this time period 118 volunteers participated in the user study, 61 of whom filled the entire questionnaire. The distribution algorithm assigned 31 users into the CoSKQVis group (group 1), and 30 into the Google Maps group (group 2). However, one user from group 2 explained in the comment section that they did the task with the prototype before they had to start over with the questionnaire for some reason. This user has thus been entered into group 1 manually, which changes the final distribution to 32 / 29.

5.1 General Feedback

The majority of responses were very positive and assertive of the direction this research is going. One user wrote, "I really like the application and I think it is something very useful and helpful. There is definitely a need having such an application and I would use it." Another positive reaction was "This is a brilliant solution for multiple searches at the same time." Another: "I find it very simple in terms of visualization which is very good. In such requests, we want to have good and fast answer, and not concentrate on many more options which are usually offered in other services." Users called the research a "really interesting concept", a "Great Experiment" and "Interesting Work".

On the other hand, participants wished for more guidance, e. g. for the usage of the yellow query location marker, or placeholder texts for the search bar. One user remarked that the demography questions were too detailed and "may scare away users who are willing to support".

5.2 Completion of the Task

A large number of participants were not able to finish the task successfully. From the 61 users finishing, only 38 users submitted a set of PoIs that could be considered entirely correct according to the task (see Figure 5.1).

5.2.1 Error Types

Five different errors could be identified and are explained below. Figure 5.2 shows the distribution of error types in relation to the two user groups.

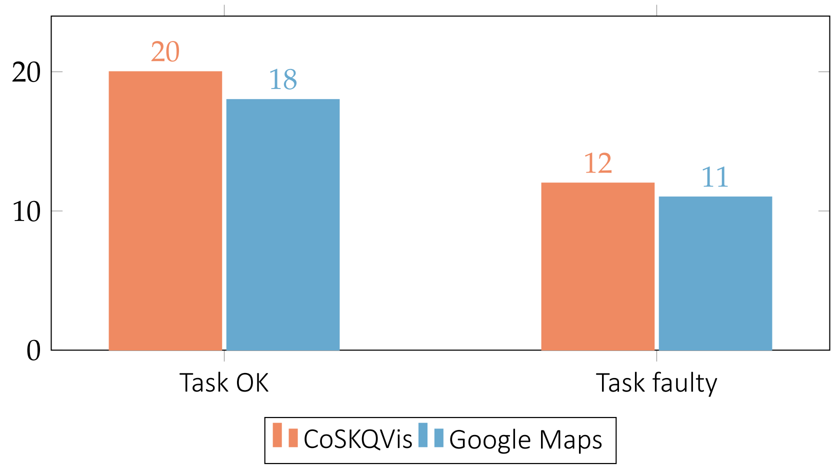


Figure 5.1: Task fulfilment

Error 1: Undesired PoI Categories

By far the most common mistake was to return PoI categories which obviously were not part of the task. Many users offered restaurants, bars, and touristic spots like the Imperial Castle of Nuremberg or the Albrecht-Dürer-Haus. Other unexpected PoIs included exhibition grounds, train stations, bridges or beverages shops.

This led to the assumption that the task was either not understood or not read completely. These users seemed to have the feeling that it was part of their task to make suggestions for activities in the target area.

Error 2: Generic PoIs

Another mistake that was encountered multiple times was the submission of generic PoIs. That is, instead of giving the names of particular PoIs, these users repeated the category names, e. g. “zoo” or “bank”. Most errors of this type were actually combinations with the first category, with users suggesting new categories: “museum”, “Biergarten”, “animal shelter” or “stadium” were results.

The assumption for the source of this kind of mistake is actually the same as for error 1: users probably did not understand the task entirely.

Error 3: Second Program Used

This error happened only once, but this person did not stick to the mapping application they were supposed to use. They were part of the CoSKQVis group, but supplied PoI names that were obviously taken from Google Maps, e. g. “Spielplatz mit Reifendrehwippe” is a term that does not occur in the prototype, but does on Google Maps.

The user supplied some information on the nature of this error: they mentioned that they were "not able to search for the facilities [they] selected so it was like starting over again". They added, "if the point is to find the same places as i found on google or even just one of them then the whole process is anoying for someone not familiar with the area" [sic]. This user apparently assumed that the task was to find PoIs that were pre-chosen in another application.

Error 4: Not Enough Categories

A number of users did not manage to supply all five PoIs or repeated one PoI category. For example, one user gave two playgrounds, but forgot to enter a bank, while others did not fill all fields or simply gave five hotels.

There might be different reasons for this error: forgetting single categories, while supplying multiple items of a different category suggests that the user might have made an error while transferring the PoIs from the application to the form. The user from the Google Maps group who supplied five hotels indicated that "only hotels showed up". This leads to the suggestion that the user indeed tried to find PoIs simultaneously, which is obviously not supported by Google Maps.

Error 5: Not Nuremberg

The last error that occurred was the fact that users did not supply PoIs in Nuremberg. Most users with this error supplied PoIs that appeared near Ingolstadt, which is approximately the center of Bavaria and the centre of the initially shown map area after opening the web map.

This mistake occured exclusively in the CoSKQVis group, which indicates that users did not pan the map to Nuremberg. The default view when starting the CoSKQVis application is centred near Ingolstadt, so if users submitted a query before panning, the query location was set there. Users then did not understand the need to move the query location marker to the target area to get results closer to Nuremberg. One user wrote, "I was also confused because the areas with the 5 PoIs that I found were not in Nuremberg... so I just chose the area closer to the city."

The diagram in Figure 5.2 shows the distribution of errors in the five categories for the two user groups. It can be seen that several errors occurred exclusively with the CoSKQVis prototype. In contrast, participants using Google Maps were more prone to suggesting unwanted PoIs.

Some users even fell in multiple of these error categories, which is why the sum of entries in Figure 5.2 is higher than the number of erroneous submissions. Figure 5.3 shows how many people presumably made which number of errors.

5.2.2 Dealing with Erroneous Submissions

Although some of the mistakes made by the participants were not as serious as others and it would make sense to include them in the evaluation of the results because they used the correct application, presented a (from their point of view) correct result and could therefore make certain

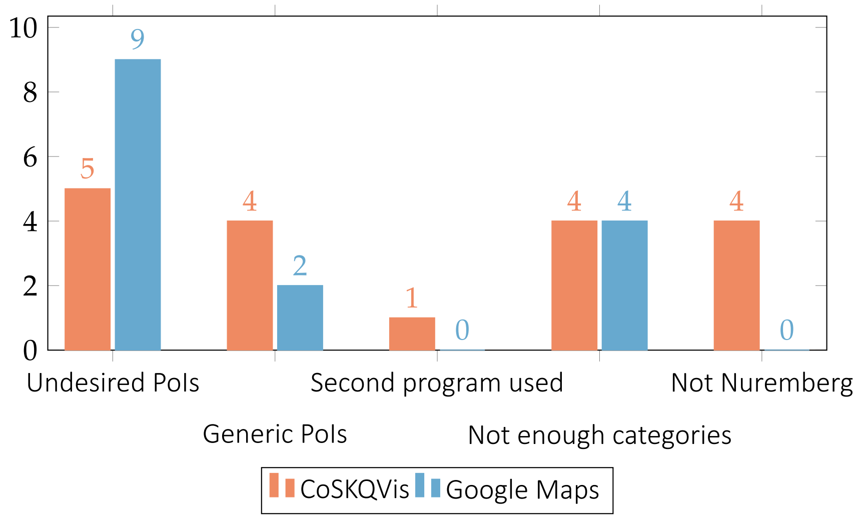


Figure 5.2: Categories of errors

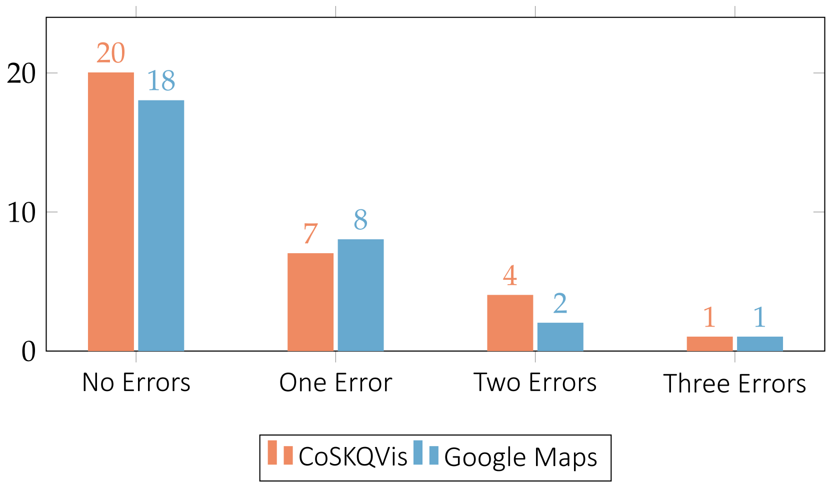


Figure 5.3: Number of errors per user

statements about it, it was decided that all erroneous results should be left out of the quantitative evaluation. This is the case, since the types of errors defined in the previous section are still very broad – errors sorted into the same group can result from a wide variety of reasons, and it is in general not possible to infer the reason of a mistake from just seeing the result.

Therefore only those 38 results that provided a clear, reproducible set of PoIs were admitted to the evaluation of quantitative results regarding the solved task. However, for qualitative questions and for general statistical purposes all submitted answers were taken into consideration.

5.3 Demographic Information

5.3.1 Gender

Since the questionnaire employed an algorithm to equally divide the participants between the two test groups, it was assumed that the demography of both groups might be very similar. Unfortunately this proved false for the distribution of the gender of the participants. More female users than male were assigned to the CoSKQVis application, while the statistics for Google Maps showed an inverted distribution (see Figure 5.4).

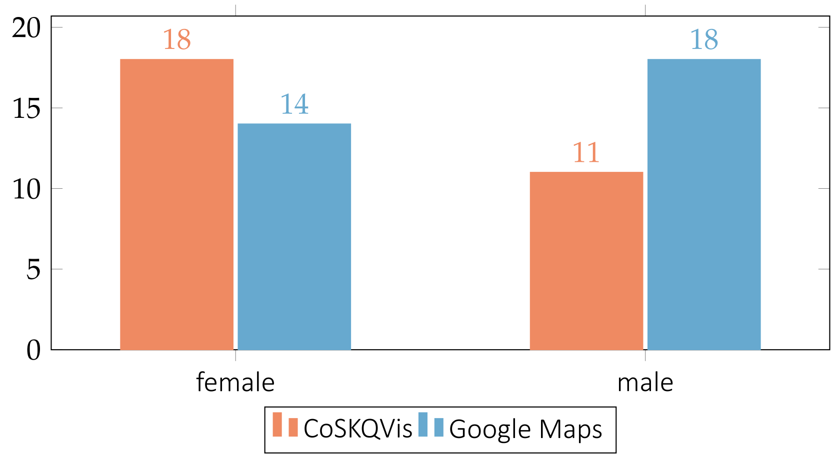


Figure 5.4: Gender of participants

5.3.2 Age

In contrast to the gender distribution, the age distribution was very even. Both groups have a large number of participants between 25 and 29, which is probably due to many students being part of the peer network of the author. Less users were older than 29 or younger than 25 (see Figure 5.5).

5.3.3 Education

For education, the largest part of participants were graduates with a university degree; six persons did have a PhD or a higher degree. One person classified himself as “Other”. (see Figure 5.6).

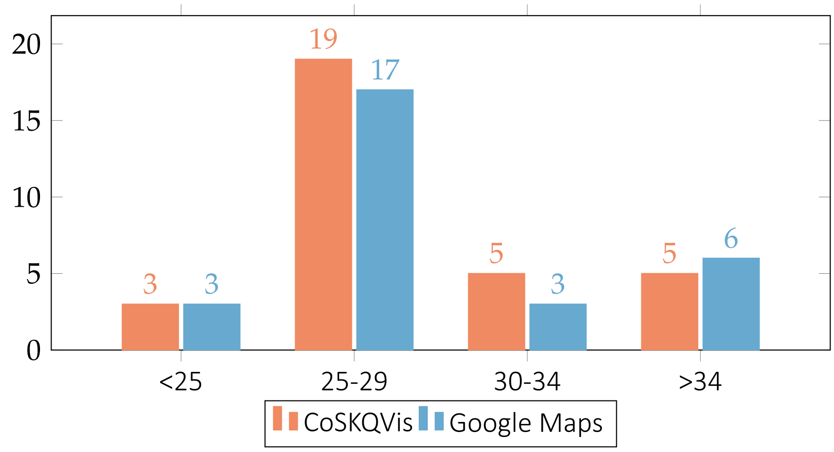


Figure 5.5: Age of participants

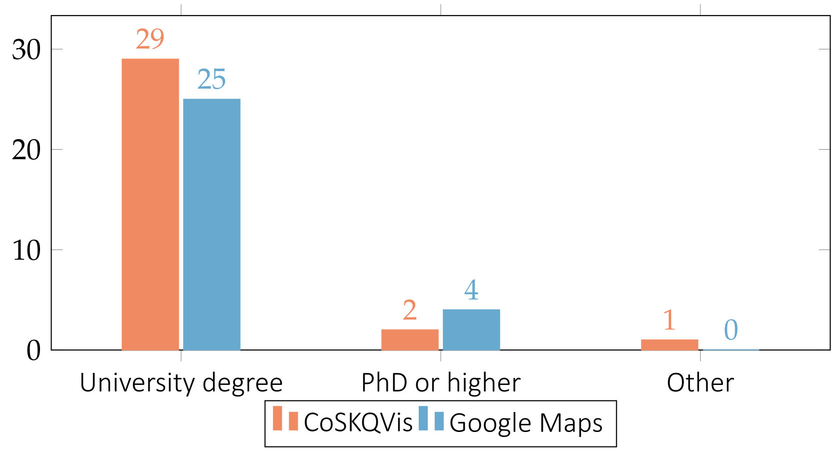


Figure 5.6: Education of participants

5.4 Introductory Questions

All participants were asked regarding their usage of web mapping applications, web mapping navigation and car-bound navigation before starting their tasks.

5.4.1 Usage of Web Mapping Applications

From the answers to question 1 it is visible that almost all participants were heavy users of web mapping applications, which was expected with regard of the target audience (see Figure 5.7).

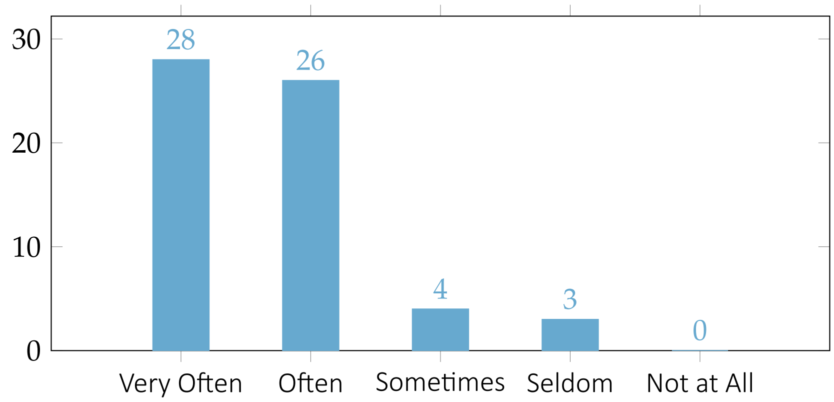


Figure 5.7: Usage of web maps

5.4.2 Mentioned Web Map Products

Users that were regarded as advanced users, as they specified to use web maps very often, often or sometimes, were asked, which applications they use to search for PoIs. Almost everyone gave Google Maps as one of their search applications. A notable number of mentions were given to OpenStreetMap, which was mentioned nine times. In contrast, all other products were only suggested once or twice (see Figure 5.8). A full list of all answers given can be found in Table A.3 in Appendix A.3.

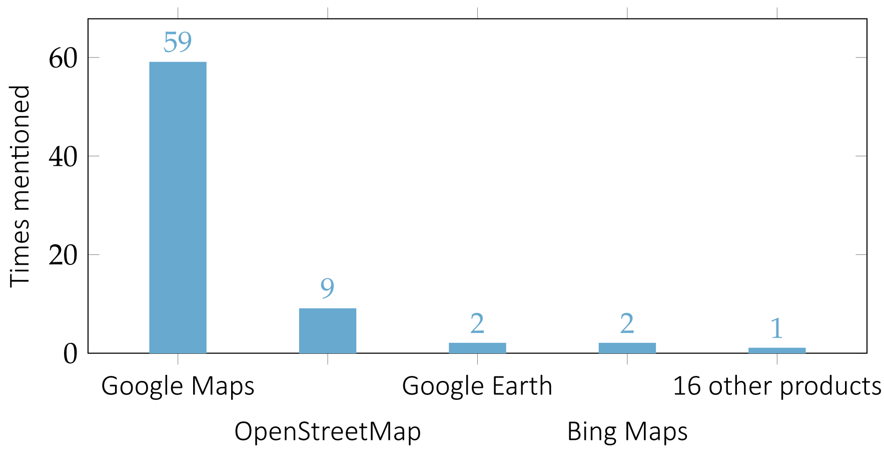


Figure 5.8: Mentioned web mapping products

5.4.3 Usage of Navigation Systems

Regarding navigation, the results for web map navigation and car bound navigation show entirely opposite results. Absolutely every participant in the study specified using web maps for navigation at least sometimes, the majority even "very often". In contrast to that is the usage of car bound navigation, which the majority of participants employ seldom or never (see Figure 5.9).

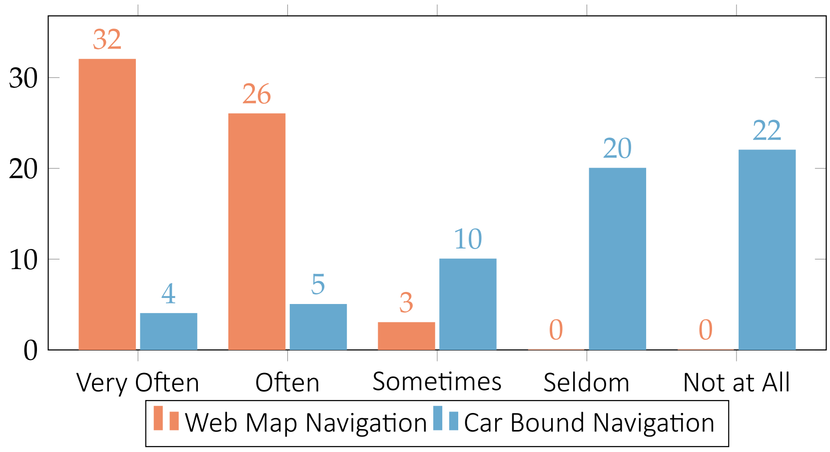


Figure 5.9: Usage of web mapping and car bound navigation

5.4.4 Need and Ease of Simultaneous Search

Users were also asked whether they had ever felt the need to search for multiple PoIs at the same time, and if so, if they had the feeling this was an easy task. The vast majority (about 85%) indicated they actually had this problem before (see Figure 5.10).

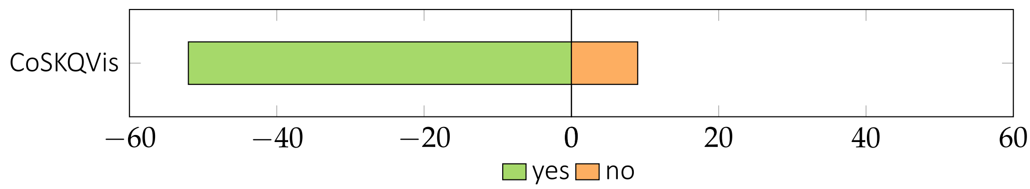


Figure 5.10: Distribution of answers for Q5: *Have you ever felt the need to search for more than one PoI (e.g. a hotel and a restaurant) at the same time, with them being as close together as possible?*

From this majority, most users (63%) answered that, confronted with this issue, it was not easy to find appropriate points (see Figure 5.11).

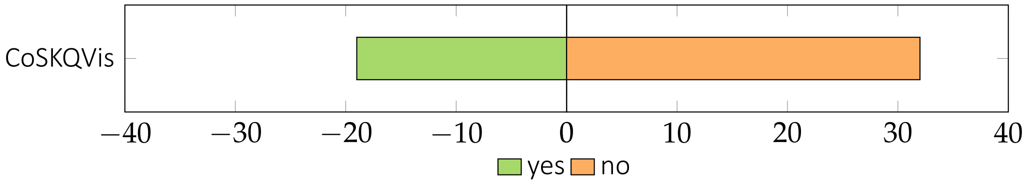


Figure 5.11: Distribution of answers for Q6: *Did you have the feeling it was easy to find appropriate places?*

5.5 Task Results

After the introductory questions users had to solve the task and find and submit five PoIs of the categories hotel, bank, cinema, playground and zoo with either CoSQVis or Google Maps. The difficulty in this task was to find a set of PoIs as close to each other as possible, when there is no obvious solution. For example the PoIs zoo and cinema do not appear close to each other in the requested area, as zoos appear on the outskirts of the city, while cinemas are usually in the city center.

For users of Google Maps this meant a hard decision to pick PoIs that were either close to the zoo or close to a cinema or somewhere in between. For users of CoSKQVis, this decision was more or less taken from them, only the general area of the request had to be specified (see Figures 5.12 and 5.13).

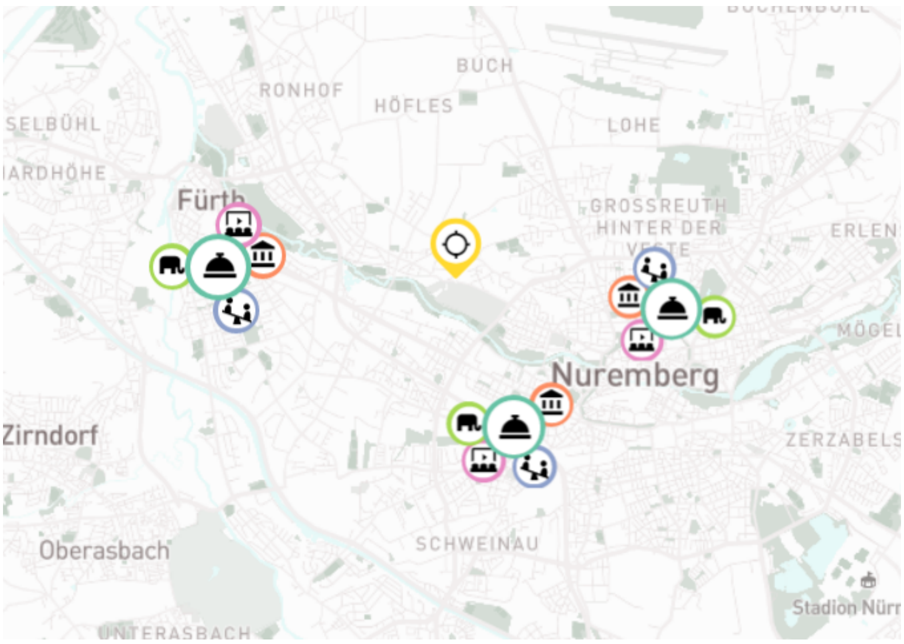


Figure 5.12: Possible result set with three results symbolised as combined markers as given from CoSKQVis

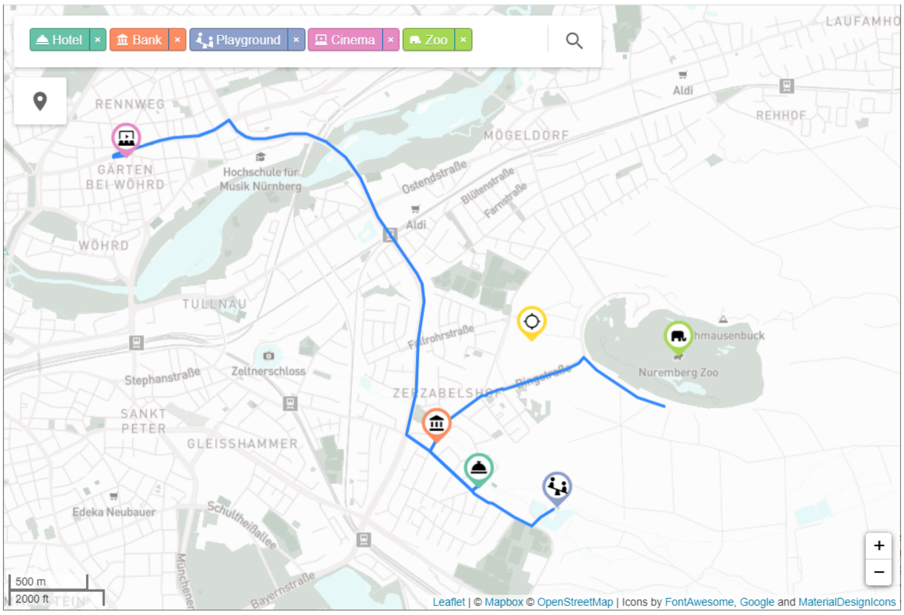


Figure 5.13: Possible result with individual markers and routes as given from CoSKQVis

However, since CoSKQVis and Google Maps use different data sets as source, a direct comparability is unfortunately not given. The following information about PoI distributions should be therefore used with caution and is not meant to make a statement about the quality of the results.

The 38 successful participants handed in a total of 79 different PoIs, whereas everyone picked the “Tiergarten Nuremberg” as their zoo.

See Figure 5.14 for a spatial distribution of all PoIs. In this figure the different PoI categories are symbolised by differently coloured dots, while the circles signify the minimal diameter of results of single users. As can be seen from the graphic, the CoSKQVis group received a lot of similar results, while the Google Maps group had a larger variety in their selection of PoIs. This led to some results with very large, but also very small diameters for this group. But again, this is probably due to the different PoI data sets.

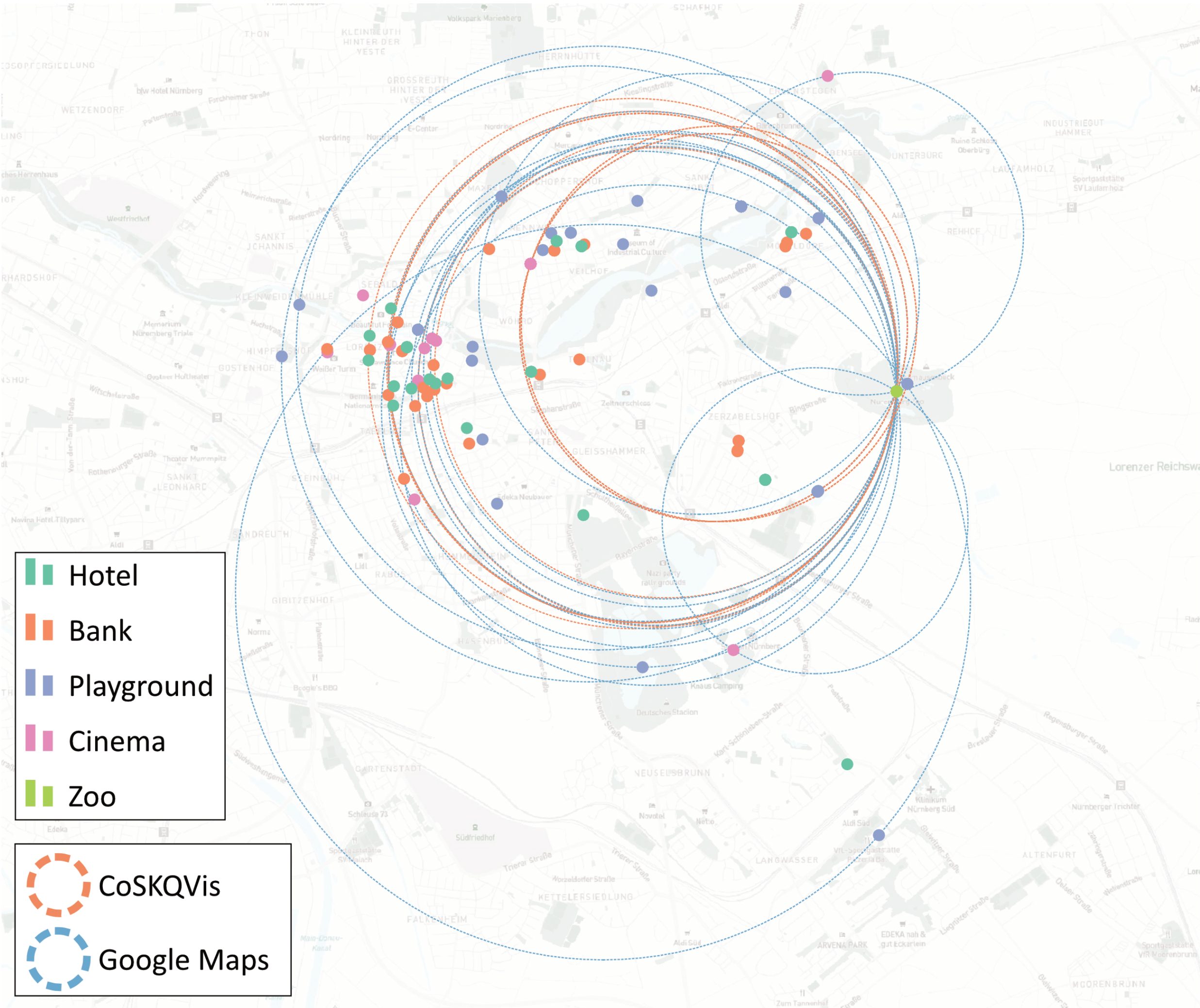


Figure 5.14: PoIs chosen by the participants and radii of answers

5.6 Attribute Questions

Five attributes of usability were collected in the study: learnability, ease of use, efficiency, errors (accuracy) and subjective satisfaction. Except for accuracy, where an input field for open answers was used, two questions with 5-point Likert scales from “very” over “neutral” to “not at all” were posed for each attribute. Answer values in between were intentionally left blank so as not to define a centre that may not be exactly in the middle between two values. These are given in the following diagrams as *(somewhat)* and *(not very)*.

Although there are voices that support the usage of statistical methods like t-test or ANOVA on ordinal data such as the data at hand (e. g. Norman, 2010), it was decided to use a Mann-Whitney U Test (Mann & Whitney, 1947) to test for significance of the results. This test has the null hypothesis H_0 that two statistically independent distributions of ordinal values are equal, while the alternative hypothesis H_1 means that one population is stochastically greater than the other.

An overview of the distribution of all answers to the eight attribute questions can be found in Figures 5.15 (CoSKQVis) and 5.16 (Google Maps).

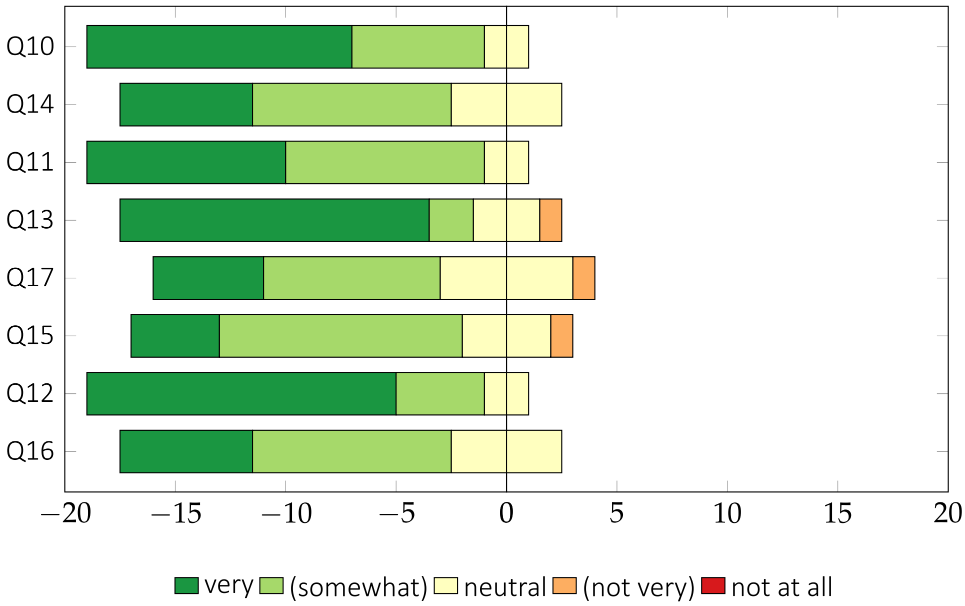


Figure 5.15: Frequency of answers to all attribute questions for CoSKQVis

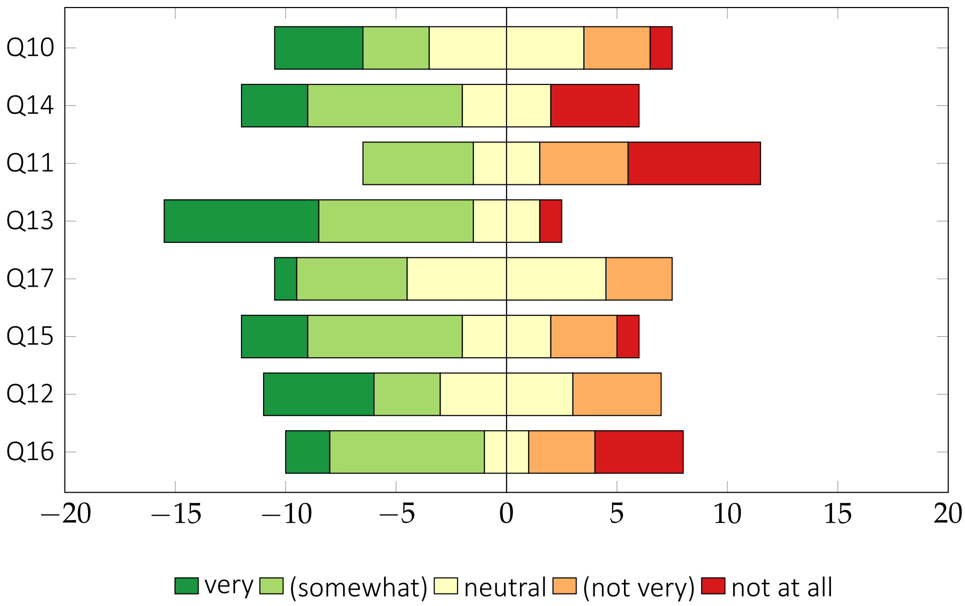


Figure 5.16: Frequency of answers to all attribute questions for Google Maps

As the Mann-Whitney U Test is used as a two-tailed test that does not make any statement about which population is superior, an index has been calculated for every question, consisting of the average of all answers translated into the range from 1 (very) to 5 (not at all). This means that the lower the resulting index, the more positive were the answers in average. This index is graphed in Figure 5.17. As can be seen from the graph, CoSKQVis received a better average for all questions than Google Maps. The alternative hypothesis for all following questions is therefore the assumption that the answers of the CoSKQVis group are stochastically more positive.

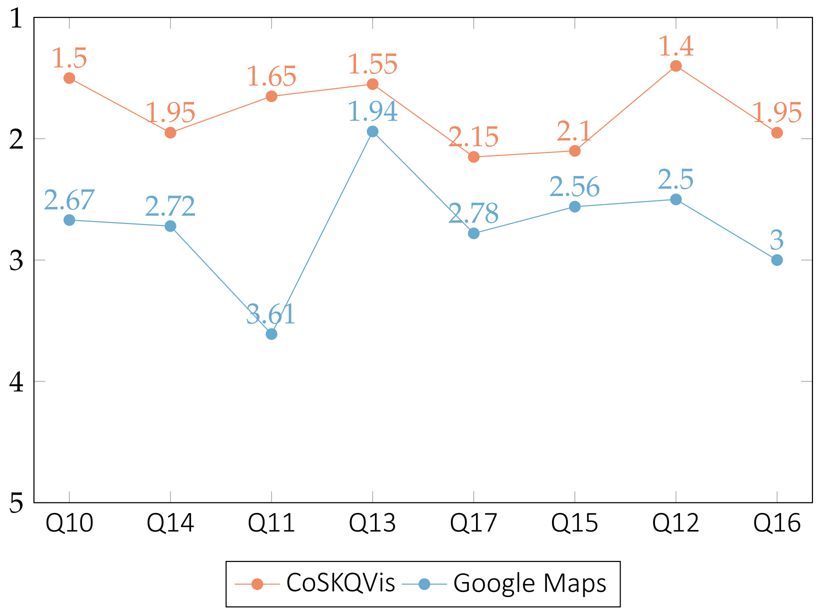


Figure 5.17: Average answer value for all questions for CoSKQVis and Google Maps

In the following sections all raised usability attributes are presented individually.

5.6.1 Ease of Use

Ease of use is one aspect of usability. Users must be able to find their way through an application independently and without confusion.

The two questions to examine this attribute were:

- Q10: How easy was the process to find a set of PoIs?
- Q14: How intuitive was the process to find a set of PoIs?

The answer distributions for those two questions regarding CoSKQVis and Google Maps can be seen in Figures 5.18 and 5.19.

As can be seen from the diagrams, all users of CoSKQVis had a positive or at least neutral feeling towards ease and intuitivity of the prototype, whereas Google Maps was rather neutral in both cases with positive and negative answers. In both variables, CoSKQVis performed better, for Q10

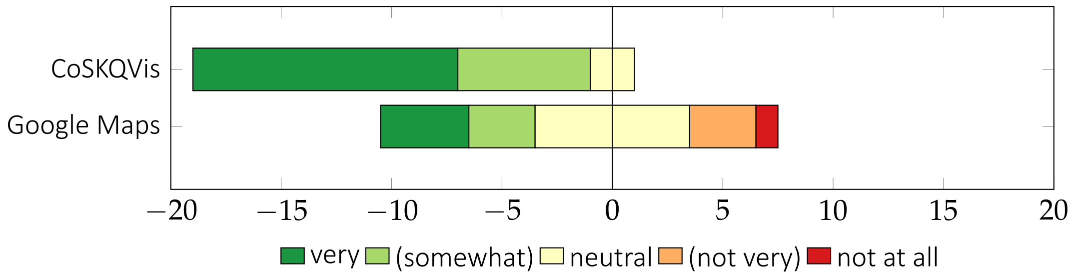


Figure 5.18: Distribution of answers for Q10: *How easy was the process to find a set of PoIs?*

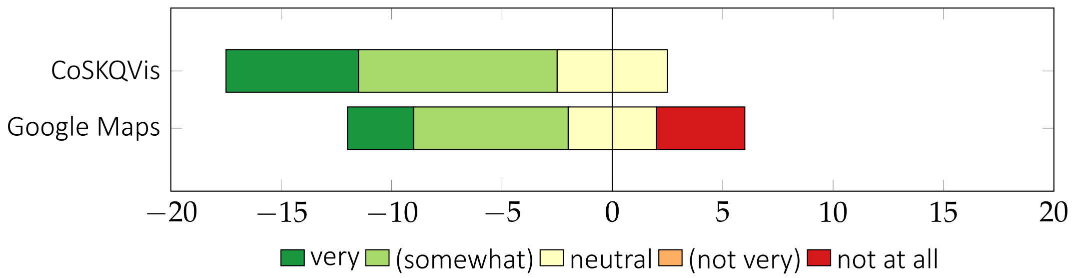


Figure 5.19: Distribution of answers for Q14: *How intuitive was the process to find a set of PoIs?*

significantly on a $p < .01$ level ($p = .00298$), for Q14 not significantly ($p = .12852$). Overall, the populations are significantly different, on a $p < .01$ level ($p = .0009$), which means that the null hypothesis can be rejected for this attribute.

5.6.2 Efficiency

Efficiency is the aspect of usability that deals with how fast a user can do a task and how many resources (time, actions, clicks) they have to use to accomplish it.

The two questions to examine this attribute were:

- Q11: How efficient was the process to find a set of PoIs?
- Q13: How helpful was the search in solving the task?

The answer distributions for those two questions regarding CoSKQVis and Google Maps can be seen in Figures 5.20 and 5.21.

The answer distributions show a clear result for the question how efficient the process was, but not for the question how helpful the search was in solving the task. For Q11, everyone found the CoSKQVis process *very efficient*, *efficient* or *neutral*, while for Google Maps the majority of users found the process *not very efficient* or even *not at all efficient*. In contrast, almost all users for both applications found the search *very helpful* or *somewhat helpful* in solving the task.

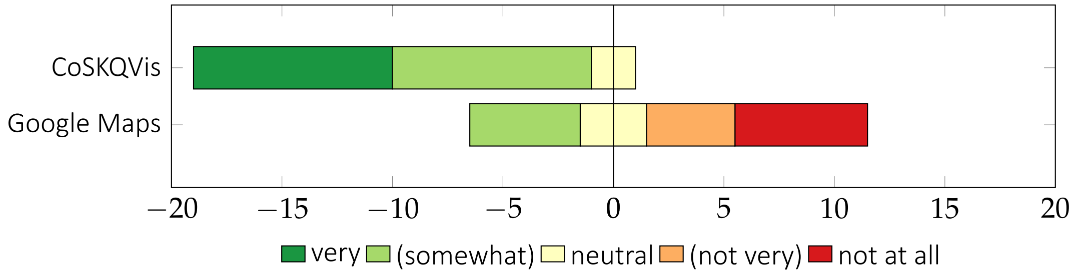


Figure 5.20: Distribution of answers for Q11: *How efficient was the process to find a set of PoIs?*

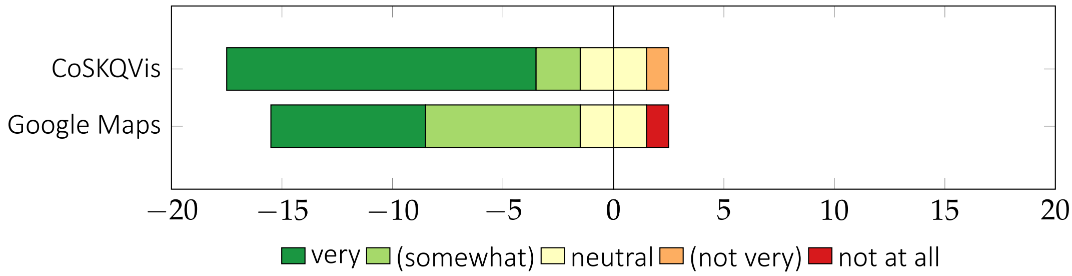


Figure 5.21: Distribution of answers for Q13: *How helpful was the search in solving the task?*

For Q11 CoSKQVis performed significantly better ($p < .00001$), while the difference was not significant for Q13. Overall, the difference is significant ($p = .0002$) and the null hypothesis can also be rejected for this attribute.

5.6.3 Subjective Satisfaction

Satisfaction is the usability aspect influenced by how well wishes, needs or expectations were met. Also pleasure can create satisfaction.

The two questions to examine this attribute were:

- Q17: Would you rate the retrieved PoIs as satisfactory?
- Q15: Did you enjoy working with the web mapping platform?

The answer distributions for those two questions regarding CoSKQVis and Google Maps can be seen in Figures 5.22 and 5.23.

Answer distributions for these two questions were rather similar for both groups. While CoSKQVis users were generally somewhat more positive when it came the rating of their found PoIs, a majority of Google Maps users found them rather *neutral*. This question Q17 is significant on a $p < .05$ level, but not $p < .01$ ($p = .04236$). Q15 is not significant ($p = .25848$). Overall, the difference is also significant on a $p < .05$ level ($p = .02088$). A user remarked to this question, "[t]he results feel satisfying."

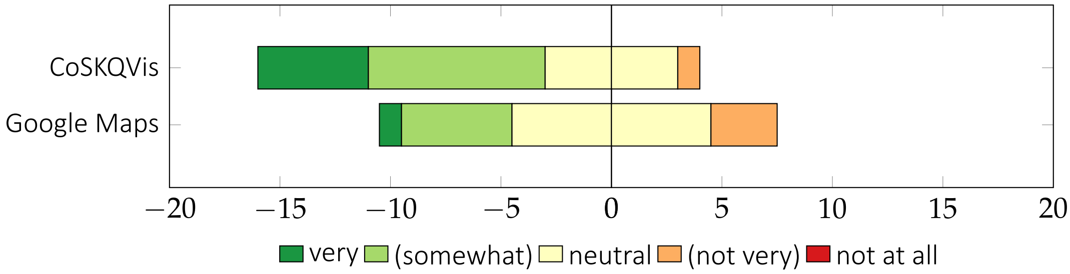


Figure 5.22: Distribution of answers for Q17: *Would you rate the retrieved PoIs as satisfactory?*

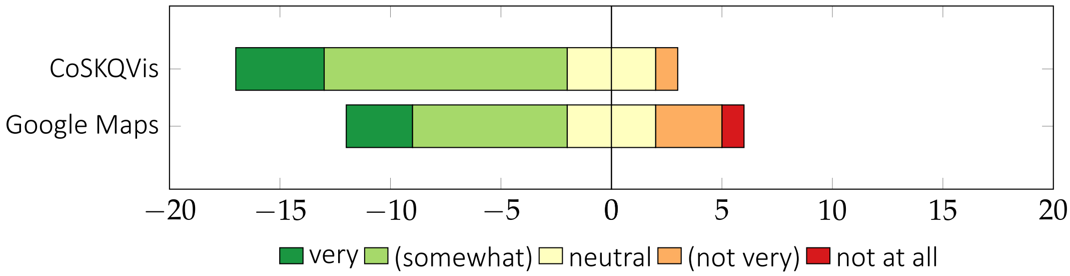


Figure 5.23: Distribution of answers for Q15: *Did you enjoy working with the web mapping platform?*

5.6.4 Learnability

Learnability is the aspect of usability that describes how well users can work with a new system without having to refer to documentation and how quickly this learning process progresses.

The two questions to examine this attribute were:

- Q12: How easy to learn was the process to find a set of PoIs?
- Q16: How user friendly was the process to find a set of PoIs?

The answer distributions for those two questions regarding CoSKQVis and Google Maps can be seen in Figures 5.24 and 5.25.

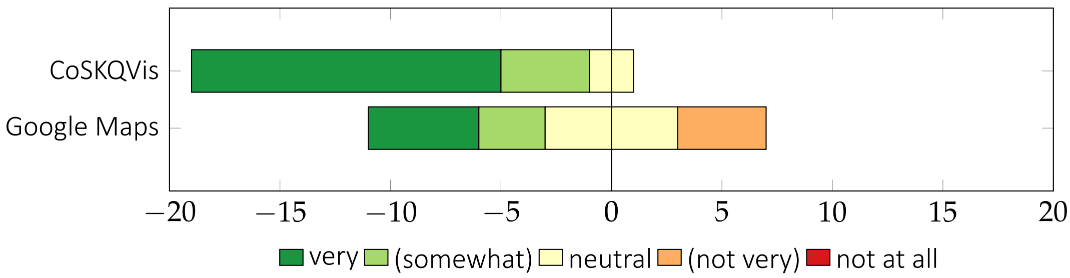


Figure 5.24: Distribution of answers for Q12: *How easy to learn was the process to find a set of PoIs?*

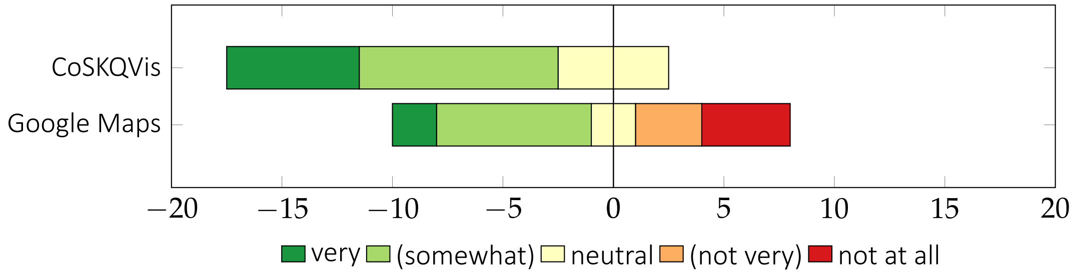


Figure 5.25: Distribution of answers for Q16: *How user friendly was the process to find a set of PoIs?*

The diagrams show that a majority of users found the CoSKQVis application *very* easy to learn and the process *somewhat* user friendly. Google Maps in contrast got some negative answers, especially when it came to user friendliness of the search process. Hereby Q12 is significant on a $p < .01$ level ($p = .0048$) and Q16 on a $p < .05$ level ($p = .03078$). Overall, the populations are significantly different ($p = .00032$) so that the null hypothesis can also be discarded here.

5.6.5 Confidence in Found Set

Another question was regarded as very important for the assessment of the usefulness of the prototype, but did not exactly fit into the attribute categories:

- Q18: How confident are you that you found the selection of PoIs that has the smallest distances between each other?

The answer distribution for this question regarding CoSKQVis and Google Maps can be seen in Figure 5.26.

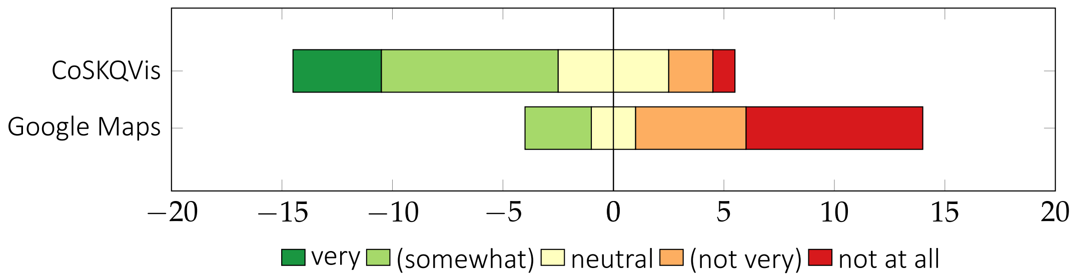


Figure 5.26: Distribution of answers for Q18: *How confident are you that you found the selection of PoIs that has the smallest distances between each other?*

The distribution is surprisingly clear – for CoSKQVis the majority of users considered themselves *very* or *somewhat* confident, while Google Maps users were very uncertain about this fact, as the majority of users chose *not very* or *not at all*. The difference between the two groups is also significant ($p = .00054$).

5.6.6 Accuracy

Section 5.2 has already shown that a significant portion of participants failed in some aspect to solve the task given. Since this questionnaire was conducted online, an assessment of the actual error sources – did the user not understand what to do, or did they have problems with the application – is impossible.

Therefore an open question about errors that happened was used to further make an assessment about accuracy. For this assessment remarks from all 61 users, also the ones not taken into account for the previous questions, are listed.

Remarks for CoSKQVis

A lot of remarks were given for CoSKQVis, which is why they are assigned to different categories here. Comments were omitted if they were irrelevant or mentioned before in this thesis (e. g. Section 5.2).

Category 1: Program errors

This category probably contains the most grave issues that were mentioned. Errors were assigned this category when the described issue is not according to the programmed behaviour and should not have happened, or was known beforehand, but could not be resolved.

- One user "did not receive proportionally different sized icons."
- Another user experienced that "the query cannot process more than 3 items at a time. When I would like to search for cinema other than hotel, bank and playground at the same time, I couldn't fill it in anymore"
- One user "was shown 3 clusters of POI's however only one cluster had all the 5 POI's in the vicinity"

All three of these errors cannot be reproduced by the author and have not been experienced otherwise. The first issue may be due to the fact that only one cluster was shown or all shown clusters were approximately identically fit.

- One user observed that "the route from hotel to playground is longer than it should be. By walking, there is much shorter way available."

This problem was known beforehand. The routing software used employs different profiles for pedestrian, bicycle or vehicular navigation. But the respective routing depends on the correct modeling of streets and the presence of attributes in the underlying OpenStreetMap data. This may lead to suboptimal routing in some cases.

Category 2: Feature Requests

Feature requests are issues that exceed the current possibilities of the application. These are potential topics for later iterations of the software.

- One user answered to the question of whether something didn't work as expected, "Yes, the location search"
- The same issue was mentioned by another user: "I tried to search for Nuremberg in the searchbox, because Nuremberg did not show as a label on the map for my initial zoom level. That did not work."
- Another user suggested: "It would be nice to be able to add the area (city, state) where you want to search for those PoIs."

Several users tried to search for the target city through the search bar. This makes sense insofar as the search bar acts as a mixture between a simple and an advanced form, accepting thematic input (the "what") in a structured form, but no location (the "where"). This is planned for a later iteration of the prototype (see Section 7.2).

- One user mentioned that "sometimes it wasn't possible to write the PoI type (e. g. cinema) in the search bar; it had to be selected from the dropdown list."
- Another user said, "I could not find something specific (i. e. italian restaurant, dinosaur museum)"
- A different user also found it distracting that "the colors change with the order as well [..] – I would want the colors to stay with the type of POI once they are entered to the query."

All three of these issues with the search bar are potential features for future versions of the application: the possibility to spell out the full name of a PoI category without explicitly picking it from the list, a higher specificity of PoI categories and fixed colours for PoI categories may all be implemented in a later version.

- One user "thought the names will be displayed nearby the found POIs by default."
- Another suggestion was that "When hovering over the paths, I would like to know the total* distance of commuting from the hotel to each* of the other facilities, a total number for the whole cluster"
- A user was "confused because the names of the main cities were not shown."

These issues with the map interface are all comfort features that may or may not be considered in a later version.

Category 3: Understanding problems and room for improvement

These issues are usually due to a lack of understanding of the application, or suggest improvements of application components that have been deliberately programmed as they are.

- One user said, that "the invisible limit of distance based on [..] the query location feels kind of strange, when I was not really sure where I wanted to center my search."
- A user described their issue as follows: "The results are dependent on the location of the yellow pinpoint. But what if you don't have an exact preferred location and you would rather base your selection on the proximity of the results. Perhaps multiple clustered results would than be preferable over setting a start location."

- Another user found that "sometimes the set was suggested unexpectedly far from the location where I've put the yellow marker" and that too "few sets were shown close to my marker." because they saw that "there were also other good sets available if I just moved the marker for a street or a block. I would prefer to get all the options in a neighbourhood, not just one or two."

The specification of the query location has led to some confusion, but was deliberately chosen as is. These issues can be traced back to the lack of explanation of the function of the query location and may have been cushioned by providing a bit more support for the users.

- Another problem with the prototype was described like this: "I searched for the five things together and it only gave me one option of each. I thought it would give me more choices and I could choose from among them."
- A user mentioned that "when I searched the five POIs together, the results are fixed. There is only one place found in each category. Especially hotel and bank, I would expect more than one result shown on the map."

Since PoIs are not allowed to appear in multiple results, it happens easily that only one cluster appears, e. g. when only one zoo is in the vicinity. This could have been understood if users had thoroughly explored the application beforehand.

- A user mentioned, "it is not clear to me how the ordering of the POIs in the query affects the result (which it does apparently)."

This issue is understandable, since the "center point" semantic (see Section 3.1.1) is not obvious to users that are unaware of it. This could have been also avoided with some more explanations. For a discussion of possible improvements see Section 6.4.

Remarks for Google Maps

As Google Maps is a commonly used and well tested product, real issues with it were sparse. Only two topics could be observed – minor usability issues, and the inability to search for multiple PoIs at once.

- One user observed that "when I entered the search term (like cinema) google maps somehow always zooms out which is a bit confusing if you are not familiar with the area."
- One user experienced that "when I do my search of POIs while in Nuremberg, it sometimes goes back to and does the search in my current location"

These usability issues are rather small, probably not keeping anyone from using the application.

- One user found it "just frustrating you had to find one poi at a time and make an educated guess about where the hotel closest to all of them was located."
- Another user followed the same line: "Very difficult to find all five POIs in a smaller area"

- One user remarked that “the zoo pois restricted the choices of the other pois (plenty of them really well distributed among the city)”
- Another user saw that there’s “no possibility to search for all five pois at once (i. e. hotel near zoo near playground near bank near cinema near nürnberg)”

These users basically subsumed the purpose of this thesis with their remarks. This shows that Google Maps may be not optimal for this special case.

Conclusion

It can be seen that CoSKQVis still has some usability issues that need to be investigated. Users mainly had understanding problems, as some of the mechanics built into the application are at least unfamiliar. Many users also had ideas for improvement and some errors in the application seem to persist.

In contrast Google Maps showed a very small amount of issues. These mainly centered around the fact that the application was not designed for a task like the given one.

5.7 CoSKQVis Questions

Those 20 users that were assigned to the CoSKQVis group were given an additional set of questions regarding some specific features of the application. Besides the efficiency of the search bar and the attractivity of the marker symbols these asked for the intuitiveness of the three visual variables that are explained in Section 3.3.3.

5.7.1 Efficiency of the Search Bar

The search bar is one of the three UI elements explicitly presented in this thesis. To help users find their PoIs efficiently, it is mandatory that they find their way around the search bar. To examine this efficiency, the following question was posed:

- Q19: How quickly did you find the items you were looking for in the search box?

The answer distribution for this question can be seen in Figure 5.27.

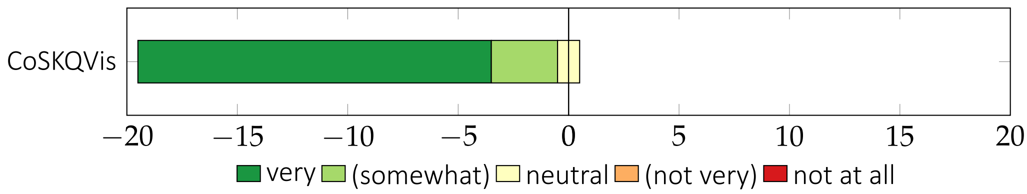


Figure 5.27: Distribution of answers for Q19: *How quickly did you find the items you were looking for in the search box?*

As can be seen from the graph, the majority of users found the speed of finding items in the search bar to be very fast, everyone except one participant even had a positive opinion about it.

5.7.2 Attractivity of the Markers

The UI elements that probably have the highest amount of novelty are the combined markers. This question did not explicitly aim for the combined markers, but rather all markers used in the prototype. To examine the subjective attractivity, the participants were asked the following question:

- Q20: Are the marker symbols an attractive solution?

The answer distribution for this question can be seen in Figure 5.28.

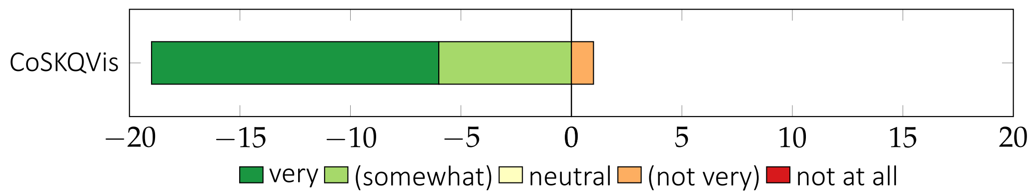


Figure 5.28: Distribution of answers for Q20: *Are the marker symbols an attractive solution?*

The graph shows that again almost all users found the marker images to be very attractive or somewhat attractive.

5.7.3 Intuitiveness of the Visual Variables

The three visual variables that were encoded in the combined marker symbols (colour, size, orientation) were examined by similar questions. Each was accompanied by an explanatory image in case it did not catch the user's eye while solving the task (see appendix A.2).

The questions to examine the intuitiveness of these visual variables were:

- Q21: The colours of the marker symbols correspond with the colours in the search bar. How intuitive do you think this is?
- Q22: The orientation of the smaller marker symbols correspond with their approximate orientation in the map space. How intuitive do you think this is?
- Q23: The size of the combined marker symbols correspond with how appropriate the algorithm thinks the result is. How intuitive do you think this is?

The answer distributions for these three questions can be seen in Figures 5.29, 5.30 and 5.31.

The first graph shows that the majority of users found the colours very intuitive or somewhat intuitive. Only two users considered the colours not very intuitive, making the usage of colours for identification of PoI categories feasible concept. One user remarked, "The colors used for PoIs markers and in the search bar are a good idea but [were] distracting while I was using the search

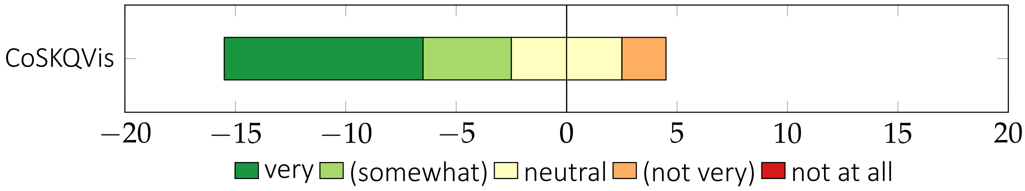


Figure 5.29: Distribution of answers for Q21: *The colors of the marker symbols correspond with the colors in the search bar. How intuitive do you think this is?*

bar. Later, I didn't look at the search bar again, so I didn't even realize the colors are the same as in the markers." This shows that the concept for colors does work in general, but may need be tuned regarding their salience.

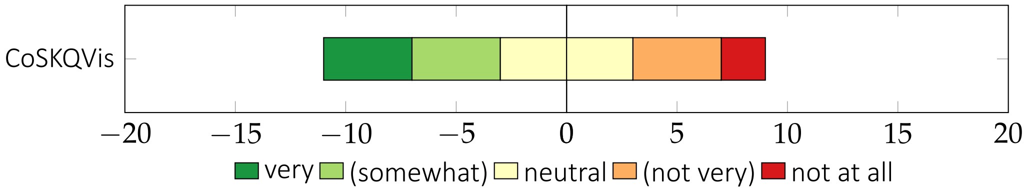


Figure 5.30: Distribution of answers for Q22: *The orientation of the smaller marker symbols correspond with their approximate orientation in the map space. How intuitive do you think this is?*

Unlike colour the orientation in the map space was not received very positive. Only eight participants found this feature intuitive at all, while the remainder had a neutral or negative opinion about the feature.

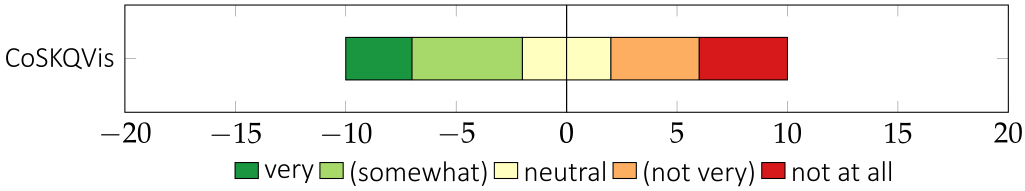


Figure 5.31: Distribution of answers for Q23: *The size of the combined marker symbols correspond with how appropriate the algorithm thinks the result is. How intuitive do you think this is?*

Even less than orientation, many users did not find the size variations for combined symbols intuitive. The answers were fairly evenly distributed, with the same number of people rating the characteristic positive as negative. Seeing that more people used the "not at all intuitive" option than the "very intuitive" option, this question is the only question about CoSKQVis that had a rather negative feedback.

5.7.4 Usefulness

Two more questions were asked about the usefulness of collective queries and the tasks to which they may be applicable. The second question was hereby marked as optional and only raised when the first was answered positively.

- Q24: Do you think that this kind of search may be useful for certain tasks?
- Q25: What certain tasks do you think of?

The answer distribution for this question can be seen in Figure 5.32.

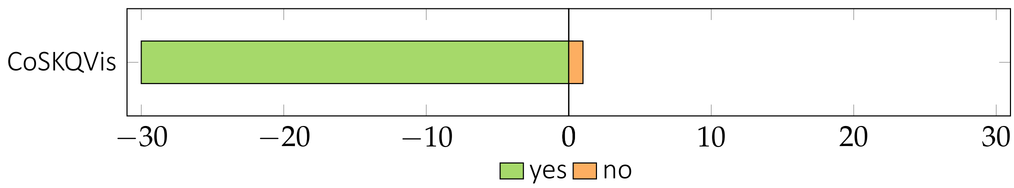


Figure 5.32: Distribution of answers for Q24: *Do you think that this kind of search may be useful for certain tasks?*

Of the 32 persons in the CoSKQVis group (including erroneous submissions) 31 answered the question, and everyone except one found the kind of search useful for certain tasks.

For the second question 59 suggestions were given. For a full list refer to appendix A.3. Notable are some recurring themes, e. g.

- Finding accommodation or a place to live
- Planning trips or holidays
- Efficient routing
- Shopping / Running errands
- Tourist purposes

One participant even noted: "The option of searching for combinations of PoIs in a cluster has unlimited possibilities and now that I have used it I have realized what we were missing on."

5.8 Conclusion

The user test gained substantial participation in the two weeks it ran, and a lot of feedback on the prototype, the task and the questionnaire was positive. It was surprising though that a significant number of participants was not able to finish the task successfully.

Usability of the prototype was examined using five different attributes. Opinions on four of these attributes – ease of use, efficiency, subjective satisfaction and learnability – were surveyed quantitatively and for the specific task given all of them were rated significantly better than the commercial alternative Google Maps. One user remarked that "It is overall intuitive, convenient and easy to learn."

Additionally, the users' confidence in the found set of PoIs was a lot higher than for the alternative.

The qualitative attribute accuracy gained a large number of responses, some containing possible program errors, but mainly feature requests and understanding problems. It was visible that users had many more remarks when it came to a previously unknown system that did not cover all aspects and behaved partly unexpected (CoSKQVis) than a well-known and established application they were accustomed to use (Google Maps).

The prototype received positive reactions to the search bar and the markers, but the use of the visual variables was evaluated as not very intuitive. The absolute majority of users also thought that collective spatial keyword queries can be useful in certain scenarios.

6 Discussion

As stated in Chapter 1 this thesis aims to **propose a visualisation for collective spatial keyword queries**. Three sub-objectives were derived from this main objective:

- The proposal of a visual concept for searching PoIs in the sense of collective spatial keyword queries
- The proposal of a visual concept for displaying the results of such a query on a map
- To test whether the usability for such queries is an improvement over existing applications for the target audience

The previous chapters have provided sufficient information to consider these objectives fulfilled. Chapter 3 outlines a methodology for creating such queries, including a novel query type that employs some unique characteristics. Visualisation of query results on a map can be done by using typified markers, as detailed in the same chapter. A user test showed that the usability of the implemented prototype is significantly better for several attributes than the commercial alternative, at least for the provided scenario.

Three research questions, each containing several sub-questions, were formulated in Chapter 1 in order to achieve these objectives. All of them were answered in detail in their respective chapters, and are now discussed one by one. Afterwards, limitations and possible improvements of the methodology are listed. Finally, to classify this research in the current state of research, a comparison to the SpaceKey application is carried out.

6.1 The Visual Concept for Collective Querying

As Chapter 2 explains, a spatial keyword query is a keyword query that contains a spatial component, operating on geo-spatial data. It is characterised by the fact that the user can specify a location together with the keywords, be it using a text-based or a map-based interface. Results of the query are commonly displayed on a map component using markers with varying iconicity.

When the system is allowed to answer a request with not just one or multiple homogeneous objects, but rather a set of heterogeneous items that collectively satisfy the keyword query and possess a certain spatial closeness, we arrive at collective queries. Here the context is shifted from finding the best match to finding the best set of partial matches. There are different approaches for answering collective queries, e. g. with and without a query location that influences the calculation of the fitness of results.

As Chapter 3 details, this thesis proposes a novel type of collective query called TYPE2a Query. This query uses a so-called center point semantic, where the first given keyword denotes a central point on which the finding of the other PoI categories depends. On one hand, this differs from the current state of the art where all keywords have the same weight and the ordering of keywords is irrelevant, making it harder for the user to gain understanding of the usage of the query. On the other hand, returning multiple results is easy and natural this way and it plays well together with the visualisation of markers proposed in Section 3.3.

Three UI elements are necessary for the realisation of the TYPE2a Query: a search bar, a button to define the query location, and a map component. First, the search bar has the feat to accept multiple keywords using an auto-complete feature to select from a list of available keywords. All selected keywords are then sent to the geodatabase, together with the query location, which can be set to the center of the screen using the query location marker or by dragging and dropping a special marker using the map component. This map component makes up the main part of the screen, displaying a base map and rendering the results of the query using map markers and routes.

6.2 The Visual Concept for Displaying Results

For representing query results on a map two types of map markers are proposed (see Chapter 3): individual and combined markers. Individual markers are shown above a certain map scale when markers are well separate from each other, and combined markers below this threshold to avoid overlap and clutter. These combined markers consist of several circular elements that each represents one PoI or keyword. To encode properties of individual results like fitness, spatial distribution of results, categorical membership and the center point semantic into the marker, visual variables like size, colour and orientation are used. According to the user test, a majority of users found the markers an attractive solution.

The user test, as described in Chapter 5, showed that these visual variables are accepted by the audience, but do not have the significance for understanding the combined markers as expected. The use of colour to indicate categorical affiliation was considered more intuitive than the other two visual variables. To encode the fitness of the result into the combined marker differently sized markers were used. This was evaluated as being too subtle and received a mixed verdict in the user test. Orientation as denominator for the spatial distribution of individual items also received mixed comments; here additional research needs to be conducted as to find why their support was so low and how it can be raised.

Whereas most collective queries are aimed at returning just one result, TYPE2a queries possess the intrinsic characteristic to return multiple results, up to one for each result of the first keyword match. Visualising multiple results on the map is done with disparate combined markers and mouseover interaction for individual markers. The user test showed that users got used to these mechanisms easily although some wished for more information about the result upon hovering over it.

To integrate routing information into the visualisation of results, the routes from the center point to all other PoIs in the result are requested from a routing service and displayed amongst the individual markers. Not all routes generated by the used OSRM server were optimal, which confused some users as they saw that shorter routes were possible.

6.3 Usability of the Visual Concept

The proposed methodology was implemented as a client-server application called CoSKQVis and a subsequent user test was conducted. The user test separated all participants into two groups, requesting them to solve a task with either CoSKQVis or Google Maps, which does not support collective queries. Both groups were asked for their opinion about several aspects of usability, like learnability, ease of use, subjective satisfaction, accuracy and efficiency.

The user test showed that a general interest in the technology and its visualisation exists. A large majority of users have previously tried to search multiple PoI categories simultaneously and most found it difficult or impossible to do so. The demography was certainly according to the target user group – rather young, highly qualified and mostly advanced users of web mapping applications.

Many users were able to use the application intuitively and without instructions. But a surprisingly high percentage of users submitted erroneous results, which can at least partly be traced back to the task itself, as both groups were similarly affected. Suggestions to improve on this for a future follow up study can be found in Section 6.4.

Those users who successfully solved the task rated the usability of the CoSKQVis application – at least for the scenario of the task – as significantly higher than the users of Google Maps. This is valid for the usability aspects learnability, ease of use, efficiency and subjective satisfaction. Especially the question as to how efficient the process to find a suitable PoI set was has been answered in a much more positive way. Users were also considerably more confident that they had found the best available solution than with Google Maps. On the other hand, users enjoyed working with both platforms in much the same way and considered the process of finding PoIs to be approximately equally intuitive.

When it comes to accuracy users submitted a large number of remarks, especially for the previously unknown prototype. This did not come unexpectedly, since an application that leaves the user with a completely new search paradigm which employs potentially confusing functionality that the user does not understand immediately, but does not provide all accustomed features from similar platforms, will probably always generate more reactions than a well-established market leader. These remarks were mostly of a minor nature, consisting mainly of feature requests and understanding difficulties; serious program errors were sparse on both sides.

Some characteristics of the TYPE2a query, namely the query location marker, the center point semantic and the algorithmic selection of results, were subject to confusion, e. g. users did not understand why only one result was given in certain situations or how the order of items affected the result.

However, no users commented on the understandability of the combined markers, which leads to the conclusion that all participants were content with the meaning of the marker components and no misunderstandings have occurred.

When asked about the features of the CoSKQVis prototype, people reacted very positively towards the functionality of the search bar and the attractivity of the markers, but rather mixed towards the usage of the visual variables colour, size and orientation. Here a better result was certainly expected, since these were expected to contribute significantly to the understanding and acceptance of the combined markers.

Finally, almost all users admitted the usefulness of collective querying for certain tasks, e. g. planning trips, shopping or tourist purposes.

Regarding the combined markers it can be concluded that the commitment to typification as anti-clutter mechanism was certainly positive. The claim of Pombinho et al. (2009) can therefore be supported, who called their typified marker symbols "very helpful in creating a less confusing visualization".

The hypothesis that the possibility to search for multiple PoIs simultaneously is definitely useful and possesses advantages over the current commercial state of the art, at least in certain scenarios, can therefore be supported.

However, the user test only had a rather small number of participants with very specific education and experience levels. Also the distribution of genders was not very similar in the two groups. Therefore a statement of generality cannot be made.

6.4 Limitations

This section reviews the methodology and user test in the light of the experiences gained from user participation. There are some aspects that may need to be revised and improved in future research. It is crucial to find out how the methods developed in the previous chapters can be adapted to the actual needs of the users.

6.4.1 Methodology

The most intriguing change in the methodology of the prototype is in regard of the search bar – multiple users tried to use it for location search, which is logical considering they are using a web mapping application in much the same layout as the well-known competitors. So, for the next version there needs to be a way to not only query the theme (the "what"), but also the location (the "where"). A suggestion on how to realise this can be found in Chapter 7.2.

The second change in methodology was noticed during the development of the prototype. In some rare cases it happens that two combined markers overlap, because their cluster centres fall into the same area. The nature of the markers with their circular components being quite volatile in their positioning can lead to confusing results where it is not clear which component belongs to which marker. There needs to be some improvement on this, e. g. by displacing the markers when a collision is detected.

And finally, the use of the three visual variables that were expected to aid strongly in the understanding of the results received rather mixed opinions in the user test. Here more thought needs to be given towards which pieces of information need to be included in a search result and they can be encoded intuitively.

6.4.2 User Test

Some difficulties were not part of the methodology, but rather introduced in the development of the user test. These include the general layout of the test and smaller aspects of the questionnaire.

For example, the grouping of users between a prototype based on OpenStreetMap and Google Maps turned out to be difficult in terms of comparability, since both services have very different databases. If both applications shared a common database better comparisons of task results (e. g. diameters of all found PoIs) would have been possible.

What emerged as a likely problem during the user test was the wording of the task – it seemed to be too complex or not clearly enough formulated. A large number of users were not able to finish the task accordingly, some even clearly misunderstood what they had to do. In hindsight a stricter, simpler formulation of the task description would have been an option. The verbose scenario-like wording of the task seemed to encourage the users to do what they speculated was the task (thinking about what PoIs one could visit) instead of what was expected (finding an exactly formulated set of PoIs). However, ignoring the instructions in a user test seems to be a recurring problem (e. g. Degbelo, Kruse & Pfeiffer, 2019).

Also, when wording is concerned, it may have been reasonable to emphasise that a good result has a small result diameter. The current formulation of "choosing PoIs only according to their position" gave most users the right idea, but others focused on choosing PoIs in the city centre rather than in the vicinity of the others. One user formulated the problem as follows: "I wasn't sure if I need to choose a set by location in the sense that the PoIs are the closest possible to each other or that I actually also like their location in the city." Therefore a clearer wording of what defines a good result would be appropriate, considering the novelty and unfamiliarity of the concept.

Some users wished for more guidance, especially when it came to the query location marker. This desire could have been met with additional help texts inside the prototype. On the other hand, many users were apparently not reading all the task instructions, so it is doubtful whether they would have read an application tutorial or some help texts. A solution could be small help icons that give more information about an element on request.

The attribute questions also have some room for improvement: it is not clear whether the two questions for each usability attribute actually test this attribute. Especially the two questions regarding efficiency evoked very different reactions, so it must be questioned whether they actually tested the same attribute. Here the use of a standardised test (e. g. AttrakDiff[1]) or at least standardised set of questions would have been a good choice.

6.5 Comparison to SpaceKey

In Chapter 2 the SpaceKey framework by Fang, Cheng, Wang et al. (2018) was introduced. In order to integrate the present methodology into existing work, this section compares the research of this thesis with the existing SpaceKey system in terms of similarities and differences.

As both systems are web-based and show a map as their main interface component, they have the same basic functionality, visualising collective spatial keyword queries. But there are several significant differences: while SpaceKey has its focus on the different algorithms and lets the user choose between several options, this thesis employs the TYPE2a query as only algorithmic option.

Both systems are capable of retrieving more than one result at a time, but SpaceKey can only display one result at a time, requiring the user to seek through all results one by one, while this thesis proposes a method to show several results at once.

In SpaceKey PoIs are always displayed as uniform markers, and their type seems to be encoded as either symbols (in the sidebar of the interface) or text (on the map). This research promotes typified markers to reduce visual clutter and overlap, and shows additional information about the PoI cluster using icons, colours and by varying size and orientation.

Lastly, SpaceKey has a quite extensive interface, using several windows, popups, graphics and statistics for interaction and visualisation, while this research concentrates on three self-explanatory components: a search bar, a query location button and the map itself.

[1] http://attrakdiff.de/

7 Conclusion and Outlook

Inspired by the scientific progress in algorithms for collective querying, but an obvious lack of aesthetic visual efforts thereof, this thesis aimed at proposing a visualisation concept for collective spatial keyword queries and to test its usability and usefulness. This chapter reports on the main findings in doing so and gives an outlook towards future research that needs to be conducted in this field of work.

7.1 Conclusion

To achieve the research objectives of creating a visual concept that enables the querying and visualisation of collective spatial keyword queries, as well as to evaluate its usability, all research questions were investigated and elaborated upon.

Based on the current state of the art a methodology was developed that enables the querying and visualising of collective spatial keyword queries in a map-based application context. This methodology was applied into a prototype, which in turn was evaluated in a comparative user study.

The qualitative and quantitative results of the user study indicate that usefulness of the concept is given at least for certain scenarios. While the rather small number of successful participants makes it hard to assume generality of the results, it can be concluded that for the given task and the relevant user group the usability of the prototype is significantly higher for certain attributes of usability than of the commercial alternative. However, the number of errors encountered and the comments made by the participants in the questionnaire suggest that the features of the proposed approach are not easily understood by everyone, so there is still room for further research in this direction.

Concluding, this thesis proposes concepts for querying and visualising collective spatial keyword queries, offering first insights into this scientific area and providing a starting point to further research on this topic. This is expected to have a positive impact towards search efficiency in the long term.

7.2 Outlook

While the user test produced predominantly positive results, it might be useful to conduct a follow-up user test. Since usability testing should usually be conducted in iterative cycles, this research needs to be refined and continued in a future study.

The conducted user test gives ideas on how to improve the proposed methodology further, as listed in Chapter 6.4. The most needed refinement is probably the integration of a location search into the search bar to provide the possibility of specifying the query location through the search bar. It may be possible to add a keyword (e. g. “NEAR”) to the search, that, when encountered, separates the following term and treats it as a denominator for a location. This location is then sent to a geocoding service such as GeoNames[1] that translates the name into coordinates.

Further research might go into the necessity to employ visual variables for the combined markers. The results for orientation and size from the user study were not as clear as expected. This might need more investigation in a future continuation of this work. Also the selection of icons has not undergone a more detailed scientific process. A selection that considers cultural differences between users is here be advisable.

Also, the high error rates for the task might be subject to future studies. It might be interesting to see whether the same task with a different wording and the introduction of some help texts would produce the same amount of erroneous submissions or not.

[1] https://www.geonames.org/

A Appendix

A.1 PoI Categories and Icons Used in CoSKQVis

Name	Items in Dataset	Icon
Amusement Arcade	14	
Animal Shelter	76	
Arts Centre	296	
ATM	1748	
Bakery	6393	
Bank	5206	
Bar	1221	
Beverages Store	1918	
Bicycle Parking	8779	
Bicycle Rental	402	
Biergarten	1956	
Bookmaker	61	
Bowling Alley	41	
Brewery	7	
Bus Station	272	
Butcher	3005	

Continued on next page

Name	Items in Dataset	Icon
Cafe	4998	
Canteen	47	
Car Dealership	2888	
Car Rental	298	
Car Repair	3198	
Car Sharing	396	
Car Wash	1274	
Casino	126	
Chapel	7	
Charging Station	2218	
Childcare	401	
Cinema	259	
Clinic	174	
Clothing Store	5162	
Club	17	
Community Centre	1381	
Convenience Store	1490	
Courthouse	180	
Coworking Space	14	
Dancing School	13	
Dentist	1843	
DIY Store	923	

Continued on next page

Name	Items in Dataset	Icon
Doctor	4303	
Dog Park	114	
Driving School	888	
Fast Food	4125	
Fire Station	5322	
Fishing	105	
Fitness Centre	535	
Fitness Station	460	
Florist	1441	
Food Court	27	
Furniture Store	955	
Gallery	12	
Garden	4500	
Garden Centre	534	
Golf Course	217	
Graveyard	1770	
Gym	9	
Hackerspace	28	
Hairdresser	4665	
Hookah Lounge	17	
Horse Riding	428	
Hospital	521	

Continued on next page

Name	Items in Dataset	Icon
Hotel	2854	
Ice Cream Parlour	554	
Ice Rink	59	
Kindergarten	5545	
Language School	12	
Letter Box	7	
Library	931	
Marina	220	
Marketplace	228	
Massage	233	
Miniature Golf	303	
Monastery	112	
Museum	805	
Music Venue	6	
Nature Reserve	643	
Nightclub	363	
Park	5396	
Parking	74424	
Petrol Station	3188	
Pharmacy	3034	
Picnic Table	2596	
Place of Worship	17327	

Continued on next page

Name	Items in Dataset	Icon
Planetarium	5	
Playground	15685	
Police	417	
Pool	11	
Post Box	11474	
Post Office	1754	
Prison	54	
Pub	2677	
Public Bath	28	
Public Telephone	3516	
Recreation Ground	169	
Recycling	11523	
Restaurant	20015	
Sauna	161	
School	5996	
Social Facility	1986	
Solarium	23	
Sports Centre	5139	
Sports Hall	26	
Stadium	348	
Supermarket	5814	
Swimming Area	97	

Continued on next page

Name	Items in Dataset	Icon
Swimming Pool	5844	
Theatre	424	
Toilet	4103	
Townhall	1718	
University	378	
Veterinary	669	
Waste Basket	13004	
Waste Disposal	337	
Water Fountain	1354	
Water Park	653	
Wildlife Hide	28	
Zoo	144	

Table A.1: PoI categories and icons used in CoSKQVis

A.2 Questionnaire

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A.2.1 Section 1 – Introduction and Consent

Cartography M.Sc.

Hi!

Welcome to this questionnaire about **Visualisation and Usability of Collective Spatial Keyword Queries**.

This user test and the following evaluation are part of my M.Sc. Cartography thesis, that aims to answer questions regarding the usability of collective spatial keyword queries, that is, the simultaneous search for multiple spatial objects that lie close to each other.

The purpose of this research study is to find insights regarding learnability, usability, ease of use, satisfaction and efficiency of this technique. If you agree to take part in this user test, you will be asked to complete an online survey with a task that involves you to search for points of interest on either Google Maps or another application. The survey will ask about your experience and it will take you approximately 20 minutes to complete.

- Your participation in this study is completely **voluntary** and you can withdraw at any time. You are free to skip any question that you choose.
- All information you submit is **anonymous**. The publication of results will be in aggregated form so that a recognition of identities is not possible.
- All **data** is stored in a database solely for the purpose of this thesis. Raw data will not be passed on to third parties.

If you have questions about this project or if you have a research-related problem, you may contact the researcher, Jonas Beinder.

By clicking "I agree" below you are indicating that you are at least 18 years old, have read and understood this consent form and agree to participate in this research study.

☐ No, I do not agree (do not participate in this study)
☐ Yes, I agree

A.2.2 Section 2 – Web Map Usage

Web mapping is the process of serving and using maps delivered via the World Wide Web. A *web mapping platform* or *web mapping application* is a service where users can retrieve data like points of interest (PoIs), navigation routes or similar information in a dynamic map interface.

1. How often do you use web mapping applications to search for points of interest (PoIs)?
Examples for points of interest are: hotels, campsites, restaurants, fuel stations, schools, supermarkets, churches etc.

☐	☐	☐	☐	☐
Very often	Often	Sometimes	Seldom	Not at all

Only shown when the user selects "Very Often", "Often" or "Sometimes":
2. Which mapping applications do you use to search for points of interest?

3. How often do you use web mapping applications for navigation?

☐	☐	☐	☐	☐
Very often	Often	Sometimes	Seldom	Not at all

4. How often do you use navigation systems that are not on the web (e. g. car-bound navigation)?

☐	☐	☐	☐	☐
Very often	Often	Sometimes	Seldom	Not at all

5. Have you ever felt the need to search for more than one PoI (e. g. a hotel and a restaurant) at the same time, with them being as close together as possible?

☐ Yes
☐ No

Only shown when the user picks "Yes":
6. Did you have the feeling it was easy to find appropriate places?

☐ Yes
☐ No

A.2.3 Section 3 – Task

Please read the following task slowly and thoroughly. You are supposed to solve the following task with the provided web mapping software. Afterwards please come back to this questionnaire and answer the following questions.

> Imagine you want to go to *Nuremberg* (German: *Nürnberg*, a city in northern Bavaria) with your nephew. To sleep, you need a **hotel**. For cash, you want a **bank** nearby. And for your activities, it would be good to know the closest **playground**, **cinema** and **zoo**.
>
> **Task: find exactly this set of the five points of interest (PoIs) that appear suitable for your trip (a hotel, a bank, a playground, a cinema and a zoo). Each of the five categories should be represented once in your result. Please write down the names of the five found PoIs before returning to this questionnaire.**

Make sure to choose PoIs only by their location, not because of other criteria like ratings or imagery. Don't choose PoIs that are neither of the mentioned categories.

Now, please go to https://curiousmap.com/cosqvis / https://google.com/maps[1] (the link will open in a new tab).

Take some time to familiarize yourself with the software before starting your task.

When you are done, please answer the following question and click "Next".

[1] Only one of these links was shown to the user, depending on their group

7. Do you currently live or have you ever lived in the city of Nuremberg?

☐ Yes
☐ No

A.2.4 Section 4 – Attribute Questions, CoSKQVis Specific Questions

8. Please write down the five names of the PoIs that you found. The order of the PoIs is not relevant.

Make sure to use the names as displayed, e. g. "Bank 12345" or "Intercity Hotel".

9. Is there something that did not work as expected or at all?

10. How easy was the process to find a set of PoIs?

☐	☐	☐	☐	☐
Very easy		Neutral		Not at all easy

11. How efficient was the process to find a set of PoIs?

☐	☐	☐	☐	☐
Very efficient		Neutral		Not at all efficient

12. How easy to learn was the process to find a set of PoIs?

☐	☐	☐	☐	☐
Very easy		Neutral		Not at all easy

13. How helpful was the search in solving the task?

☐	☐	☐	☐	☐
Very helpful		Neutral		Not at all helpful

14. How intuitive was the process to find a set of PoIs?

☐	☐	☐	☐	☐
Very intuitive		Neutral		Not at all intuitive

15. Did you enjoy working with the web mapping platform?

☐	☐	☐	☐	☐
Very much		Neutral		Not at all

16. How user friendly was the process to find a set of PoIs?

☐	☐	☐	☐	☐
Very user friendly		Neutral		Not at all user friendly

17. Would you rate the retrieved PoIs as satisfactory?

☐	☐	☐	☐	☐
Very satisfactory		Neutral		Not at all satisfactory

18. How confident are you that you found the selection of PoIs that has the smallest distances between each other?

☐	☐	☐	☐	☐
Very confident		Neutral		Not at all confident

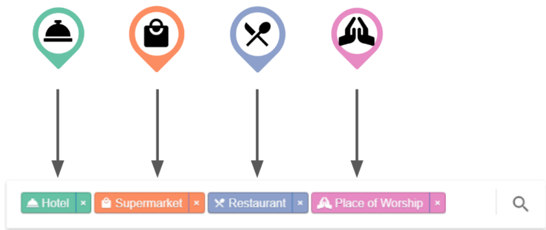
19. How quickly did you find the items you were looking for in the search box?

☐	☐	☐	☐	☐
Very quickly		Neutral		Not at all quickly

20. Are the marker symbols an attractive solution?

☐	☐	☐	☐	☐
Very attractive		Neutral		Not at all attractive

21. The colors of the marker symbols correspond with the colors in the search bar. How intuitive do you think this is?



☐	☐	☐	☐	☐
Very intuitive		Neutral		Not at all intuitive

22. The orientation of the smaller marker symbols correspond with their approximate orientation in the map space. How intuitive do you think this is?

☐	☐	☐	☐	☐
Very intuitive		Neutral		Not at all intuitive

23. The size of the combined marker symbols correspond with how appropriate the algorithm thinks the result is. How intuitive do you think this is?

☐	☐	☐	☐	☐
Very intuitive		Neutral		Not at all intuitive

24. Do you think that this kind of search may be useful for certain tasks?

☐ Yes
☐ No

25. (Optional) What certain tasks do you think of?

A.2.5 Section 5 – Demography

26. What is your gender?

☐ female
☐ male
☐ other

27. How old are you?

☐ younger than 15 years old
☐ 15 to 19 years old
☐ 20 to 24 years old
☐ 25 to 29 years old
☐ 30 to 34 years old
☐ 35 to 39 years old
☐ 40 to 44 years old
☐ 45 to 49 years old

☐ 50 to 54 years old
☐ 55 to 59 years old
☐ 60 to 64 years old
☐ 65 years or older

28. What is the highest level of education you have completed?

☐ none
☐ Finished school
☐ A-levels or other higher education entrance qualification
☐ University degree
☐ PhD or higher
☐ other

29. (Optional) Do you have any remarks regarding the task or questionnaire?

A.3 Questionnaire Answers

	Very Often	Often	Sometimes	Seldom	Not at all
Q1	28	26	4	3	0
Q3	32	26	3	0	0
Q4	4	5	10	20	22

Table A.2: Answers to Questions Q1, Q3 and Q4

Name	Times mentioned
Google Maps	59
OpenStreetMap	9
Google Earth	2
Bing	2
Maps.me	1
OpenTopoMap	1
ÖPNVKarte	1
2GIS	1

Continued on next page

Name	Times mentioned
Yandex Maps	1
Esri Online	1
Official Maps provided by agencies	1
Baidu Maps	1
Wolt	1
Donkey Republic	1
Apple Maps (iPhone)	1
Here Maps	1
BAGviewer	1
Openportal	1
City Maps 2 Go	1
Locus Android	1

Table A.3: All mentions of web mapping products in Question Q2

	Yes	No
Q5	52	9
Q6	19	32
Q7	0	61

Table A.4: Answers to Questions Q5, Q6 and Q7

Mention		
261535 Playground	Admiral Filmpalast	Admiral Filmpalast
Admiral Filmpalast	Admiral Filmpalast	admiral filmpalast
Admiral Filmpalast (Cinema)	Admiral Filmpalast (Cinema)	Admiral Filmpalast (Cinema)
Admiral Filmpalast Cinema	Albrecht-Dürer-Haus	Ammerland Hotel
Animal Shelter	art&business hotel	ATM
Bank	Bank	Bank - Sparkasse Fürth
Bank Sparkasse Nürnberg	Bank Sparkasse Nurnberg Geschaft Salzbacher Strasse	Bar
Behringers City Hotel	Behringers City Hotel	Ber-Li
Beverages Store	biergarten	Bundesbank
But there was no result in Niremberg	Cinema - Cineplex Fürth	Cinema Cinema

Continued on next page

Mention

Cinema Metropolis	Commerzbank Ingolstadt	Commerzbankl Filiale Allersberger Straße
das PAUL	Deutsche Bank	Deutscher Apotheker- und Aerztebank
Filmhaus kinoeins	Freiluftkino	Gätrenkeabholmarkt Heinz
Hauptbahnhof	Hotel - Excelsior Hotel Nürnberg Fürth	Hotel am Heidelloffplatz
Hotel NH	HVB Bank	Hypo Vereinsbank
HypoVereinsbanck	Hypovereinsbank	HypoVereinsbank
Hypovereinsbank	Hypovereinsbank	HypoVereinsbank (Bank)
HypoVereinsbank (Bank)	HypoVereinzbank	I couldn't finish the task
I couldn't finish the task	Ibis Hotel Nuremberg Hauptbahnhof	Intercity Hotel
jaegerheim hotel	Jägerheim Hotel	Jägerheim Hotel
Jägerheim Hotel	Jugendherberg	Kleinzoo Wasserstein e.V Zoo
Kleinzoo Wasserstern	kommkino im Künstlerhaus	Konditorei Bauer
Landgasthof Wagner	Marilena (Hotel)	Marilena hotel
Metropolis (Cinema)	Metropolis (Cinema)	Metropolis (Cinema)
metropolis bank	Metropolis cinema	Metropolis Cinema
Metropolis cinema	MO Hotel	museum
museum	No Shoes	No Shoes
No Shoes (Hotel)	No Shoes (Hotel)	No Shoes (Hotel)
No Shoes (Hotel)	No shoes Hotel	No Shoes Hotel
No Shoes hotel	Novina Hotel Wohrdersee	NürnbergMesse
Other cities only	park	Parking 96729
Playgorund 261544	Playground - Spielplatz mit Reifendrehwippe	Playground 241501
Playground 261535	Playground 261535	Playground 261535
Playground 261535	Playground 261535	Playground 261535
Playground 261535	Playground 261535	Playground 261535

Continued on next page

Mention		
Playground 261544	Playground 261544	playground 261609
Playground 261611	Playground 261611	Playground 261673
Playground 261682	playground 261682	Playground 261682
Playground 275073	Playground 275103	Playground 275510
restaurant	restaurant	Ritterplatz
Sparkasse	sparkasse nuremberg	Sparkasse Nürnberg
Sparkasse Nürnberg (ATM)	Sparkasse Nürnberg Geschäftsstelle Sulzbacher str . bank	Sparkasse Nurnberg Geschaftsstelle Sulzbacher Strasse (Bank)
stadium	Straussenfarm	The first try was in curiosity map
Tierfarten Nuernburg	tiergarten nuremberg	Tiergarten Nurnberg
Tiergarten Nurnberg	Tiergarten Nürnberg	Tiergarten Nürnberg
Tiergarten Nürnberg	Tiergarten Nürnberg	Tiergarten nürnberg
Tiergarten Nürnberg	Tiergarten Nürnberg	tiergarten nürnberg
Tiergarten Nürnberg	Tiergarten Nurnberg (zoo)	Tiergarten Nurnberg (Zoo)
Tiergarten Nürnberg (Zoo)	Tiergarten Nürnberg (Zoo)	Tiergarten Nurnberg Zoo
Tirgarten Nürnberg	toilet	Union Cinema
Volksbank Reiffeisenbank	VR- Bank Nürnberg	zoo
Zoo - Wildschweingehege	Zoo Tiergarten Nürnberg	Zur Linde (Hotel)

Table A.5: All PoIs given in Question Q8 (CoSKQVis group)

Mention		
(Tiergarten Nürnberg)	A&O hotel	Airtime Trampoline Park
Albrecht Dürer's House	AZIMUT Hotel Nuremberg	B&B Hotel Nuremberg Hauptbahnhof
Bank Volksbank Raiffeisenbank Nürnberg eG Filiale Königstraße	Bank: Bethmann Bank AG Bank Karl-Grillenberger-Straße 3, 90402 Nürnberg	Bank: HypoVereinsbank Nürnberg Mögeldorf
Behringers City Hotel Nürnberg	Boutique Hotel Hauser	Bruderherz - Brauwerkstatt Restaurant Stadthotel

Continued on next page

	Mention	
BURGHOTEL STAMMHAUS	Café Franz Köln	Casablanca Filmkunsttheater
Cinecittà Nürnberg	Cinecittà Nürnberg	Cinema Admiral-Filmpalast Nürnberg
Cinema: Buddy's Filmgear Rental and Studio Lübener Str. 26, 90471 Nürnberg	Cinema: Open Air Kino Naturgarten Bad	Cinemagnum 3D
Cineplex Nürnberg	Cineplex Nürnberg	City Center Apartments
Commerzbank Spitalgasse 5	DB Museum	deutsche bank
Deutsche Bank Filiale	Deutsche Bank Filiale	Deutsche Bank Filiale, Karolinenstraße 30, 90402 Nürnberg, Germany
deutsche post	Duck and Curry	Dürer - Hotel Nürnberg
Essotankstelle Aachen	Euronet - Geldautomat - ATM, Le Méridien, Bahnhofstraße 1-3, 90402 Nürnberg	Filmfabrik - Kino im Komm e.V.
Filmfabrik - Kino im Komm e.V.	Fit Star	Five Reasons
Fleischbrücke	Fußballkäfige Insel Schütt	Geldautomat (Deutsche Bank)
Getränkemarkt	Goldenes Posthorn	Hallerwiese
Hotel - ibis Nurenberg Hauptbahnhof	Hotel FIVE	Hotel Motel One Nuremberg-Plärrer
Hotel no shoes hotel	green bar	hotel restaurant jägerheim
Hotel Restaurant Jägerheim	Hotel Restaurant Jägerheim	hotel victoria
Hotel: Hotel Langwasser Thomas-Mann-Straße 71, 90471 Nürnberg 49.415174, 11.138279	Hotel: Zur Friedenslinde	hypovereinsbank
HypoVereinsbank Nürnberg Zabo	ibis budget Hotel Neurnberg City Messe	Imperial Castle of Nuremberg
Imperial Castle of Nuremberg	IntercityHotel Nuremberg	Italian Restaurant
Kino Pippi	Kongreshalle	Le Méridien Grand Hotel Nuremberg

Continued on next page

Mention		
LIGA Bank eG, Filiale	Maritim Hotel Nuernberg	Mata Hari Bar
Maxbrucke, Karlsbucke	Metroplois Filmtheater	Metropolis Filmtheater
Metropolis Filmtheater	Metropolis Filmtheater	Metropolis Filmtheater
Mobiles Auto Kino	Nenis Köln	Nikon Store
NOVINA HOTEL Wöhrdersee Nürnberg City	Nuremberg Zoo	Nuremberg Zoo
Nuremberg Zoo	Nuremburg Zoo	Nürnberg Central Station
Nürnberg zoo	Nürnberg Zoo	Nürnberger Buch- und Kunstantiquariat
Parhaus	Petron Ampitheater	Playground Aufseßplatz
Playground Fußballkäfige Insel Schütt	Playground Island Schütt	playground: Spielplatz Astrid-Lindgren-Schule
Playground: Spielplatz Mögeldorfer Park	Postbank Filiale	PSD Bank Nürnberg
PSD Bank Nürnberg eG, Hauptstelle	Ramada by Wyndham Nuernberg Parkhotel	Ramada by Wyndham Nuernberg Parkhotel
Ringhotel Loew's Merkur	Sparda Bank branch Nuremberg Sonnerstrabe	Sparda Bank Filiale Nürnberg Mögeldorf
Sparda-Bank SB-Center Nürnberg Hauptbahnhof	Sparkasse Nürnberg - ATM	Sparkasse Nürnberg - Geschäftsstelle (Schmausenbuckstraße 4, 90482 Nürnberg)
Sparkassen Automat	Speilplatz (Kontumazgarten)	Spielplatz "Cramer-Klett-Park"
Spielplatz (Apinusstraße 7, 90482 Nürnberg)	Spielplatz an der Siegfriedstraße	Spielplatz Erfahrungsfeld
Spielplatz Hadermühle	Spielplatz Hadermühle	Spielplatz Kirschbaumweg
Spielplatz Mögeldorfer Park	Spielplatz Rechenberg	Spielplatz Rosenaupark
Spielplatz Valznerweiher	Stadtpark	Sudfriedhof
Tiergarten Nuernberg	Tiergarten Nürnberg	Tiergarten Nürnberg
Tiergarten Nürnberg	Tiergarten Nürnberg	Tiergarten Nürnberg
Tiergatren Nürnberg	Turmdersinne	Volksbank

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Mention

Volksbank Raiffeisenbank Nürnberg eG Geldautomat Äußere Sulzbacher Straße	Volksbank Raiffeisenbank Nürnberg eG Kompetenzzentrum Tullnaupark	Volkspark Dutzendteich
Woehrder See	Wuestenhaus (Tiergarten Nuremburg)	Wüstenhaus
Wüstenhaus,Tiergarten Nürnberg	Zoo Nuremberg Zoo	zoo: Nuremberg Zoo Tiergarten Nürnberg, Am Tiergarten 30, 90480 Nürnberg
Zoo: Tiergarten Nürnberg	Zoológico de Núremberg	Zur Friedenslinde
Zur Friedenslinde	Zur Friedenslinde	

Table A.6: All PoIs given in Question Q8 (Google Maps group)

Mention
(1) The route from hotel to playground is longer than it should be. By walking, there is much shorter way available. (2) Sometimes the set was suggested unexpectedly far from the location where I've put the yellow marker. (3) To few sets were shown close to my marker. After I've chosen a set, I saw there were also other good sets available if I just moved the marker for a street or a block. I would prefer to get all the options in a neighbourhood, not just one or two.
After playing a bit with location marker I saw 2 sets of solutions. It was definitely unexpected.
At first I typed "ATM" instead of "BANK" and I did not get the same results. I was also confused because the areas with the 5 PoIs that I found were not in Nuremberg... so I just chose the area closer to the city. I was also confused because the names of the main cities were not shown.
Considering the task (writing down the name of POIs), I thought the names will be displayed nearby the found POIs by default.
I could not find something specific (i.e. italian restaurant, dinosaur museum (was under parks)); I did not receive proportionally different sized icons.
I had to re start survey because it was dissapeared after opening a web application. Besids it was not loading with the first to attempt POIs in the area of Nürnberg
I searched for the five things together and it only gave me one option of each. I thought it would give me more choices and I could choose from among them.
I tried to searched for Nuremberg in the searchbox, because Nuremberg did not show as a label on the map for my initial zoom level. That did not work.
I was shown 3 clusters of POI's however only one cluster had all the 5 POI's in the vicinity

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Mention
It is not clear to me how the ordering of the POIs in the query affects the result (which it does apparently). The colors change with the order as well which I find distracting - I would want the colors to stay with the type of POI once they are entered to the query.
no [mentioned several times]
No, from my observation (except the query cannot process more than 3 items at a time. When I would like to search for cinema other than hotel, bank and playground at the same time, I couldn't fill it in anymore).
Not able to search for the facilities i selected so it was like starting over again. The yellow marker to select the area to search is anoying if you know the name of what you are looking for but are not spatially aware about places on the map so. If the point is to find the same places as i found on google or even just one of them then the whole process is anoying for someone not familiar with the area. Even when i did find my base Facility(the hotel i wanted to stay. It would change facilities as i added more variables/ facilities that i wanted to go to. This may not be feasible in real life .
On mobile, the "slippiness" of the maps is very difficult to work with.
Sometimes it wasn't possible to write the PoI type (e.g., cinema) in the search bar; it had to be selected from the dropdown list.
The invisible limit of distance based on where the query location feels kind of strange, when I was not really sure where I wanted to center my search.
The results are dependent on the location of the yellow pinpoint. But what if you don't have an exact preferred location and you would rather base your selection on the proximity of the results. Perhaps multiple clustered results would than be preferable over setting a start location.
The Zoo is an outlier to the cluster of PoI's
When hovering over the paths, I would like to know the total* distance of commuting from the hotel to each* of the other facilities, a total number for the whole cluster
When I searched the five POIs together, the resutls are fixed. There is only one place found in each category. Esperially hotel and bank, I would expect more than one result shown on the map.
Worked perfectly find and absolutely intuitive
Yes, the location search

Table A.7: All mentions of errors or unexpected behaviour for CoSKQVis in Question Q9

Mention
5 pois are too much, I could do only with two pois
everything worked perfectly
Everything works as expected
just frustrating you had to find one poi at a time and make an educated guess about where the hotel closest to all of them was located.
No [mentioned multiple times]
No possibility to search for all five pois at once (i.e. hotel near zoo near playground near bank near cinema near nürnberg)
The Zoo is an outlier to the cluster of PoI's
the zoo pois restricted the choices of the other pois (plenty of them really well distributed among the city)
Undecided
Very difficult to find all five POIs in a smaller area
Well, the playground for instance was just named "Playground" (Spielplatz). That's why I added the address as well.. selecting the PoI's just based on their proximity is somehow a little bit intriguing. Not really knowing the metro or bus line can be a little challenging. Google Maps provides a reasonably good routing service though. Ignoring ratings or images when selecting is somehow odd though, as I am used to base my decision also on imagery and ratings.
when I do my search of POIs while in Nuremberg, it sometimes goes back to and does the search in my current location
when i entered the search term (like cinema) google maps somehow always zooms out which is a bit confusing if you are not familiar with the area.
Yes only hotels showed up
zoo is hard to identify

Table A.8: All mentions of errors or unexpected behaviour for Google Maps in Question Q9

	Very		Neutral		Not at all
Q10	19	19	17	3	3
CoSKQVis	14	14	2	0	2
Google Maps	5	5	15	3	1
Q11	12	26	9	6	8
CoSKQVis	11	17	3	0	1
Google Maps	1	9	6	6	7

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	Very		Neutral		Not at all
Q12	25	15	14	6	1
CoSKQVis	19	8	3	1	1
Google Maps	6	7	11	5	0
Q13	28	16	11	3	3
CoSKQVis	19	7	4	1	1
Google Maps	9	9	7	2	2
Q14	15	25	15	2	4
CoSKQVis	9	16	7	0	0
Google Maps	6	9	8	2	4
Q15	13	29	13	4	2
CoSKQVis	6	18	7	1	0
Google Maps	7	11	6	3	2
Q16	12	25	12	7	5
CoSKQVis	9	14	6	2	1
Google Maps	3	11	6	5	4
Q17	11	24	18	7	1
CoSKQVis	7	15	7	2	1
Google Maps	4	9	11	5	0
Q18	5	17	14	12	13
CoSKQVis	4	14	8	3	3
Google Maps	1	3	6	9	10
Q19 (CoSKQVis only)	20	7	3	0	1
Q20 (CoSKQVis only)	17	11	2	1	0
Q21 (CoSKQVis only)	14	7	6	4	0
Q22 (CoSKQVis only)	8	8	7	6	2
Q23 (CoSKQVis only)	4	10	6	6	5

Table A.9: Answers to Questions Q10 to Q23

	Yes	No
Q24	30	1

Table A.10: Answers to Question Q24

Mention
Accommodation Hunting
analytical comments over the distribution of PoIs
Cinema + restaurant
Designing Routes
emergency
Errands
Even for daily chores, this kind of an application would make a lot of sense
Find a place to buy food (supermarket) while on a trip to a given (recreational?) location.
Finding a neighbourhood to live in
Finding a park in connection with a place to eat.
Finding a playground in connection with a place to eat.
Finding a playground in connection with a sightseeing.
finding PoIs
Finding the best bicycle route that includes certain POI
finding the most optimally located bars, restaurants etc.(like in the task)
Finding the next ATM on my way to go somewhere when I need to pay something in cash
food delivery
For planning trips, this would be a pretty cool feature
for sb who wants to go shopping. He can plan to visit different stores with the most efficient route
Help in finding things to do around a criteria specific location that the map does no account for. ie. From my hotel which i have chosen because of the following 10 reasons - where can i find xyz.
Holidays
If the algorithm can include personal preferences and limitations of facility rating, cost etc to be modeled to provide comparable alternative options that offer shorter travel times then its value increased. loss of the personal element / configurability limits its use to just things that have a much looser limit on them
It can be used for delivery agencies, I guess
Itinerary Planning
Looking for a place to stay for holidays with a group with different interests

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Mention
Looking for a restaurant nearby
Looking for non criteria specific activities. ie cinema, zoo , bank, church, museum etc.
Looking for stores/ATMs that are still open at certain times (e.g., at midnight)
Looking for the closest public transport stops
Managing different tasks during a restricted amount of time in a foreign city
Multiple destination queries
multiple-destination daily trip
Navigation
organizing a conference
organizing a trip
Orienteering
parcel delivery
Planning a family trip to a restaurant and the trip must include a playground.
Planning a travel/trip
Planning vacations/day trips
Primarily any activity you want to do + restaurant
Running errands to different types of stores.
Selecting a proper place in a new city for reserving a Hotel
Someone wants to find an answer quickly and automatically without doing much research on their own
The option of searching for combinations of PoIs in a cluster has unlimited possibilities and now that I have used it I have realized what we were missing on
time management
Time saving tasks
to plan a task from morning to night e.g. a tourist plan to visit a city which doesn't want to waste time on the way from place to place
To sum up, similar tasks to the ones proposed in the example given.
Tour for attraction places
tour guides
Tourism in any sphere

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Mention
Tourist attraction + restaurant
Traveling to a foreign city
travelling
Travelling Spontaneously, but for this I would like to have the option to get more information on the respective hotel etc.
Trip design
When traveling to new places where you need some basic information and you don't have time or don't know the language
Where's the next bike or bike repair shop on my way to a bike trip?

Table A.11: All mentions of purposes for collective querying in Question Q25

	Female	Male	Other
Q26	29	32	0
CoSKQVis	18	14	0
Google Maps	11	18	0

Table A.12: Answers to Question Q26 (gender)

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	>60
Q27	0	6	36	8	7	2	1	0	1	0
CoSKQ	0	3	19	5	2	2	0	0	1	0
GMaps	0	3	17	3	5	0	1	0	0	0

Table A.13: Answers to Question Q27 (age group)

	none	Finished school	A-Levels	University degree	PhD or higher	Other
Q28	0	0	0	54	6	1
CoSKQVis	0	0	0	29	2	1
Google Maps	0	0	0	25	4	0

Table A.14: Answers to Question Q28 (education)

Mention
(1) I wasn't sure if I need to choose a set by location in the sense that the PoIs are the closest possible to each other or that I actually also like their location in the city. E.g., if I travel to another city, I wouldn't want to stay in the suburbs just because PoIs are super close to each other. I have used both of these criteria in my decision. I also decided based on seeing that the playground is much easier to reach than using the proposed route. (2) Related to question 21: The colors used for PoIs markers and in the search bar are a good idea but was distracting while I was using the search bar. Later, I didn't look at the search bar again, so I didn't even realize the colors are the same as in the markers. Maybe the color could be used in a much lesser amount in the search bar (like on the markers, where it makes just a subtle differentiation). The symbols used in the search bar are useful. The color could be used only with the symbols, and not as the fill of the whole text box. (3) Related to question 22: I didn't understand what was asked because I didn't experience that on the map. Maybe I've missed to notice it, or it didn't work as planned. If I zoomed out, all symbols got grouped together in a different location (which I understand because the zoo was far away and was "pulling" the others), but their order was wrong. E.g., the cinema is the most west, but there was shown in the north-east location in a set. (4) Related to question 23: I didn't notice different sizes of symbols. It looked to me like each set has the same size. I only noticed it after having a second look after reading the question. It was a good idea, but maybe too subtle. The differences could be larger to notice them more easily, even though, I am not sure if I would also then relate them to the more or less good results.
1. The results show only on the map with marks. As a user, I would also expect more information (rating, house number and etc.) about the searched place by clicking. 2. The results are too less. If I search for hotels in the city center in Nuremberg, only three results are shown on the map. 3. Maybe two search bars would be a good idea. One can be used for searching the POIs, the other one can be used to locate the user' interested region.
I find it very simple in terms of visualization which is very good. In such requests, we want to have good and fast answer, and not concentrate on many more options which are usually offered in other services.
I really like the application and I think it is something very useful and helpful. There is definitely a need having such an application and I would use it.
I was missing the ability to copy-paste the label/name of the PoI to the questionnaire. Same functionality could be good for someone using the tool and then searching for the hotel in another tab, for instance.

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Mention
I was not sure if I was to put the location marker in a particular place to get the result, or was it supposed to be anywhere in Nurnberg city centre?
Interesting application! I wasn't sure if I was supposed to select the 5 points that automatically were shown or do more exploration and find the points that seemed to work best intuitively. I didn't understand the points about the orientation and size of the symbols because they all seem to be the same orientation and size on the map.
It is overall intuitive, convenient and easy to learn. The mechanism of PoI search within the search bar may need some improvement but it might also be a problem of my computer.
It would be great if the search would include opening hours and/or prices. I guess that is for a more advanced implementation and this looks great as a proof of concept. I would also consider adding an option to choose different modes for single day activities and multiple day activities (example): - If you're looking for a park + restaurant + cinema combo, you might be looking for a cluster of PoIs for some kind of "single day plan" (e.g. a date...) so you would probably want an algorithm connecting all those nodes in a sequence. - If you're looking for a "multiple day plan" you might be looking for a hotel (main node) + 4/5/6... PoIs that are nearby. In that case, you might be more interested in knowing how all those points are connected with the hotel, because you may visit the zoo one day, then go back to the hotel, then go to a tourist attraction the next day, then back to the hotel again... Being able to choose the order of visiting the PoIs might also be interesting. Overall, really interesting concept, keep up the good work!
Some of the questions are redundant and can be aggregated. The questions related to demographic attributes are a bit too detailed, this may scare away users who are willing to support.
Task could be clearer about what you are supposed to do when the user switches to https://curiousmap.com/cosqvis/ Should the user look for the facilities they found in the first place or just any facilities.
Could explain what to do with the yellow "search here" marker.
could have leading texts search in the search bar that disappear when a user clicks in to the search bar
The orientation of the markers is great but the relative distance to the markers can be a problem.

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Mention
Great Experiment.
The results feel satisfying. Clear and quick results with simple tags made the web service attractive to me.
This is a brilliant solution for multiple searches at the same time. However, what if I want destinations far away from each other or well spread out in the area so that I can explore the city better as a tourist? Perhaps you could include search criteria by distance or method etc. I enjoyed taking part in the survey.

Table A.15: All comments for the task and questionnaire in Question Q29 (CoSKQVis group)

Mention
Great Job, Jonas. The questionnaire was clear and easy to understand.
I didn't quite understand the "simultaneous" search mentioned at the beginning of the page. At least I was searching for the PoI's consecutively, one after the other trying to locate them as close to each other as possible, not knowing distances or travel time in Nürnberg. Searching for PoI's at the same time is somehow different for me though. Searching for points of interest "at the same time" would mean entering the five key words (5 PoI's) at once and being given a set of combinations connecting all 5 PoI's at once. Regarding filtering options I could then narrow down my search.. not sure if this is correct, but I have a different understanding of searching for something at the same time.
Interesting Work
It is a good approach to get the user thoughts on web mapping to work on usability of your app.
It was easy using two search terms e.g. hotel near bank. By adding a 3rd search term it becomes more complicated
No, nice job, really well structured questionnaire.
Regarding the questionnaire I found a bit difficult to understand the task and the definition of (PoI). Regarding the task, I searched for individual aspects and visually selected the closest to the rarer element: the zoo. I used words in english even though my google maps was in German. May the search change if I introduce "Tiergarten" instead of "Zoo"??
The real task is still coming right?

Table A.16: All comments for the task and questionnaire in Question Q29 (Google Maps group)

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