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Master's Thesis in Informatics

Connected Mobility Ecosystem Explorer – Concept and Agile Development

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Connected Mobility Ecosystem Explorer – Konzeption und agile Umsetzung

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I confirm that this master's thesis is my own work and I have documented all sources and material used.

Garching, 15.12.2016 Johann Arendt

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Abstract

The current trend of digitization has led members of the Connected Mobility Ecosystem to interact with each other. Nonetheless their interaction lacks support by software systems in order to support innovation. It became clear, that a major challenge for the Connected Mobility Ecosystem Explorer would be providing a model, which would be flexible enough to allow for different granularity of detail and enticing members of the ecosystem to participate and volunteer information. Choosing a system, which has already taken care of such menial tasks appears to be a good choice, as development efforts can go to the unique aspects of the solution. Data was gathered, evolvable models created and a system populated. Two different visualization types were created and served in a web application. An evaluation was conducted to validate the feasibility of the project.

Contents

1. Introduction

The car manufacturers are under pressure to produce innovative ideas, if they do not want to be left behind by modern concepts. These consist of autonomous driving, electric powertrains, disruptive startups, and a general shift towards treating mobility as a service [Ism14]. German car manufacturers in particular have yet to embrace the trend of digitization [Bro16]. Innovation networks require software that allows members to share and exchange information [RRS14]. Strategic benefits that an innovation network brings to an individual organization include reaching and opening new markets and the prospect of forming long-term partnerships that outlast several "New Product Development" (NPD) projects and pave the way for future innovations [RGJ16]. This research attempts to identify the lack of such software within the Connected Mobility Ecosystem, and proposes the Explorer as a solution.

1.1. Motivation

The primary factors motivating the Connected Mobility Ecosystem Explorer (CMEE) are driving innovation and increasing the potential of the members of the Connected Mobility Ecosystem. The ecosystem contains many different actors: large, multinational corporations, local companies, universities, small and medium-sized enterprises (SMEs) as well as start-ups and individuals. The idea is to set up communication between these members, enabling exchange of information, data and knowledge, to aid their goals. A fundamental part of the concept is to allow members to focus on what they do best, as well as their interests, and find partners to aid them with other tasks [Bro16]. Kodama found in 1999 that "SMEs often miss out on the opportunity to leverage "partners of partners" to enlarge their reach" [Kod99; RGJ16]. How to enable organizations to engage with partners of partners remains a relevant and unsolved question. One possible answer lies in the usage of innovation networks, which "are vital in advancing new product and service development" [RGJ16]. If the CMEE is capable of documenting what is already happening in a reusable fashion, which can evolve, then it has the potential to be a success.

1.2. Thematic Platform Connected Mobility

The Center Digitization.Bavaria (ZD.B)[1] has established several thematic platforms. These attempt to link research of fundamental and applied nature [ZDB16]. Each of

[1] `http://zentrum-digitalisierung.bayern/` [Online; accessed: 11-December-2016]

the six existing platforms attempt four core tasks. They seek themes of digitization, illustrate references and guidelines, provide opportunities for networking and bundling of interests as well as communicate results. These platforms aim to act as an overview in their particular field. An attempt is also made to coordinate different platforms by instating a "platform coordination manager". The responsibilities include sharing and coordinating events, connections, and results between platforms [ZDB16].

The Thematic Platform Connected Mobility is one of these six platforms founded by the ZD.B [BMW16]. The platform, coordinated by Dr. Mara Cole, currently supports two lighthouse projects: The "Connected Mobility Lab" (CML) and the "TUM Living Lab Connected Mobility" (TUM LLCM)[2] with funds from the "Bavarian Ministry of Economic Affairs and Media, Energy and Technology" (StMWi)[3]. The scientific speaker is Prof. Dr.-Ing. Reinhard German from the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)[4]. The economic speaker is Dr. Christoph Grote from the Bayerische Motoren Werke (BMW)[5] [ZDB16].

The platform enables new systems to be developed as the result of research and projects, which can take advantage of multiple sources of data. By combining information about traffic, maps, and public transportation, new services can be offered. An example would be to provide mobile applications, capable of providing "seamless intermodal route information" to its users [BMW16]. It would allow a user to select a destination, and receive updated routing information. These could take advantage of multiple mobility services and adapt to current weather and traffic situations. Depending on the connected services, it could even provide indoor mapping information [BMW16]. Such solutions are critically tested as part of the thematic platform.

1.2.1. Connected Mobility Lab

The aim of the CML is to research next generation mobility solutions. The initiative was pioneered by BMW and Siemens[6], together with the Technical University of Munich (TUM)[7] [BMW16]. The CML is tasked to create a pooled portal for data resources, to provide third party developers easy access to data spanning traffic information, vehicle information, mapping and navigation services, public transportation, car and bike sharing as well as parking information, in order to facilitate new innovative projects and opportunities [BMW16]. At the same time the shared platform is designated to provide security, accounting, performance management, identity management, and data management, to further aid development [BMW16]. Having a shared mechanism for requesting, retrieving and managing data is meant to streamline the process of requesting and granting access to non-public information via services.

[2] `http://tum-llcm.de/` [Online; accessed: 11-December-2016]
[3] `https://www.stmwi.bayern.de/` [Online; accessed: 11-December-2016]
[4] `https://www.fau.eu/` [Online; accessed: 11-December-2016]
[5] `http://www.bmw.de/` [Online; accessed: 11-December-2016]
[6] `https://www.siemens.com/` [Online; accessed: 11-December-2016]
[7] `http://www.tum.de/` [Online; accessed: 11-December-2016]

1.2.2. TUM Living Lab Connected Mobility (TUM LLCM)

The TUM LLCM was founded to provide a practical environment in which possible next generation solutions can be tested and refined [Mat16]. TUM LLCM is funded by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology (StMWi) via the Center Digitization.Bavaria (ZD.B) [Mat16]. TUM LLCM is to be an independent research project, the results of which can be used by leading digital providers to create market ready solutions [Mat16].

Another ambitious goal of the TUM LLCM is the networking between already established and upcoming mobility providers, service providers, developers and users on a personal, organizational and technical level. The aim is to reduce the financial, organizational and technical burden, especially on smaller companies and startups, in order to facilitate innovation. This proves to be the underlying goal for this research: the attempt of providing a way to the members of the TUM LLCM ecosystem to explore each other. TUM LLCM aims to partake in the establishment of a market place for mobility and its ecosystem. The project acts in close proximity with BMW and Siemens. It works together with start-ups and software companies from the Connected Mobility environment, such as Moovel[8], Iteratec[9] and msg systems[10]. Further contact points are the cities public institutions, such as the City of Munich[11], the Munich Transport Corporation (MVG)[12], and the Deutsche Bahn (DB)[13].

The TUM LLCM project also connects students with companies. This is done in the form of courses, internships, theses and hackathons. At the 2016 HackaTUM[14], the first hackathon of the TUM Faculty of Informatics[15], students were able to work on problems posed by companies. The topics of most problem statements were either "Internet of Things" (IoT) or Connected Mobility related. The results of the HackaTUM are used by the Connected Mobility environment or used as starting points for further projects and research. This illustrates part of the interaction of the Connected Mobility Ecosystem.

1.2.3. The Ecosystem

The ecosystem of the Connected Mobility Lab consists of established organizations, startups, universities and individuals. Members range from (car) manufacturers to mapping providers. The ecosystem includes car-manufacturers (BMW, Audi[16] and

[8] `https://moovel-group.com/` [Online; accessed: 11-December-2016]
[9] `https://www.iteratec.de/` [Online; accessed: 11-December-2016]
[10] `https://www.msggroup.com/` [Online; accessed: 11-December-2016]
[11] `http://www.muenchen.de/` [Online; accessed: 11-December-2016]
[12] `https://www.mvg.de/` [Online; accessed: 11-December-2016]
[13] `https://www.bahn.de/` [Online; accessed: 11-December-2016]
[14] `https://hack.tum.de/` [Online; accessed: 11-December-2016]
[15] `http://www.in.tum.de/` [Online; accessed: 11-December-2016]
[16] `https://www.audi.de` [Online; accessed: 11-December-2016]

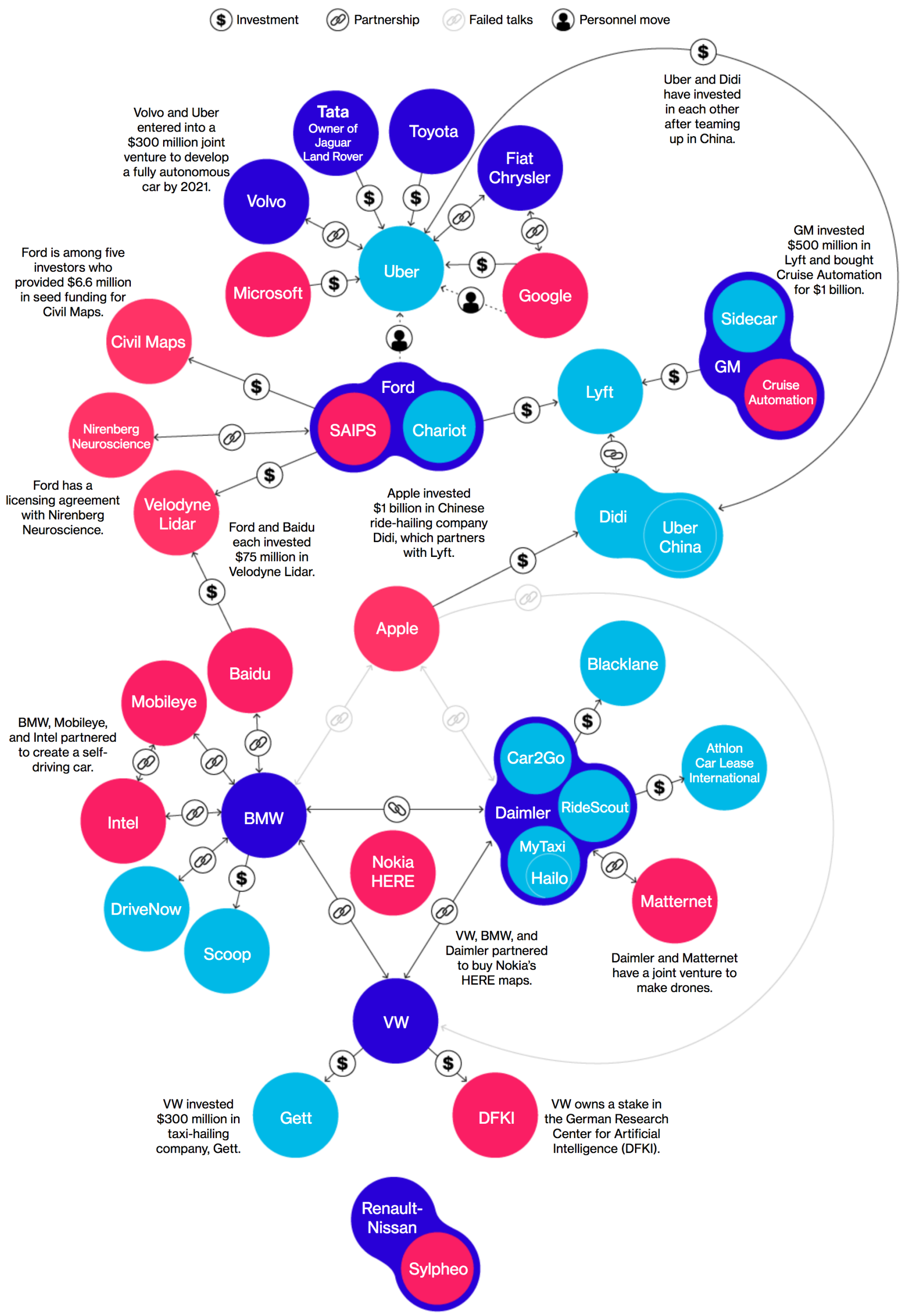


Figure 1.1.: Bloomberg: The Merging Worlds of Technology and Cars [WW16]

Daimler[17]). It also includes mobility providers (DriveNow[18] and car2go[19]), mobility software providers (Siemens, Iteratec), public institutions (TUM), public transportation (Deutsche Bahn) and mapping providers (HERE[20]). The automotive OEMs (Original Equipment Manufacturer) and first tier suppliers are investing heavily in new technology and tech startups [Nay16].

The diverse ecosystem makes it difficult to document who is working on which project with whom. Since companies, especially newcomers, rely increasingly on services provided by existing companies, it was a recurring issue to understand the constantly developing marketplace.

The research goal was to aggregate, document, visualize, and make information explorable. An interactive visualization was suggested as a means of exploration, to facilitate innovation among the Connected Mobility Ecosystem. In addition, members of the ecosystem should be able to exchange information and collaborate. The positive outlook of the Connected Mobility Ecosystem Explorer was to see, what innovative solutions could be created, when developers are given multiple data sources from different organizations. The developers would also be able to contact the organizations for help in using and utilizing the data.

Some inspiration for the design of the Connected Mobility Ecosystem Explorer came from visualizations. Typically such visualizations were created manually by data analysts in conjunction with designers. An example for such a visualization is shown in Figure 1.1. It is found in the Bloomberg[21] article *Bloomberg: The Merging Worlds of Technology and Cars* by Webb and Whiteaker [WW16]. The figure shows how car manufacturers are increasing collaboration with technology companies. Technology companies have a much easier time adjusting to the market, unlike the sluggish changes of the traditional car manufacturers [Ism14]. As such, their existence is threatened by start-ups and disruptive technologies.

1.3. Knowledge Management

It is difficult to manage knowledge contained within a company [Krc15]. The situation within an ecosystem is comparable, although there is no shared employer. "Knowledge Management is an integrated intervention approach, that deals with the design options of the organizational knowledge base" [PRR03]. With the CMEE knowledge is gathered, presented in usable chunks in useful views.

Figure 1.2 shows the knowledge process according to Probst, Raub, and Romhardt. The CMEE interacts with several parts of the process. Transparency regarding existing knowledge is the result of knowledge identification. Knowledge is also acquired, because

[17] `www.daimler.com/` [Online; accessed: 11-December-2016]
[18] `https://de.drive-now.com/` [Online; accessed: 11-December-2016]
[19] `http://car2go.com/` [Online; accessed: 11-December-2016]
[20] `https://here.com/` [Online; accessed: 11-December-2016]
[21] `http://bloomberg.com/` [Online; accessed: 11-December-2016]

not everything about the Connected Mobility Ecosystem is known. Conserving and sharing knowledge is a primary motivating factor for the CMEE.

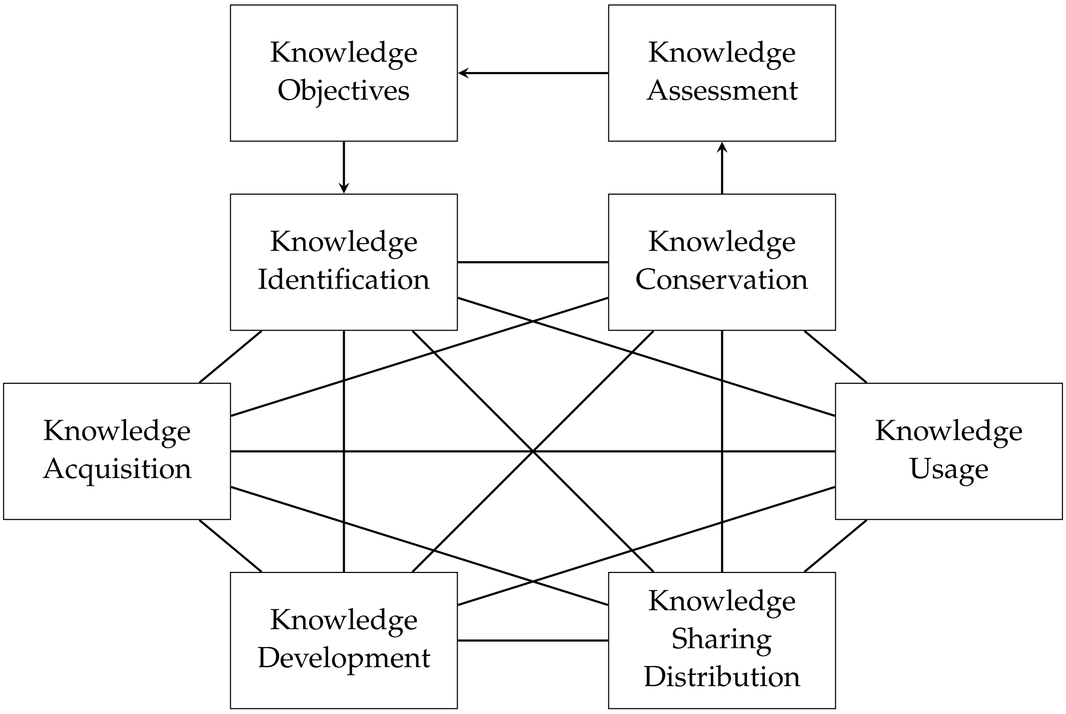


Figure 1.2.: Knowledge Work and IT [PRR03]

1.4. Exponential Organization

This section is based on *Exponential organizations: why new organizations are ten times better, faster, and cheaper than yours (and what to do about it)* by Ismail and has been supplemented with own observations [Ism14]. It is possible to observe a stark difference between types of organizations. On the one hand, many organizations have existed for years, producing a limited number of products and services and rely on incremental improvements. On the other hand, new organizations are emerging that scale incredibly well and disrupt the marketplace.

Traditional organizations have grown over the years, usually resulting in companies that have developed a strong hierarchical structure. Being driven by financial outcomes causes innovation to appear only as a means to increase the existing products. Due to the style of management, a risk intolerance can be observed, for fear of change. The thinking style is based on trying to control as much as possible. The term "Not Invented Here" (NIH) has been used to describe the corporate strategy to not buy existing products or services that have been supplied by third parties. Often NIH is employed for fear of external costs, dependencies, and for fear of needing to disclose or leaking private company data.

Exponential organizations are able to grow much faster than their competition. They are typically small, disruptive organizations, willing to take risks. Success is usually more important than (immediate) financial outcomes. Examples include Airbnb, which rents out private apartments, even though they do not own any of them. Other examples include Google, Facebook, GitHub, and Valve. These all share, that they are largely technology companies. As a result, they are very quick to change. Technology companies can react to changes much faster than companies in other markets. Development cycles can last weeks, rather than months or years. According to Ismail Exponential Organizations make use of five external factors (SCALE): Staff on Demand, Community & Crowd, Algorithms, Leveraged Assets, and Engagement. When comparing a software company with a car manufacturer, it becomes apparent that it is much easier to update software, rather than the multitude of processes which have to be adapted in order to change how cars are produced such as the workforce, machinery, assembly line. In addition, all hardware, that is already in circulation can impossibly be changed on the fly. In contrast, software does just that. Deploying and updating software is all that is required in order to change all future and existing software systems.

In the Connected Mobility Ecosystem, third parties can develop applications, products and services building on the existing data, products and services. An example of such an organization is the Moovel Group GmbH, founded by Daimler. It enables searching and paying for rides. Thus far it supports payments in public transportation systems and car2go. It does so, without owning their own mobility service, payment stations or public transportation system. By developing the Connected Mobility Ecosystem Explorer, the hope is that companies can focus on their talents while at the same time building on talents of others. The goal is to encourage companies to collaborate and innovate.

1.4.1. Innovation

Research by Henning, Oertel, and Isenhardt identified that criticism of the German industry often includes the lack of innovation, as existing systems are closed off and essentially support the business goal of preventing the sharing of any information to the outside of the companies [HOI03]. They found this lack of information exchange not only shelters companies, but also hinders the process of recombining knowledge. Henning et al. further describe, how they believe that while the exchange of knowledge may be dangerous for organizations, it at the same time poses potential and can be successfully harnessed when the exchange is controlled in a channeled system. Aspects of innovation networks are the building of partnerships (Who?), integrating value contributions (What?), Coordinating innovation processes (How?) [RGJ16]. "The right combination of these factors [. . .] is instrumental to the success of innovation networks" [RGJ16]. In order to support the innovative process, knowledge should be gathered and be presented in a reusable fashion.

Henning, Oertel, and Isenhardt identified two types of innovation: innovation through the market and innovation through companies [HOI03]. The goal of the Connected

Mobility Ecosystem Explorer is to enable innovation through organizations, namely by connecting and enabling organizations to engage in mutually beneficial cooperation and exchange.

1.4.2. Accessible and Improved Networking

There are many ways to connect and communicate with members of organizations. The mediums range from traditional written and spoken word to technology enabled systems. An example of technology enabled mediums consist of social networking sites. These will be discussed in subsection 2.4.2.

It is accepted that companies find themselves in a competition amongst others in the same ecosystem [Bas+16; Kel15]. Before organizations are aware of each other they exist unilaterally. They can choose to engage in mutual interaction to begin a process of interactive learning [Man+15].

Reasons for engaging in interaction include the position in their network, the attractiveness of the organization, good will, and visibility [Man+15].

Rehm, Goel, and Junglas found that existing enterprise application software is often used as IS-support for the innovation context, but it has not been designed with that purpose in mind [RGJ16].

Such enterprise software results in many potential solutions, yet also explains why the usage of software in innovation networks is not commonplace. Many examples of successful network creation exist [...] yet one of the key problems of innovating in networks remains "the question of how to plan, organize and control the innovation processes that are distributed over several partners" (Rese and Baier) [RB11; RGJ16]

"A useful IS tool would provide the ability to analytically map out the potential space for partnerships, thus aiding the identification of the required type of partner and preparing the definition of likely partnerships" [RGJ16]. It would support exponential organizations, by letting them concentrate on the tasks they specialize in, and letting strong partners help them with the others.

1.5. Research Questions

The goal of this research is to adequately aggregate and document knowledge pertaining to the Connected Mobility Ecosystem. Furthermore the collected data should be made explorable. In order to achieve this, knowledge must be gathered and a model for the data developed. The questions guiding this research are:

1. How can existing knowledge about the Connected Mobility Ecosystem be aggregated and documented in a reusable fashion?

2. Which types of relationships exist between Connected Mobility Ecosystem members and how can these be documented?

3. How can the acquired knowledge from 1. and 2. be visualized?

1.6. Research Method

The research method was based on the work of Alan, Hevner, March, et al. which has been adapted in Figure 1.3 [Ala+04]. It separates concerns into three distinct pillars: *Environment*, *IS Research*, and *Knowledge Base*.

People, organizations and technology make up the Environment, which defines the problems worth being concerned with. The problems, needs, and tasks the environment should ultimately be supported through the research. As a result, research should be targeted at the environments needs.

The IS Research is conducted in two steps. In the development step, theories and artifacts are designed. The evaluation step assesses the results of the development step. As a result, development can be repeated as the evaluation may reveal new insights, leading to the refinement in the development step.

The Knowledge Base provides Foundations and Methodologies to make use of. Existing research and tested methods can be built upon. When evaluating, previous research can be used as a reference point.

The result of IS Research can ideally lead back into the Environment and modify the Business Needs. It may solve some but new ones may arise as a result. At the same time the results of IS Research can also be used by future research.

In a first step, the problem is analyzed. Next a solution can be designed and implemented, and finally tested and evaluated. The knowledge gained from this research can then be used in future works.

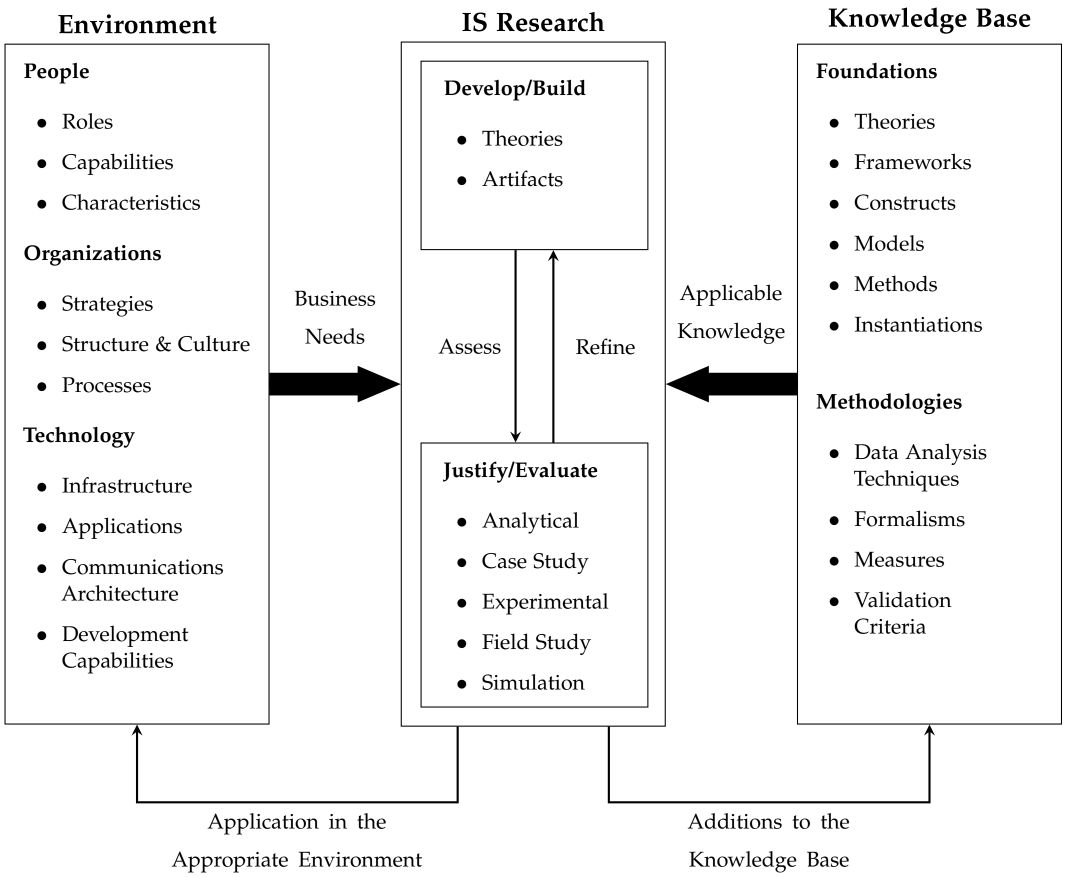


Figure 1.3.: Research Framework based on Design-Science Paradigm [Ala+04]

2. Analysis

The Connected Mobility environment has many needs involving multiple parties. The structures and inner workings are frequently unknown to organizations themselves, let alone external companies and parties. So far there is no known documentation of interorganizational relationships within the Connected Mobility environment. It is a task that is part of the Thematic Platform Connected Mobility, as well as its lighthouse projects.

Before the existing knowledge can be aggregated and documented, the existing problems of complexity and accuracy must be addressed. Requirements can be derived from the analysis.

2.1. Complexity

The layer of abstraction poses a difficulty of complexity. Precision was to be optimized, with the minimum amount of data required in order to be supportive of innovation. The goal of the Connected Mobility Ecosystem Explorer was to concentrate on the important information, which is not easily obtainable through different patterns of access. This includes information, that is normally sheltered inside companies. It also includes knowledge, and knowledge patterns which are similar across organizations, but are usually not broadcast outside of company borders. In contrast, information that is publicly available via websites or press releases have a lower priority.

An organization can be represented in multiple hierarchical levels. Oracle[1] models the competencies of an organization at different levels. Figure 2.1 shows an adapted model. An organization can consist of companies, consisting of business units, consisting of job groups, consisting of jobs, consisting of individual employees.

In SAP[2] systems, these are abstracted as "organizational units", allowing different structures and unequal levels of hierarchy for different organizations. An organizational unit can be a department, group, or project team.

An interview conducted with Robert Zepic of the Chair for Information Systems[3] at the TUM during the early requirements elicitation phase of the Connected Mobility Ecosystem Explorer brought to light the difficulty of accurately representing organizations. Remarks were made about the implications and importance of individual persons. They suggested the task of accurately representing organizations would not be complete

[1]`https://www.oracle.com/` [Online; accessed: 11-December-2016]
[2]`http://www.sap.com/` [Online; accessed: 11-December-2016]
[3]`http://www.i17.in.tum.de/` [Online; accessed: 11-December-2016]

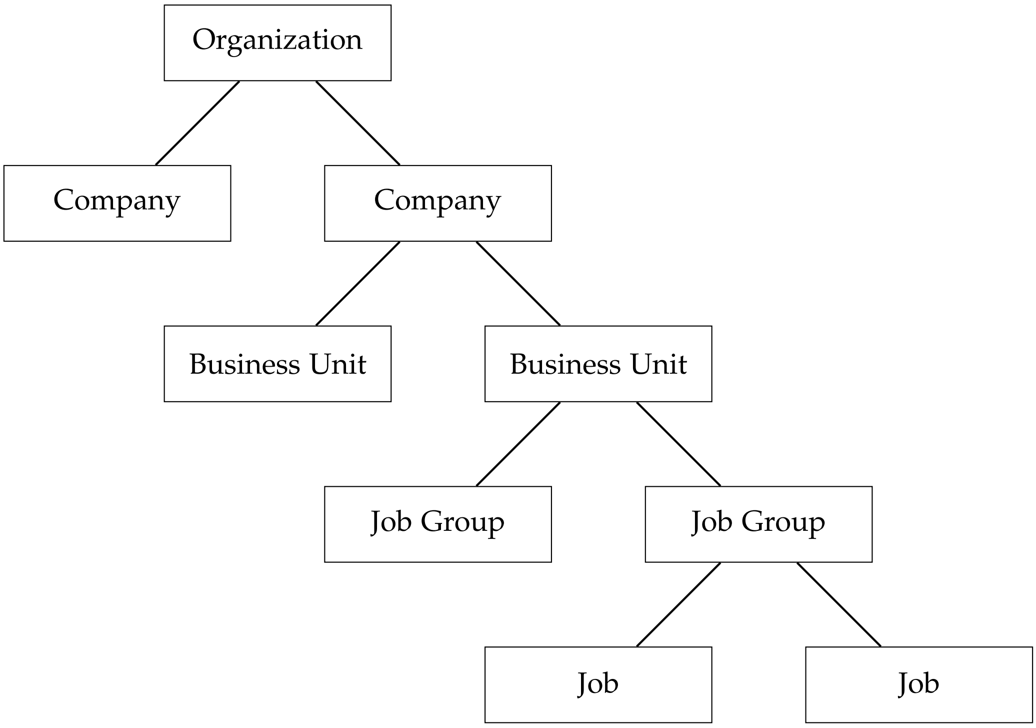


Figure 2.1.: Adapted Oracle Organization Model [Ora16]

without going down to the level of each personal employee. At the same time Mr. Zepic warned of the complexity resulting from modeling organizations down to the personnel level.

Employees leaving a company are known to cause headaches to their superiors. Knowledge regarding practices and operating procedures leave the company together with the departing employees. The departed leaves together with internalized knowledge, personal connections and understanding of the business [PRR03]. It therefore remains a struggle of companies to retain their valuable key employees. At the same time they aim to collect the knowledge in a manner that makes educating and training new employees possible. These attempts are met with disinterest by employees, which worry for their jobs. A common occurrence is that employees fear of disclosing their "secrets", for they believe it may eventually make them obsolete. It is not uncommon for employees to express fear that they could either be replaced by a cheaper hire or even made redundant due to evolving technology.

The interview resulted in two main results. It meant that any attempt made to accurately represent knowledge about entire organizations would be, in terms of the complexity, not just of the number of organizations and their hierarchical levels, but simply of the total number of employees. Mr. Zepic also warned, that attempting to be accurate may not lead to the desired result.

Trying to model an organization down to each person makes modeling organizations and their relationships difficult, but additionally enhances the problem of keeping data accurate. In the interest of adhering to the Agile development methodology, and producing a prototype, knowledge about individuals was not gathered. However it resulted in an interest, in whether this abstraction would still prove useful.

The task of gathering data about a local set of organizations, no more than 100, seemed non-trivial. This was due to the required types of information, which companies would likely oppose to disclosing. The problem is the same as observed by Henning, Oertel, and Isenhardt: Companies try to maintain as much information in secret as possible, for they want to be able to control where data flows and maintain the competitive advantage [HOI03]. It became clear, that a major challenge for the Connected Mobility Ecosystem Explorer would be providing a model, which would be flexible enough to allow for different granularity of detail and enticing members of the ecosystem to participate and volunteer information.

Since it was unknown, what data could possibly be collected, several requirements were set for the Information System (IS). The model should be based on the collected data, rather than data being collected only based on a model. The model should be adaptable and ideally evolvable. It would be helpful, if changes to the model could be carried out without technical expertise. This ease the process of allowing non-technical experts to contribute directly to the IS. The model should support differing granularity of data as well as change in format, in order to account for varying levels of participation.

The research body of a university has a very unique position when conducting this research. The distance from political agenda and financial interests makes discussion partners less defensive regarding information.

2.2. Data Management

The previously mentioned aspect of having high ambitions in regards to the accuracy of the organizational model enhances the problems of documenting data for multiple members in the first place, as well as keeping it up to date. The fact that some of the desired data is rather confidential only enhances these difficulties. Some confidential questions are: who the partners and suppliers are, and where funding comes from. The fewer sets of data to maintain, the easier it is be to retain a high level of accuracy. It is also easier to obtain the initial state, since members are more likely to share a little amount of information rather than a detailed representation of their organization, for they may fear competitors could access this information and use it as a competitive advantage.

A common fear of organizations against knowledge management systems is the fact that large sets of data can easily be exported and carried across organizational boundaries. While confidential organization data is still very much at risk due to frequent personnel changes, the damage is minimized considering each leaving employee can only "steal" information in forms that are hard to transmit easily. Usually the biggest challenge is digitizing the knowledge [Krc15]. The challenge remains the same, whether a company tries to document its knowledge, or whether a departed employee wants to sell company secrets. The human factor limits how fast large quantities of information can be taken and used. The worry is, that a knowledge system like a wiki could be copied in its entirety, and make organizations much more exposed to threats of having their secrets exposed.

Two further challenging aspects for the CMEE will be trust and quality. People have adapted outside of software systems, but in order to make the CMEE successful, answers will have to be found for fear of being tricked or suffering due to faulty data.

The result of the complexity, accuracy, and security concerns make it seem like a viable choice to maintain a rough level of abstraction in order to please all parties. Organizations would not have to share as much data, making them more comfortable with the process, the accuracy would be easier to handle, since there would be fewer sets of data to keep up to date, and finally the complexity would be less difficult for the maintainers as well as the theoretical construction of solutions.

2.3. Identified Knowledge

The research into the Connected Mobility Ecosystem identified a total of 52 organizations. 22 of these were associated as members of the Connected Mobility Ecosystem. The members of the Connected Mobility Ecosystem which were identified are listed in alphabetical order in Table 2.1. It was possible to speak to some employees of companies directly. Other information was drawn from members willing to disclose information pertaining not just their own organization.

Additionally knowledge regarding the connections between organizations was identified and documented. The data was sourced from experts, internal knowledge as well as public websites and social media. Information was limited to organizational, partnership, or ownership information.

The gathered information was stored. In the following research options were looked at in order to reuse the information. This included interacting with it, as well as visualizing it.

2.4. Existing Sources of Information

The knowledge gathered for this research could also be obtained in different ways. Most simply said, most information is stored in people involved with the field. The interviews conducted as part of the evaluation showed that some people are not convinced that knowledge management needs to be supported by Information Systems, and that personal relationships are more worthwhile. Many Information Systems (IS) already exist, which support personal and business relationships. These can also be seen as sources of inspiration for the CMEE.

Table 2.1.: CMEE Members as of 11-December-2016

	Abbreviation	Name
1	ABI	Audi Business Innovation GmbH
2	Alphabet	Alphabet International GmbH
3	Audi	Audi Deutschland
4	BMW	BMW Group
5	car2go	car2go Deutschland GmbH
6	CML	Connected Mobility Lab
7	Daimler	Daimler AG
8	DriveNow	DriveNow
9	FH Ingolstadt	Technische Hochschule Ingolstadt
10	HERE	HERE Maps
11	Iteratec	Iteratec GmbH
12	LLCM	Living Lab Connected Mobility
13	moovel	moovel
14	mytaxi	Intelligent Apps GmbH
15	Siemens	Siemens AG
16	Sixt	Sixt GmbH & Co. Autovermietung KG
17	StMWi	Bayerisches Staatsministerium für WMi
18	Tamyca	tamyca GmbH
19	TUM	Technische Universität München
20	UTUM	UnternehmerTUM GmbH
21	VSS	VSS - Vertical Social Software
22	ZD.B	Zentrum Digitalisierung.Bayern

2.4.1. Events

Different events act as suitable platforms to learn about the ongoings in innovation networks. Networking events, especially those of startup accelerators, provide a stage on which innovative ideas can be advertised. Hackathons, such as the HackaTUM are used to connect developers with companies. Individual companies also organize events, and invite others to collaborate on ideas.

2.4.2. Social Networking

Social networks allow its users to engage with contacts and form new ones. Examples of social networking companies include LinkedIn[4] and XING[5]. Both are used extensively by employees, managers and those seeking jobs. This makes them a viable source of inspiration to the Connected Mobility Ecosystem Explorer. XING reports over 10 million users in the German speaking market as of 2016, an increase of roughly 1 million users in one year [XIN15; XIN16]. The efforts of the Connected Mobility Lab were initiated in Munich, Germany, and as such the German speaking market is important as a reference. XING counts 44 % of its users as "business professionals", which it defines as "People who are either academics or have a net monthly household income of at least €3.500" [XIN15; XIN16]. Persons using XING have access to a wide amount of information, ranging from organizations and their employees. This information is entered in the platform by the users themselves. Similarly to other exponential organizations, XING profits off of data, which the user base provide. XING is employed as a source of job seeking opportunity for some members, and as such, interactions are treated like sales pitches of ideas and persons. Experience has shown, that delays are caused by the need of convincing several parties of intentions and innovative character, before the right business partners can be found for a mutually beneficial solution.

Crunchbase[6] is another source of inspiration. It acts as a mediator between startups and investors. It claims over 50 000 active contributors.

Startup portals like Munich Startup[7] can be compared to startup events. A virtual space is provided, in which startups can advertise their ideas.

[4] https://www.linkedin.com/ [Online; accessed: 11-December-2016]
[5] http://xing.com/ [Online; accessed: 11-December-2016]
[6] https://www.crunchbase.com/ [Online; accessed: 12-December-2016]
[7] http://en.munich-startup.de/ [Online; accessed: 12-December-2016]

3. Design

Designing a suitable solution for the Connected Mobility Ecosystem Explorer was difficult. The challenges of modeling the ecosystem included the uncertainty of exactly which information would be provided in what accuracy and frequency. An important requirement for the model is that it should be able to handle different levels of specificity for different members, as it became clear that more information can be gathered about some ecosystem members than others. Another requirement is the ability to represent different types of members, ranging from individual persons doing research or projects in the field, to startups, about to develop their first prototype, all the way to large multinational corporations with several research groups participating as members of the TUM LLCM. The different sizes and maturity of members should be accounted for, but not exclude members. Another challenge was the varying degree of granularity, due to the fact members of the Connected Mobility Ecosystem were expected to collaborate closely, while others were expected to be very protective of their data. This limited the accuracy and potential of any visualization. At the same time, members of the Connected Mobility Ecosystem should, in a later state of the CMEE, be able to insert arbitrary data into the system, in order to share that knowledge with others. Since members could not be expected to have information technology backgrounds, adding and maintaining data should be completed successfully with a minimal amount of technical knowledge. Meanwhile, the fact that multiple members would have access to the same system led to the requirement that collaborative editing must be supported, and problems resulting from concurrent changes be mitigated.

3.1. Process

Usability would become an important factor, as it would enable many users to concurrently work on knowledge management. It was important, that a user without programming experience be able to contribute to the body of knowledge. Ideally they would be able to modify and adapt the model as well, without requiring technical expertise. Users are able to influence the systems model. This allows them to change the model as well as the data. This calls for a data driven, meta-model based system, capable of handling the collaborative environment.

Two groups of users were designated: consumers and administrators. Users are consumers and explorers of information. Administrators are consumers, but have the additional ability to manage information. This technique was selected in order to ensure that data could not be manipulated by anybody. A graphical depiction is shown in

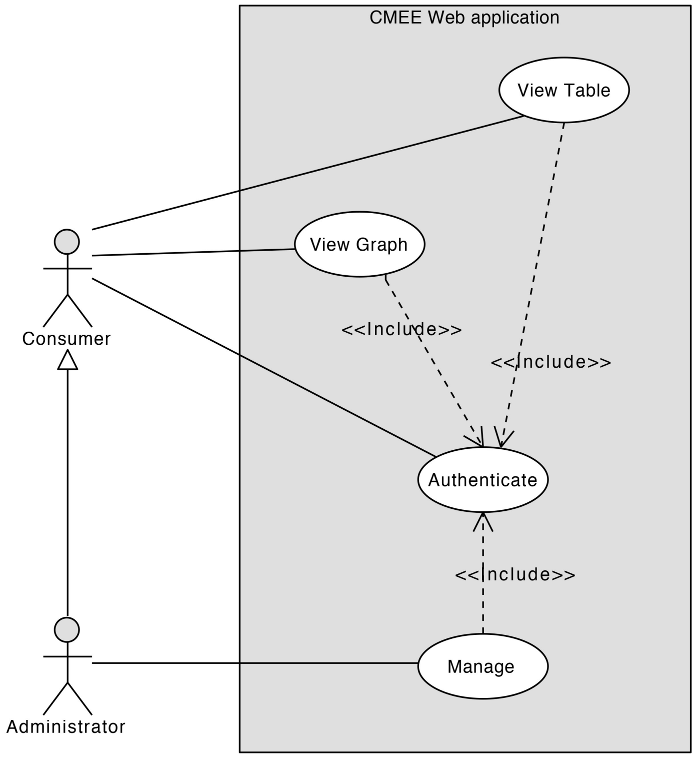


Figure 3.1.: CMEE Use Cases

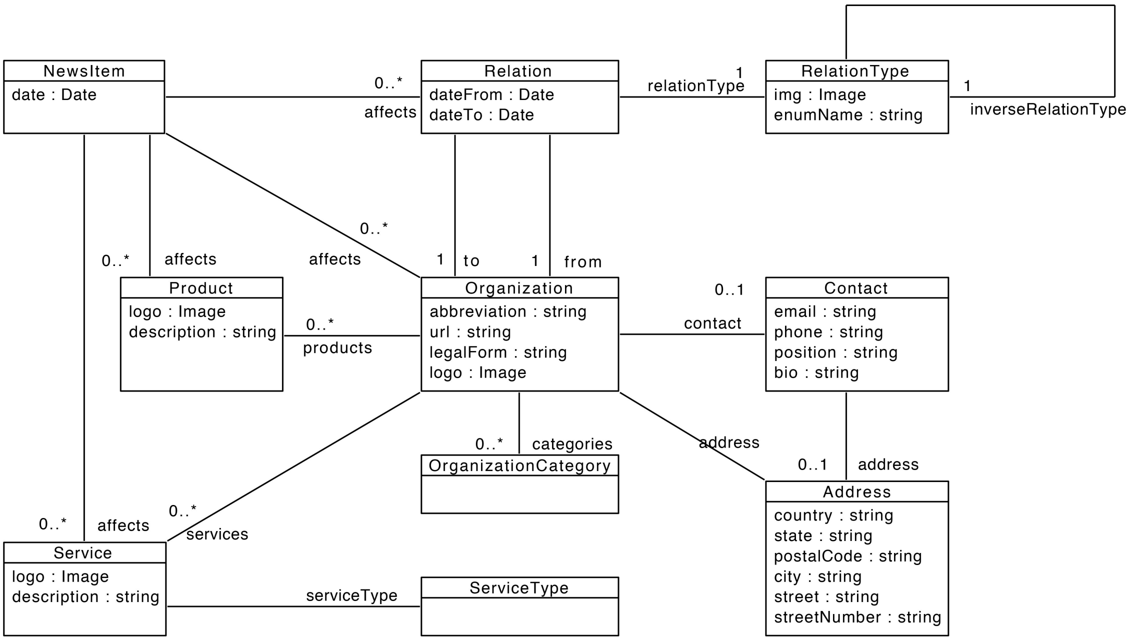


Figure 3.2.: CMEE Domain Model

Figure 3.1. The fact that all actions require authentication was to assure each member of the Connected Mobility Ecosystem that no data that is provided would be made immediately public on the CMEE.

Information was designed to flow from the sources towards the CMEE. From there, it could spread within the Connected Mobility Ecosystem, provided that the CMEE was used. In order to analyze and store the data, a domain model was derived from the collected data.

3.2. Domain Model

The ecosystem explorer can be categorized as a data driven system. It captures and visualizes information about organizations and their interactions. While the database can be independent to the underlying model, the visualization requires a model. When talking about the general sense, "a data model is a collection of conceptual tools used to model representations of real-world entities and relations among these entities" [Ang12]. In this case, the data driven nature allows the data to be collected first, and a model to naturally emerge. As a result, the model and instantiation of data impacts the CMEE.

When seeing things from the perspective of a database, "a data model consists of three components: a set of data structure types, a set of operators or inference rules and a set of integrity rules" [Ang12]. The data structure types are the most interesting to start with. The operators are limited to the typical creating, reading, updating, and deleting for each datatype. The integrity constraints are less restrictive of the ecosystem

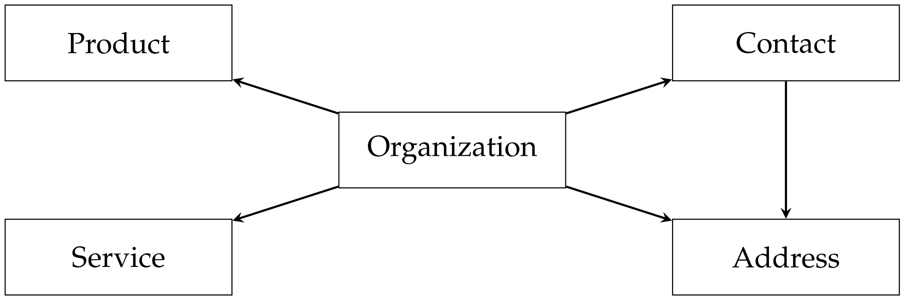


Figure 3.3.: Structure of Organizations

explorer. During the conceptualization of the Connected Mobility Ecosystem Explorer it remained unclear how detailed the information would be. Additionally it was unknown which information each member of the ecosystem would provide. This resulted in the requirement that the integrity rules should reflect this. It should be possible to add as detailed information as any member is willing to provide, but at the same time, it should not lead to constraint violations, if a member is not willing or has not yet provided that same level of detail.

As an example, one organization is willing to provide both structured and unstructured information regarding its products. This includes names, pricing information, as well as units sold for example. At the same time, it would not make sense to require products, as not every member has a product to sell. Another company may choose to disclose the name of one of their product, but choose to not disclose the number of units sold.

The implementation of the data model can be seen in Figure 3.2. Contacts, Addresses, Products, Services, ServiceTypes, and OrganizationCategories require no attention to detail, as they are utilized for storing data. In the following, Organizations, RelationTypes, Relations, NewsItems, Contacts, Products, Services, and OrganizationCategories are described from Figure 3.2.

3.2.1. Organization

The choice was made to abstract organizations contrary to the research done in section 2.1. Rather than gathering and maintaining all data regarding organizations, the organizations public website would be used as a source instead, for everything that is accessible there. This was motivated by the goal to be able to depict the current state quickly. This meant a url was stored, rather than developing a model for company size, finances and further details. An abbreviation, legal form, logo, and address was stored, in addition to the dedicated contact person. These could later be used in the visualization to enhance the presentation.

Any member of the Connected Mobility Ecosystem would be represented as an organization in the Connected Mobility Ecosystem Explorer. Even though not technically correct, their actions as members can be treated as though they are an organization, regardless of whether it is one single person, or a collaboration of entities from different companies, acting as one group.

A general overview of an organization is shown in Figure 3.3. Products and services are attached to organizations. Organizations can also have a contact associated with it, which in the case of the CMEE could be a person responsible for innovation management. Organizations are essentially the building blocks which can later be connected.

OrganizationCategory

OrganizationCategories evolved later in the development cycle. They were introduced to be able to group similar organizations. It allows users to filter out certain categories of organizations.

3.2.2. RelationType

RelationTypes categorize the individual relations. The `inverseRelationType` (see Figure 3.2) attribute is used to define the relationship in the opposite direction.
A RelationType with bidirectional properties will have a reflexive reference in the `inverseRelationType`. A type of relationship, where the directionality is important will have a different inverse type of relation. This resulted from modeling relationships without data-redundancy. An example is shown in Figure 3.4.

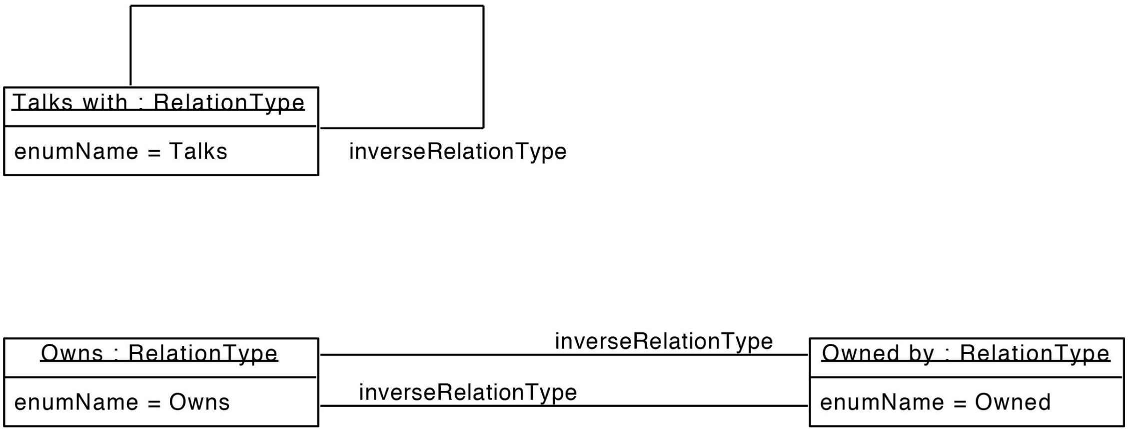


Figure 3.4.: RelationType Objects Example

The RelationType "Talks with" has an `inverseRelationType` of "Talks with". The RelationType "Owns" has an `inverseRelationType` of "Owned by". The RelationType "Owned by" in turn has an `inverseRelationType` of "Owns".

3.2.3. Relation

Relations connect two `Organizations`. These can be found in the mandatory `from` and `to` attributes. The type of a relation is given by the `relationType`.

Relationship types could either be bidirectional (talks, cooperations) or unidirectional (ownerships and talks). A system would need to be capable of handling both uni- and bidirectional relationships.

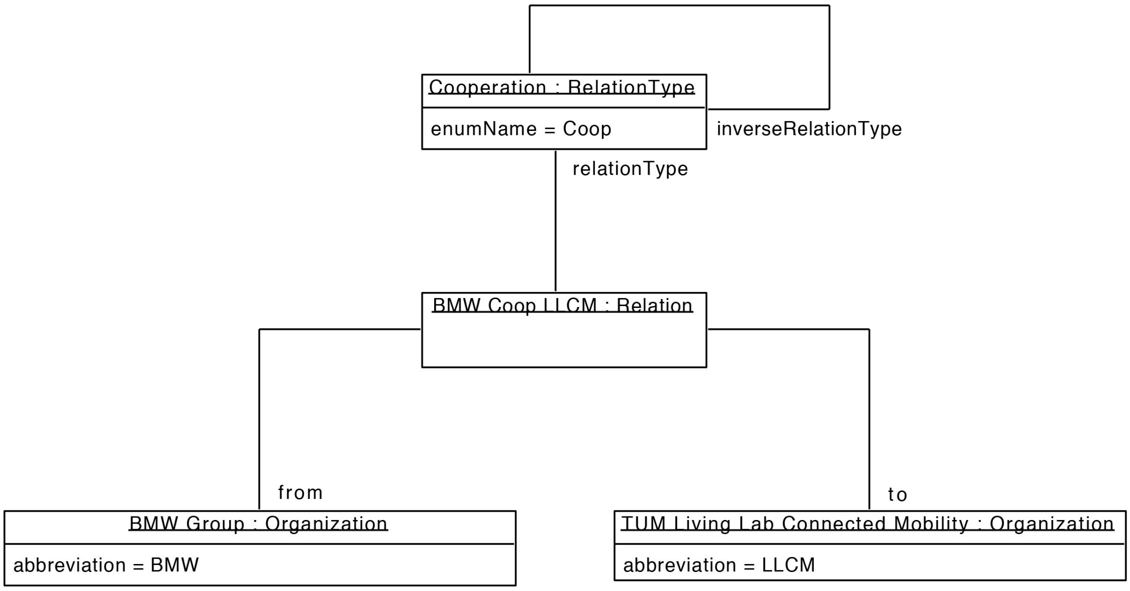


Figure 3.5.: Relation Objects Example

An example is shown in Figure 3.5. The "BMW Coop LLCM" Relation shows associations to Organizations and RelationType. The directionality is implied through "from" and "two", but the inverse would look identical, apart from reversed names and from/to parameters being switched.

The relationships between organizations, is what will set the explorer apart from other systems. Relationships are very important, as "the importance of the information relies on the relations more or equal than on the entities" [Ang12]. The relationships should be classified, in order to distinguish between different types of relationships. The relationship types identified were:

- Cooperation
- Ownership
- Funding
- Talks

Feedback from the evaluation showed that relationships could be specified in more detail. For example funding could be broken down into the type of funding (Venture Capital, loan, profitsharing). Cooperations could be described in more detail, to explain what the foundation or nature of cooperation is. This could include information regarding contracts, exchanges, or interorganizational teams.

A conscious choice was also to eliminate negative relationships. An example of a negative relationship can be seen in Figure 1.1 on page 4, where light grey connections (called "Failed talks") are drawn between Apple and BMW, Daimler and VW respectively. While deemed important information, this negative implication was omitted from the explorer for the time being.

It did show, however, that an important aspect would be to modify possible relation types. The requirement, that relationship types would need to be easily adaptable to changes and to changing information was taken into account when developing the system.

Limiting the amount of data the system collects reduced the complexity. It also made the system more maintainable, given the current situation. If the system were able to obtain information automatically, these constraints might allow for more detailed results. This includes the choice to focus on the abstract level of an organization, as well as using relationships to connect organizations, rather than using the additional products and services. This should not imply, that it would never be able to connect organizations to the products and services of other organizations, merely that for the time being, the focus was to connect organizations.

3.2.4. NewsItem

NewsItems are created to associate sources with the knowledge contained in the CMEE. A NewsItem can contain any information, but is intended to contain material leading to the source which resulted in information documented in the CMEE. It has an untyped `affects` attribute, which is intended to be used in order to attach NewsItems to Relations, Organizations, Products, and Services. This means it can be used to provide sources to Organizations, Products, and Services in addition to Relations.

3.2.5. Contact

Each `Organization` has a reference to a `Contact`. This is a representative responsible for responding to incoming queries. If the size of the organization requires it, it may also be someone responsible of delegating to the appropriate representative. Having one single entity per Organization seemed advantageous, as it allows inquiries to be targeted at the person responsible. This would be the innovation manager, in an idealized scenario. At the same time it allowed smaller companies or entities to designate a person, acting in the same role, even though they may not have had that role before.

3.2.6. Products

Any tangible and discernible items an organization produces can be categorized as a Product. In the context of Connected Mobility this includes the vehicles and devices produced by some of the members. In later stages of development, it may become possible to show which Organization uses which Product of a different Organization.

While not considered as an important requirement at this time, the structure allowed to capture Products of companies, where known.

3.2.7. Services

Services in contrast are any form of intangible value provided by companies. This includes maintenance, work done and consultations. In the Connected Mobility context, especially when talking about innovation, Services would also include the access to data. As such, being able to accurately represent Services became very important. In an ideal scenario, each member of the Connected Mobility Ecosystem could list each Service they provide. It would further be desirable, if they could document how that Service can be acquired and what (for example legal) constraints are placed on the usage of said Service.

3.3. Data Storage

The model designates how information is separated while the database is tasked with storing the data. The logical structure is defined by the database model. Additionally, a database model determines how data can be stored and accessed. While relational databases have become commonplace, graph databases provide a valid alternative for many use cases.

This section aims to highlight how the same information can be stored in either a relational database or a graph database. In the examples, the focus lies on many-to-many relationships, which reflect the requirements of the Connected Mobility Ecosystem Explorer.

Even though the data model could easily be represented in a graph database, but the relatively small model could also be stored in a relational database without any significant (performance) drawbacks. This came as a result of deciding for a data driven model-based system, capable of evolving. Since the number of nodes and edges would be very small, the performance drawbacks were outweighed by the usability concerns.

The problem of representing edges in a relational database has multiple solutions. On the one hand, each node could receive a list of attributes, including each type of edge. Each node then could, via these attributes be connected to any other node. This would have not allowed for any properties to be stored in the edge however. Since this was desired, nodes would be used as intermediaries. These special connecting nodes, called associative entities, would have a `from` and a `to` node, as well as its own RelationType and properties.

The RelationType would in the case of the Connected Mobility Ecosystem Explorer be the type of relationships between organizations. In order to accommodate the unidirectional nature of some of the relationships, each type of relationship received an inverse relationship type. Thus, it would be possible to determine the nature of each relationship. A decision would later have to be made, whether to include both directions

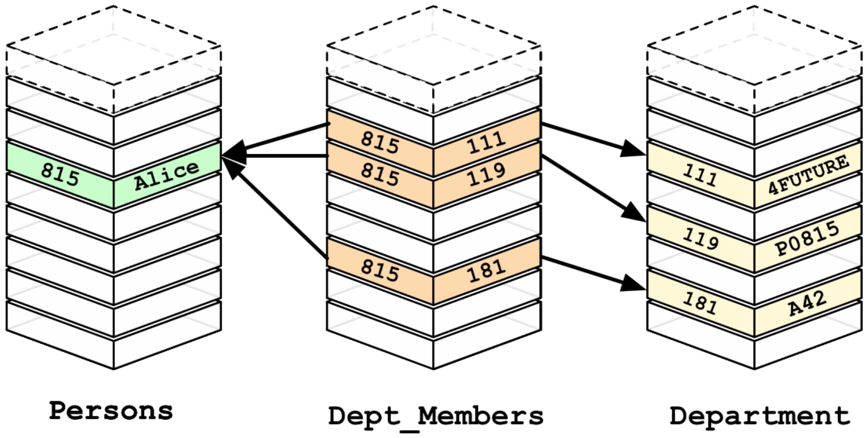


Figure 3.6.: Many-to-many (RDBMS) [Neo16a]

of each relationship, or to limit it to one relationship between two organizations and rely on the inverse type to logically compute the other direction.

Relational databases are based on a tabled setup. Each entry must conform to a predefined schema. Figure 3.6 shows an example setup of data in a relational database.

Based on how graph databases store data, the schema for entries does not have to be predefined. This allows the different entities to have different data schemas, if so desired. Figure 3.7 depicts how data can be stored in a graph database. The same data is stored as in the example with the relational database (compare to Figure 3.6).

Graph databases use a graph structure to represent information. Graph models use nodes, edges and properties to store information. Nodes are structures connected via edges. Edges are the distinguishing feature in graph databases, as nodes and properties can also be found on many other systems, such as relational databases. Both nodes and edges can have properties, permitting data to be stored in the connections in addition to the objects or nodes.

A "Graph database system follows CRUD (create, read, update, delete) methods that are used in a graph data model and it also uses index free adjacency" [Kal15]. Nodes maintain direct reference to the nodes adjacent to them. This is called a "micro index" for other nodes. It is cheaper than using global indexes. Making use of these indexes results in queries being independent on the total size of the graph and only being directly proportional to the length of the graph that is searched [Kal15].

When developing a model for organizations and their connections, graph databases came to mind quickly. Having organizations represented as nodes, and the connections between organizations represented as relationships was an intuitive solution. In this way, properties could be attached to both organizations (nodes) and relationships (edges)), while the relationships would provide insight into the type of connection existing between different organizations [Neo16b].

If represented in a graph database, one would have to choose from models which

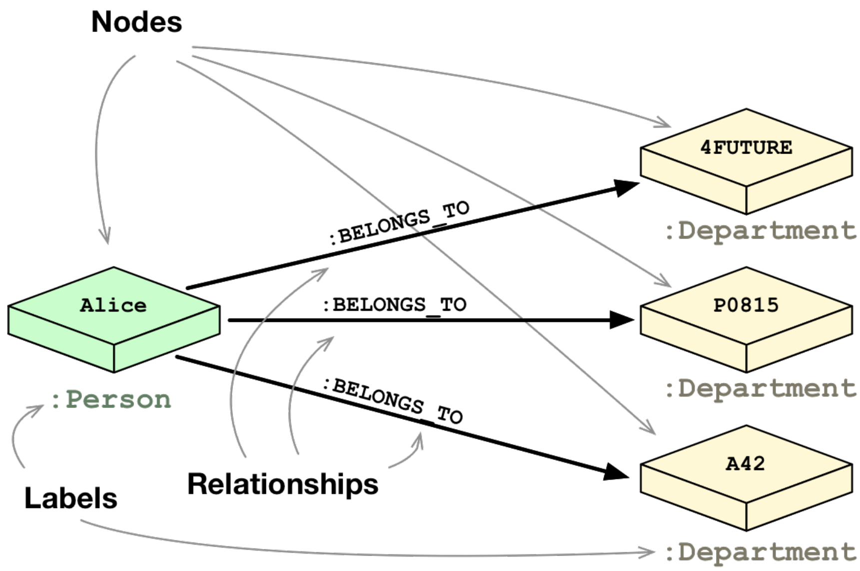


Figure 3.7.: Many-to-many (Graph) [Neo16a]

currently exist. Current graph databases include: AllegroGraph[1], Sparksee (formerly known as DEX)[2], HypergraphDB[3], InfiniteGraph[4], Neo4j[5] and Sones[6] [Ang12]. Research indicates that Neo4j outperforms Sparksee, Titan[7] (BerkeleyDB[8] and Cassandra[9]) and OrientDB[10] (local), regardless of workload or the parameters used. However, for read-only workloads Neo4j, Sparksee, Titan-BerkeleyDB and OrientDB achieve similar performances. For read-write-workloads Sparksee and Titan-Cassandra outperform OrientDB and Neo4j [JV13]. When choosing an appropriate database, this performance does not take into account the additional factors of usability, price, and system requirements. These additional factors would strongly overpower any performance concerns for the Connected Mobility Ecosystem Explorer, as the dataset and performance requirements are strongly limited.

[1] `http://franz.com/agraph/allegrograph/` [Online; accessed: 11-December-2016]
[2] `http://sparsity-technologies.com/` [Online; accessed: 11-December-2016]
[3] `https://github.com/hypergraphdb/hypergraphdb` [Online; accessed: 11-December-2016]
[4] `http://www.objectivity.com/products/infinitegraph/` [Online; accessed: 11-December-2016]
[5] `https://neo4j.com/` [Online; accessed: 11-December-2016]
[6] `https://github.com/sones/sones` [Online; accessed: 11-December-2016; last updated 18-June-2013]
[7] `http://titan.thinkaurelius.com/` [Online; accessed: 11-December-2016]
[8] `http://www.oracle.com/technetwork/database/database-technologies/berkeleydb/overview/index.html` [Online; accessed: 11-December-2016]
[9] `http://cassandra.apache.org/` [Online; accessed: 11-December-2016]
[10] `http://orientdb.com/orientdb/` [Online; accessed: 11-December-2016]

3.4. Hybrid Wiki

Hybrid wikis are an attempt to introduce structured data to a wiki system [MNS11]. Instead of semantically tagging existing information, it allows its users to add structured data to any page. The basic approach is a regular wiki system which is enhanced with features. Like in a regular wiki system pages are created, which can hold arbitrary unstructured data. The addition to regular wiki systems is that pages can be typed, associating them with a schema which defines attributes of pages.

Since this method allows the data model to emerge as time goes on, it can be contrasted to the typical top-down approach, where the data model has to be defined upfront. The goal of this approach is to prevent limiting data, and instead develop a model, capable of representing data. Additionally, a focus lies on the idea that data starts out in an unstructured fashion, and later evolves. Hybrid wikis support both of these facts, by allowing unstructured data and by enabling evolving data models. The data models, or schema, are defined by users, but can be manipulated at runtime, without needing any technical expertise.

The Software Engineering for Business Information Systems[11] (sebis) chair at the TUM has favored this approach, as it gives power to the users, by allowing them to add structured data, and still manage the complexity. Their research efforts span multiple iterations of hybrid wikis, including Tricia and SocioCortex[12] [HKM15].

A hybrid wiki fits many of the requirements perfectly. Wikis can traditionally be edited by people with very limited technical knowledge. They are also conceptualized to be used by multiple users simultaneously. In addition, using a hybrid wiki means knowledge can be kept in a structured or unstructured way, which is preferable to traditional wikis. Traditional wikis only allow non-structured data or need plugins in order to support structured data. Good examples of such solutions are Wikipedias Infobox[13] system or the Scaffolding Forms[14] plugin for Atlassians Confluence[15].

In hybrid wikis, a meta-model, referred to as schema defines attributes for pages. Users have the ability to edit this schema within the hybrid wiki. This makes the solution viable for users to update and change the underlying data model and is supportive of our requirement to make the system both usable and capable of evolving. The native hybrid wiki still lacks a method of adequately presenting the contained data in a visual way. What it has in terms of editing capabilities and simple views, it lacks in visual presentation of the collaborated data.

Hybrid wikis are capable of working with arbitrary schemas. The inner workings are designed to work with any data model.

[11] `https://wwwmatthes.in.tum.de/` [Online; accessed: 11-December-2016]

[12] `http://sociocortex.com/` [Online; accessed: 11-December-2016]

[13] `https://en.wikipedia.org/wiki/Help:Infobox` [Online; accessed: 11-December-2016]

[14] `https://marketplace.atlassian.com/plugins/net.customware.confluence.plugin.scaffolding/server/overview` [Online; accessed: 11-December-2016]

[15] `https://www.atlassian.com/software/confluence` [Online; accessed: 11-December-2016]

4. Implementation

The next step of the process included instantiation of the theoretical solution and producing a working prototype. The architecture needed to be developed and suitable technology selected.

The goal of the implementation was a proof of concept prototype, which could be shown to members of the Connected Mobility Ecosystem. Their feedback would provide valuable insight, regarding what was successful, and what left room for improvement. The implementation should show and inspire people to think about possibilities, rather than limit what was possible.

The Connected Mobility Ecosystem Explorer consists of two parts (see Figure 4.1). The first is the SocioCortex ecosystem. It contains the web application, API[1], and database. SocioCortex was developed outside of this research. An instance of SocioCortex was installed and hosted by a member of the sebis chair and used for the CMEE. While the models were created in SocioCortex, no development was contributed to it. The AngularJS based web application was however developed during this thesis.

4.1. Technology Considerations

A technology stack was to be selected, in order to support the abstract solution outlined in chapter 3. The goal was to produce a prototype, which could be displayed to members in and outside of the Connected Mobility Ecosystem. Feedback should be gathered, evaluating both the usefulness of the data, as well as the choices made for the presentation and visualization.

Users would interact with the system on a desktop computer. A simple web application is capable of fulfilling these requirements. Web technologies are further capable of adapting to differing devices in an easy manner. Since the information should be as current as possible, data would need to be fetched in real-time. The requirements arising from this would be, that a backend system is required, which would process and store data. In addition, at least one client system is needed, to retrieve data from the backend and interact with it.

A client side JavaScript application was chosen for several reasons. It provides a nice separation between itself and the backend system, with which it can communicate directly. Given the current trend, there is an abundance of development being done on frameworks, which can be used. AngularJS[2] was chosen due to the familiarity as well as

[1] `http://www.sociocortex.com/documentation/` [Online; accessed: 11-December-2016] (API v1.0.0)
[2] `https://angularjs.org/` [Online; accessed: 11-December-2016]

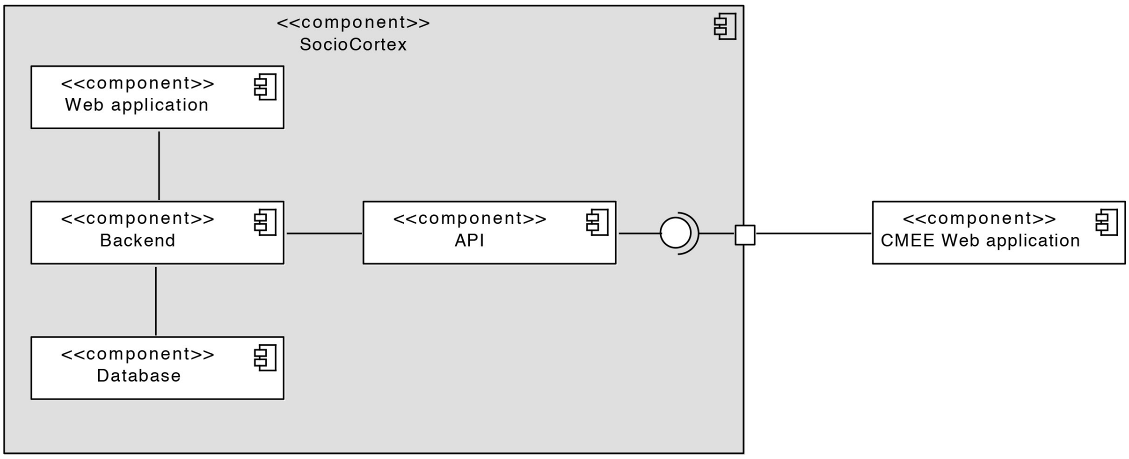


Figure 4.1.: CMEE Overview

the existence of a framework to interact with the SocioCortex backend. This framework called *angular-sc*[3] (Angular SocioCortex) provides wrappers for common tasks. It came with an implementation of the authentication as well as several ways to query data. The drawback of *angular-sc* included some incomplete functionality. It also required a very specific version of AngularJS (1.3.0). *Angular-sc* did not come with a way to insert new entities. As such it seemed more suited to presenting data in views, and less to interact or modify them.

4.2. SocioCortex

SocioCortex is a Hybrid Wiki (section 3.4). It is a model based social information management system developed by the sebis chair at the TUM. SocioCortex was started in 2015 and is based on over 10 years of research together with industry partners [MNS11; HKM15]. Common and recurring problems were identified and solution patterns proposed. It acts as a starting point, on which individual applications can be tailored. SocioCortex consists of a backend system, as well as a web application. In order to provide flexibility to developers, it is also possible to access and use SocioCortex programmatically via an API.

4.2.1. Functionality

SocioCortex provides a REST API, which offers two types of methods to developers. CRUD interactions are available via what will be referred to as a native API. The same component also provides the possibility to submit Model-Based Expression Language (MxL)[4] queries. Alternatively – or in addition to – the web application can be used. The

[3] `https://github.com/sebischair/sc-angular` [Online; accessed: 11-December-2016]
[4] `http://www.sociocortex.com/tutorial/2015/12/01/mxl01/` [Online; accessed: 11-December-2016]

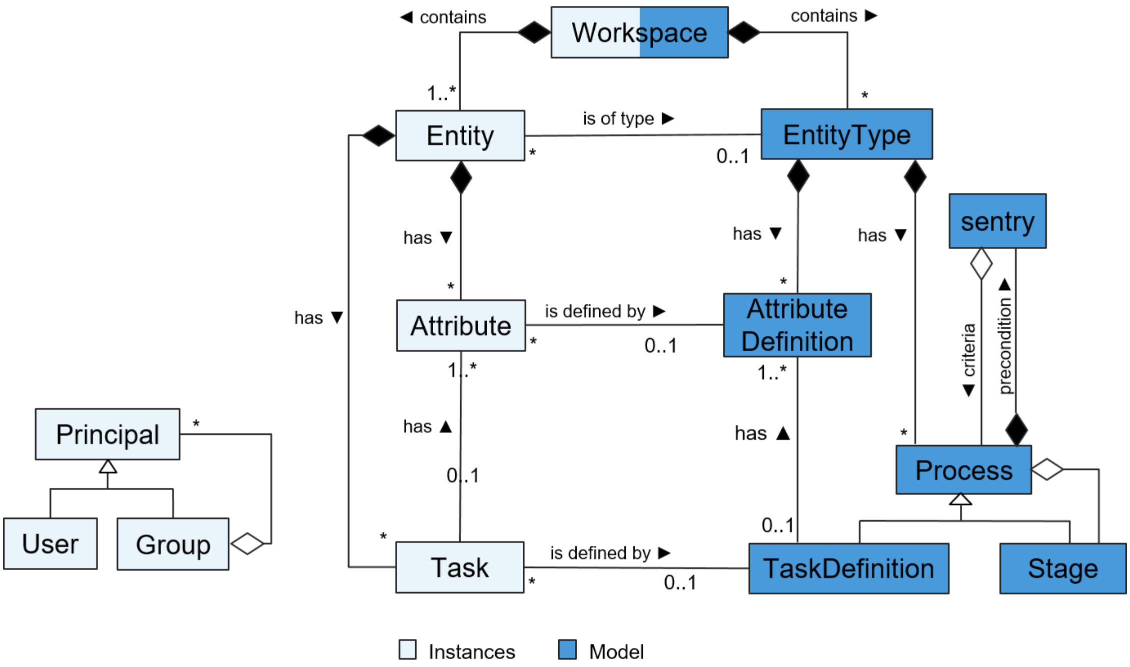


Figure 4.2.: SocioCortex: Class diagram [Els16]

web application aims to make the functionality of SocioCortex usable, even by IT novices. The system works in a collaborative way and brings desirable functionality as standard. As such, it seemed a good starting point for the Connected Mobility Ecosystem Explorer.

Figure 4.2 shows a diagram of the underlying model in SocioCortex. The system contains workspaces, in order to group workings. Workspaces can be compared to departments of an organization. It however allows users to contribute to multiple workspaces, which could be information silos.

If several entities adhere to the same structure, an EntityType can be created. EntityTypes contain attribute definitions, but can also contain processes made up of TaskDefinitions and Stages. In the case of the CMEE, EntityTypes were created for all entities described in section 3.2.

Flexibility

Users are able to collaborate and dynamically alter data. SocioCortex follows the collaborative design approach for dynamic data. Because of the ease of adapting pages and EntityTypes, it encourages the development of more sophisticated models. It is possible to start with certain assumptions about the data and model, and later change them. The flexibility allows for a degree of imperfection, since it is apparent, that the models can evolve. This encouraged the decision to model organizations in an abstract manner, for it can easily be changed later.

SocioCortex also supports the use of MxL, which is tightly integrated to its internal

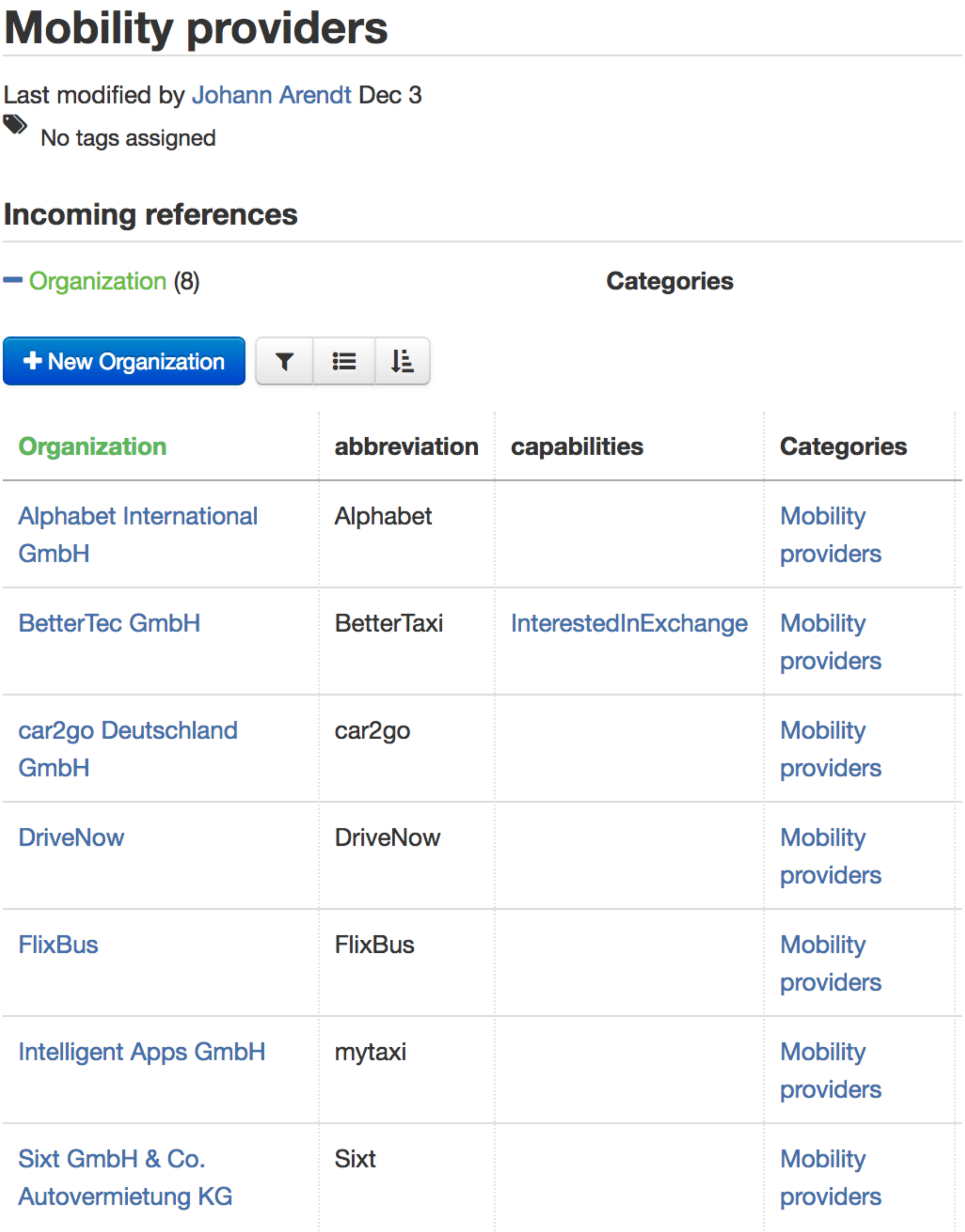


Figure 4.3.: Mobility Providers in SocioCortex

model. MxL is based on OCL[5] by the Object Management Group (OMG)[6] and LINQ[7] by Microsoft[8]. It takes advantage of the data model of SocioCortex and can be used to query information stored in it. It is a functional, sequence-oriented, object-oriented, statically type-safe query language.

Evolution Management

SocioCortex supports evolving content, by providing data consolidation and alignment support. This means that the models can evolve along with the data. The power of deciding how information is stored and presented is given to the collaborative workforce of editors. As a result from evolution management, the origin and development of knowledge can be traced. This can be used to identify sources of information, as it evolves over time.

Knowledge Management

SocioCortex supports knowledge processes, by storing the data in which ever way is most convenient. It allows to collaboratively document knowledge processes in an unstructured manner, and synthesize structure from the joint effort. It further has features that make it ideal for knowledge management. A Social Feed which feeds an Activity Stream enables user interaction. It has full text search integration, to make retrieving important knowledge information easier.

Versioning

The history is stored for content, files, and processes. It allows users to reconstruct how the current state of the system came to be. Additionally, it supports reverting changes. This is an important feature for editors, as they do not have to fear to make changes.

Access Control

There are several parts which make up the Access Control in SocioCortex. Most importantly there is a built-in Identity Provider, which allows users access to the system. This is shared throughout a SocioCortex instance, so one user can have access to multiple workspaces. SocioCortex provides User Authentication as well as User and Group Management. This provides the means to define access rights to information. SocioCortex uses a whitelisting approach and shares no information by default, requiring access to be explicitly allowed. The Access Control can also be based on attributes.

[5] `http://www.omg.org/spec/OCL/` [Online; accessed: 11-December-2016]
[6] `http://www.omg.org/` [Online; accessed: 11-December-2016]
[7] `https://msdn.microsoft.com/de-de/us-en/library/bb397926.aspx` [Online; accessed: 11-December-2016]
[8] `http://microsoft.com/` [Online; accessed: 11-December-2016]

Role-based Access Control for content and files comes out-of-the-box. It allows for flexibility when dealing with sensitive data. For example, a company could chose to share some data with all users, but keep other data visible only to employees. Having such a feature supported from the start is very helpful for the development of the CMEE, since it allows the development efforts to focus on other aspects.

The Access Control also supports third party identity providers. This makes it future proof, when such an identity provider could be connected for each member, to enable their employees to use the system.

For the rapid development of the explorer, the fact that authentication was included with the system was beneficial. This meant, that users and authentication systems were implemented already, and did not have to be reimplemented. This included functionality like resetting forgotten passwords. This functionality is a requirement in any modern web application, that has user logins, but implementing them is repetitive, cumbersome and unrewarding. Choosing a system, which has already taken care of such menial tasks appears to be a good choice, as development efforts can go to the unique aspects of the solution.

4.2.2. Advantages

The wiki system allows any rich, unstructured text to be associated with any entity. This means descriptions of any element can be included in a very graphical way. SocioCortex provides a typical rich text editor in its web user interface. Files and images can be attached to arbitrary entities. For the editors this provides the advantage, that they can work very directly and are supported by the flexibility of the system.

The system also allows connections to be formed. The EntityType system allows certain entities to be of a defined structure. These structures are associated with schemas. A schema defines property definitions. Each property definition includes the name, multiplicity, whether the attribute is read-only, and the type of attribute. The type of attribute can be left untyped, meaning any type of value is accepted. Alternatively the type can also be specified to any desired level.

A sample of what can be done in SocioCortex is shown in Figure 4.22. It is detailed in subsection 4.4.2, when the visualizations have been introduced.

The hybrid wiki allows collaboration, real time editing of knowledge. It provides a interface which non-technical experts can use out-of-the-box.

4.2.3. Difficulties

The choice of SocioCortex leads to several issues which need to be addressed. A dependency is created towards the system, which limits features and flexibility. The type and speed of possible queries is also limited through the choice. When completing this thesis and analyzing the performance there were 52 Organizations, 57 Relations, and 10 RelationTypes. The relatively small number of entities highlight how important it was to find solutions to the limitations highlighted in this section.

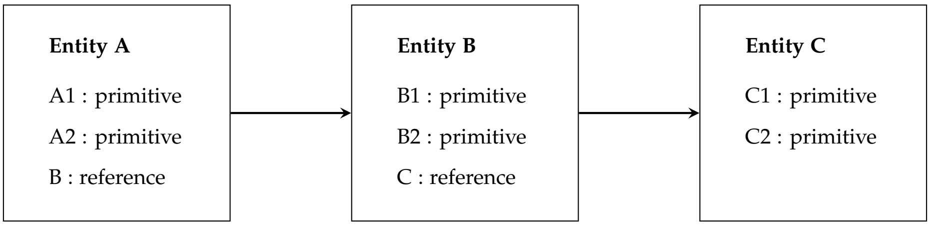


Figure 4.4.: Model for Query Example

The limitations of the *angular-sc* library was found when trying to insert data via its implemented features. Inserting data and performing certain types of queries is impossible. This made it necessary to implement the additional features. It appears to be more feasible to rely on a custom implementation of authentication as well as a query system. This way, functionality could have been implemented without distributing it amongst *angular-sc* and a custom implementation.

Speed became an issue when trying to query referenced entities. The issue arose, because of the differing use cases. SocioCortex is designed to support arbitrary data models. This makes it infeasible to know the schema of what is being queried. The position of the CMEE is rather unique in that aspect. It is possible to query referenced entities using the native API as well as the MxL interface. For cases when using the native API, there is the optional `attributes` parameter, with which it is possible to define which attributes should be returned. The limitation of this system is twofold. Only one level can be retrieved, and the process cannot be used to repetitively designate desired attributes from the referenced entity. Secondly, only the default set of attributes: `id`, `name`, and `url` are returned from the referenced entity.

When using MxL, the behavior is similar. While the limitation remains, that only one level of references can be resolved, the default behavior in MxL is to return the entire entity. This is different to the native API, where only the default set of attributes are returned. As a result, when querying with MxL, it is as though two levels of references can be fetched, since all attributes will be resolved of the queried entities. Both methods suffer from slow performance, when the attributes that should be partly fetched include a large entity.

In this case, that entire large entity would be sent back in the response. While SocioCortex is capable of executing the query very quickly, the transmission causes a noticeable delay.

Figure 4.4 shows a set of data which can be queried. Three entities: A, B, and C are depicted. A contains a reference to B, and B contains a reference to C. Assuming the query begins with entity A, the api query can access all attributes of A. Concretely, this would be A.A1, A.A2, and A.B. In the special case of B, it would also provide the entity B. The limitation is that it would only fetch `id`, `name`, and `url` of B. From this dataset, it is impossible to receive the reference to entity C immediately. Due to the url of B being in the dataset, another query of all attributes of B could be used in order to retrieve C. Using MxL, the query shown in Figure 4.5 could be run.

```
find(Entity).where(name="A").select({A1,A2,B})
```

Figure 4.5.: MxL Example Query

The fetched result would be A.A1, A.A2, A.B, B.B1, B.B2, B.C. In this case, it would be immediately possible to retrieve C, since the reference is known.

Consulting Manoj Mahabaleshwar, an expert of the SocioCortex system, revealed that a method can be used to overcome this problem. It was Manoj who proposed the solution and it is merely documented in this thesis, due to its importance for the future of the CMEE. The drawbacks resulting from the method are manageable and overcome the limitations it introduces. When returning an array instead of an object, any depth of references can be explored and returned. The downside is that the results are disassociated from their attribute names. This means some information must be temporarily stored and shared (from query to results) to (re-)associate results with attribute names. The upside of this approach is that data can be retrieved in one step, which was thought to require multiple queries. The query in Figure 4.6 returns all primitives when applied to the model from Figure 4.4.

```
find(Entity).where(name="A")
  .select(a => [a.A1, a.A2, a.B.B1, a.B.B2, a.B.C.C1, a.B.C.C2])
```

Figure 4.6.: MxL Example Array Query

The MxL query method from Figure 4.6 (for a practical example see Figure 4.12) is remarkable, because it enables traversing of three layers of references, and in fact would allow to traverse indefinitely. No other way is known, how this could be accomplished in either MxL or via the native API. While this way of extracting information via MxL requires information be kept about the order of the queried attributes, it remains feasible. In fact, a wrapper could be written to transform a query, which tries to access more than one level of attributes into the array, fetches the result, associates it with the names and returns the result.

Query Examples

Querying the API for Relations, and focusing on the cooperation between TUM LLCM and CML. Figure 4.7 shows a simple API query for all Relations (which are defined by their EntityType: `1630i9oo8te5d`). The result shows the smallest possible response. Only `id`, `name`, and `href` are returned. This is suitable for generating a simple list of Relations. If more information is required, either a secondary query has to be performed to fetch the relevant data, or the attributes have to be requested in the query.

```
GET /api/v1/entityTypes/1630i9oo8te5d/entities/

[
  ...
  {
    "id": "ms3dmdh2bqto",
    "name": "LLCM_CML_Coop",
    "href": "/api/v1/entities/ms3dmdh2bqto"
  },
  ...
]
```

Figure 4.7.: Simple API Query

The query in Figure 4.7 took 125 ms.
The size of the response was 9 073 B.

Figure 4.8 shows an example where the `attributes` parameter of the `GET` request is used in order to retrieve further attributes. It shows a special case, where the star (*) indicates all parameters should be returned.

```
GET /api/v1/entityTypes/1630i9oo8te5d/entities/?attributes=*

[
  ...
  {
    "id": "ms3dmdh2bqto",
    "name": "LLCM_CML_Coop",
    "attributes": [
      {
        "id": "12svxg118mgj9",
        "values": [
          {
            "id": "cssuxxtb88j5",
            "name": "Cooperation",
            "href": "/api/v1/entities/cssuxxtb88j5"
          }
        ],
        "name": "relationType",
        "href": "/api/v1/attributes/12svxg118mgj9"
      },
      {
        "id": "1l7wgujfv8xm1",
        "values": [
          {
            "id": "1ku3p01mj9dhs",
            "name": "Living Lab Connected Mobility",
            "href": "/api/v1/entities/1ku3p01mj9dhs"
          }
        ],
        "name": "from",
        "href": "/api/v1/attributes/1l7wgujfv8xm1"
      },
      ...
    ],
    "href": "/api/v1/entities/ms3dmdh2bqto"
  },
  ...
]
```

Figure 4.8.: API Query With All Attributes

The query in Figure 4.8 took 443 ms. The size of the response was 108 937 B.

This is most comparable to the Structured Query Language (SQL) request shown in Figure 4.9

```sql
SELECT * FROM Relation;
```

Figure 4.9.: SQL Query Equivalent to API Query with All Attributes

If only certain attributes should be returned, this is possible, just like in SQL.

Figure 4.10 shows how a simple MxL query for Relations looks. Here `iqo0a6z1mmz6` is the id of the workspace, in which the query is executed. The payload of the query is `{expression:"find(Relation)"}`. Unlike the native API query, the MxL query returns everything by default.

```
POST /api/v1/workspaces/iqo0a6z1mmz6/mxlQuery
     {expression:"find(Relation)"}

{
  "expression": ...
  "value": [
    ...
    {
      ...
      "id": "ms3dmdh2bqto",
      ...
      "name": "LLCM_CML_Coop",
      "lastModifier": {
        ...
      },
      "permissions": ...
      "attributes": [
        {
          "id": "12svxg118mgj9",
          "values": [
            {
              "id": "cssuxxtb88j5",
              "name": "Cooperation",
              "href": "/api/v1/entities/cssuxxtb88j5"
            }
          ],
          "name": "relationType",
          "href": "/api/v1/attributes/12svxg118mgj9"
        },
        ...
      ],
      "mayEdit": true,
      "href": "/api/v1/entities/ms3dmdh2bqto",
      "lastModifiedAt": "2016-08-17T21:18:46.000Z"
    },
    ...
  ],
  "type": ...
}
```

Figure 4.10.: API MxL Query

The query in Figure 4.10 took 2 163 ms. The size of the response was 303 700 B.

The query can be modified to filter out unwanted attributes. MxL uses the `select` query function, in order to achieve this. Figure 4.11 shows a query which returns only the `from`, `to`, and `relationType` of Relations.

```
POST /api/v1/workspaces/iqo0a6z1mmz6/mxlQuery
    {expression:"find(Relation).select({from, to, relationType})"}
```

Figure 4.11.: API MxL Query with Attributes

The query in Figure 4.11 took 13 898 ms. The size of the response was 1 377 489 B. The long duration can be attributed to the size of the data that is transferred.

```
POST /api/v1/workspaces/iqo0a6z1mmz6/mxlQuery
      {expression:"
        find(Relation)
          .select([
            id,
            from.id,
            from.abbreviation,
            to.id,
            to.abbreviation,
            relationType.id,
            relationType.enumName,
            relationType.inverseRelationType.id,
            relationType.inverseRelationType.enumName
          ])
      "}
```


```
{
  "expression": {
    ...
  },
  "value": [
    ...
    [
      "ms3dmdh2bqto",
      "1ku3p01mj9dhs",
      "LLCM",
      "uve85xsqsoey",
      "CML",
      "cssuxxtb88j5",
      "Coop",
      "cssuxxtb88j5",
      "Coop"
    ],
    ...
  ],
  "type": {
    ...
  }
}
```


Figure 4.12.: API MxL Array Query

Table 4.1.: Query Comparison

	Time (ms)	Size (B)
API	125	9 073
API with All Attributes	443	108 937
MxL	2 163	303 700
MxL with Attributes	13 898	1 377 489
MxL Array	469	21 122

The query in Figure 4.12 took 469 ms. While it is required to maintain the order of attributes in order to work with the result, the tradeoff is worth it. Querying via the array method is over an order of magnitude faster. The total loading time was 8.65 s. The size of the response was 21 122 B.

Table 4.1 shows a comparison of all query examples. The table however is not able to show the differences in responses. Both API (Figure 4.7) and MxL (Figure 4.8) would most likely require further queries in order to be useful. The query from Figure 4.10 (API MxL Query) is useful, but unable to provide attributes of the RelationType. MxL with Attributes (Figure 4.11) does, but is unable to go a level further and provide attributes of the `inverseRelationType`. Additionally it results in a significant amount of overhead, for very little gain. The MxL Array (Figure 4.12) is the only query which is able to traverse indefinitely. While it does not provide as much data as some others, it is possible to specify exactly which data is desired. While it might not always be feasible to know the schema, which the MxL Array method requires, in cases where the schema is known it seems to be the preferable method. By querying the EntityType, it is also possible to make the system flexible. It does mean that data will have to be post-processed, but that is possible in less time than the system requires. It can also be done as the first batch of data can be exposed to the view model for example. Our research finds the MxL Array method is a suitable fix to performance problems resulting from the way EntityTypes are connected if they resemble the problem found here.

4.3. CMEE Web Application

The CMEE web application was created to complement the SocioCortex instance. It was designed to enhance the capabilities, and make the explorer more user friendly. The visualizations are displayed within the CMEE web application. Additionally, a tool was created to support the creation of Relations, which could also be used from within the CMEE web application.

A Single-Page Application (SPA) was created to achieve these goals. The advantage of packaged SPAs is that they can easily be deployed to any server environment. Express[9]

[9] `http://expressjs.com/` [Online; accessed: 11-December-2016]

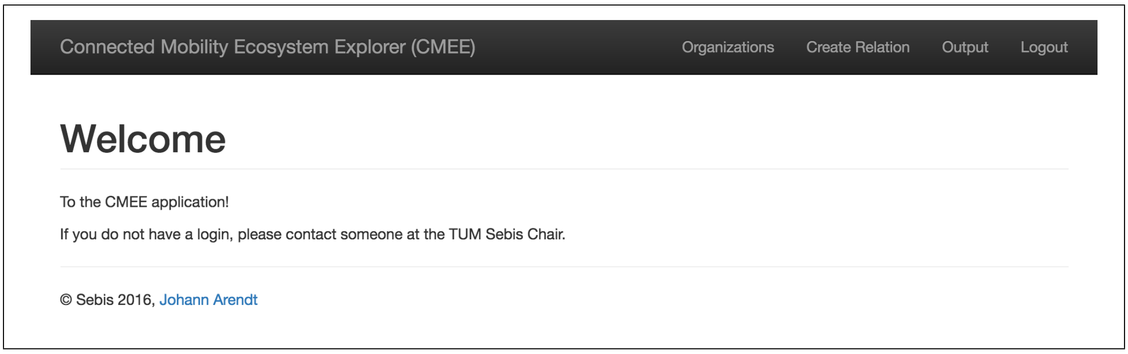


Figure 4.13.: Welcome

was used to develop the application, but it was later deployed to a server running Apache[10].

The web application runs only on the client. This means the client communicates directly with the API, making use of both native API queries and MxL. While this moves some of the logic towards the client side, which can be undesirable, it meant no backend had to be created. The web application only needed a minimum of logic in order to communicate with the SocioCortex API.

Besides AngularJS and some AngularJS plugins, the frontend made use of several frameworks which were not created during this thesis. A complete list of dependencies can be found in section A.2 (page 76).

In section A.1 the iterations of the web application, beginning with a paper prototype, are shown. The result of the iterative agile process development can be seen in Figure 4.13, Figure 4.14, Figure 4.15, and Figure 4.16.

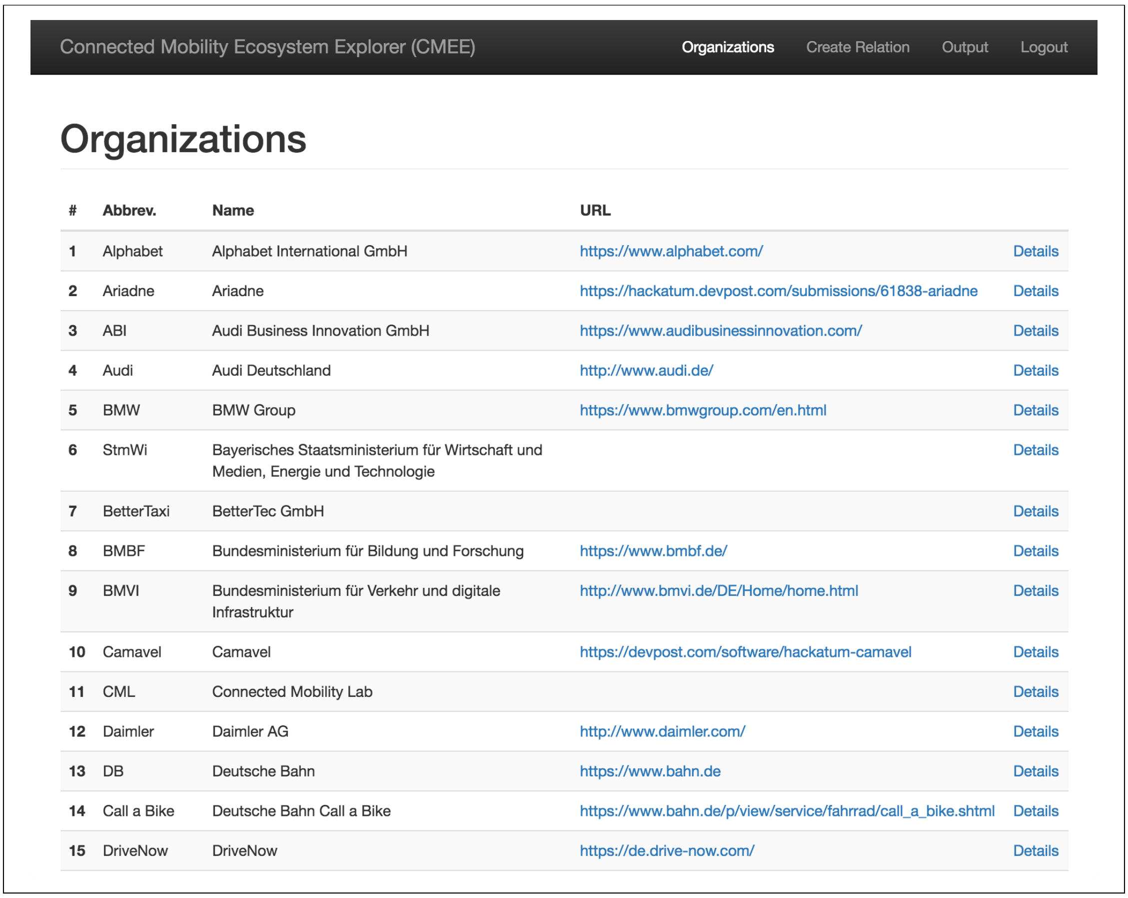
Figure 4.13 shows the initial view of the web application. Users that are unable to authenticate will not be able to progress past this view.

Figure 4.14 shows a list of all organizations known to the CMEE. It is meant to provide a concise overview of all organizations. From the organization list it is possible to get to the SocioCortex page of the respective organization as well as the company website, if the url is stored in SocioCortex.

Figure 4.15 shows the create relation view. It makes creating relations between existing organizations easier. While relations can be created from within SocioCortex, this part of the web application reduces the number of steps. Additionally it can prevent creating unnecessary entries, by checking the existence of other relations.

Unnecessary entries are those, which add no additional information. Examples include duplicate relations (same from, to, and RelationType parameters) or Relations which have already been added in the corresponding opposite direction. In these cases it is preferable to prevent confusion and only enter one direction. The create relation tool checks these factors before inserting. For the users convenience it also shows any related

[10] `https://httpd.apache.org/` [Online; accessed: 11-December-2016]



Connected Mobility Ecosystem Explorer (CMEE) Organizations Create Relation Output Logout

Organizations

#	Abbrev.	Name	URL	
1	Alphabet	Alphabet International GmbH	https://www.alphabet.com/	Details
2	Ariadne	Ariadne	https://hackatum.devpost.com/submissions/61838-ariadne	Details
3	ABI	Audi Business Innovation GmbH	https://www.audibusinessinnovation.com/	Details
4	Audi	Audi Deutschland	http://www.audi.de/	Details
5	BMW	BMW Group	https://www.bmwgroup.com/en.html	Details
6	StmWi	Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie		Details
7	BetterTaxi	BetterTec GmbH		Details
8	BMBF	Bundesministerium für Bildung und Forschung	https://www.bmbf.de/	Details
9	BMVI	Bundesministerium für Verkehr und digitale Infrastruktur	http://www.bmvi.de/DE/Home/home.html	Details
10	Camavel	Camavel	https://devpost.com/software/hackatum-camavel	Details
11	CML	Connected Mobility Lab		Details
12	Daimler	Daimler AG	http://www.daimler.com/	Details
13	DB	Deutsche Bahn	https://www.bahn.de	Details
14	Call a Bike	Deutsche Bahn Call a Bike	https://www.bahn.de/p/view/service/fahrrad/call_a_bike.shtml	Details
15	DriveNow	DriveNow	https://de.drive-now.com/	Details

Figure 4.14.: Organizations

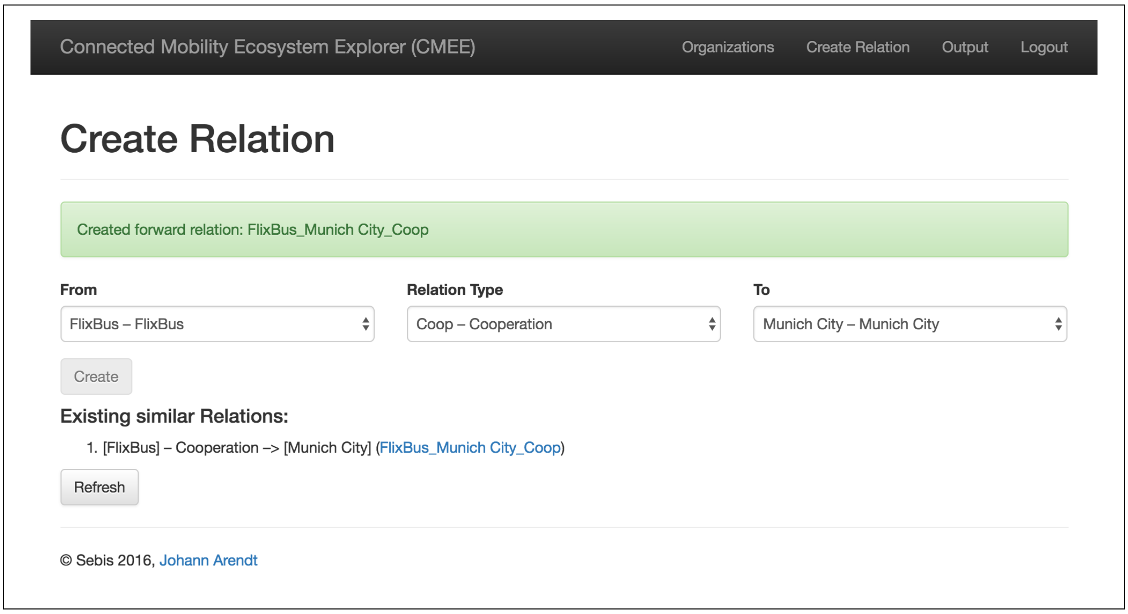


Figure 4.15.: Create Relation

Relations – which are defined as Relations containing both of the organizations involved. By linking the users to the corresponding Relation pages in SocioCortex, editing the correct Relation can be handled easily.

Figure 4.16 shows the view selection of the CMEE web application. From it, users can select the desired visualization. The large preview images give the user an idea of what the result will look like.

4.4. Visualization

Visualizations have the power to answer questions, or discover them in the first place. Seeing data in context allows those viewing them to find patterns and make decisions based on data. Visualizations can be used as inspiration or be used to present an argument. Users can use the visualizations provided by the CMEE to decide which company to approach for a partnership, which company to fund or who to ask for technical expertise.

The value of visualizations lies in recording information. For example, it can record the current state of the Connected Mobility Ecosystem at a given time. This information can be communicated to others by using the visualization. An employee can explain to their superiors why they are in favor of a business decision.

The choice was made to encode organizations and relationships in two visualizations. The representation as a node-link graph followed interests of a visually appealing structure, capable of supporting the decision making process and exploring ecosystem

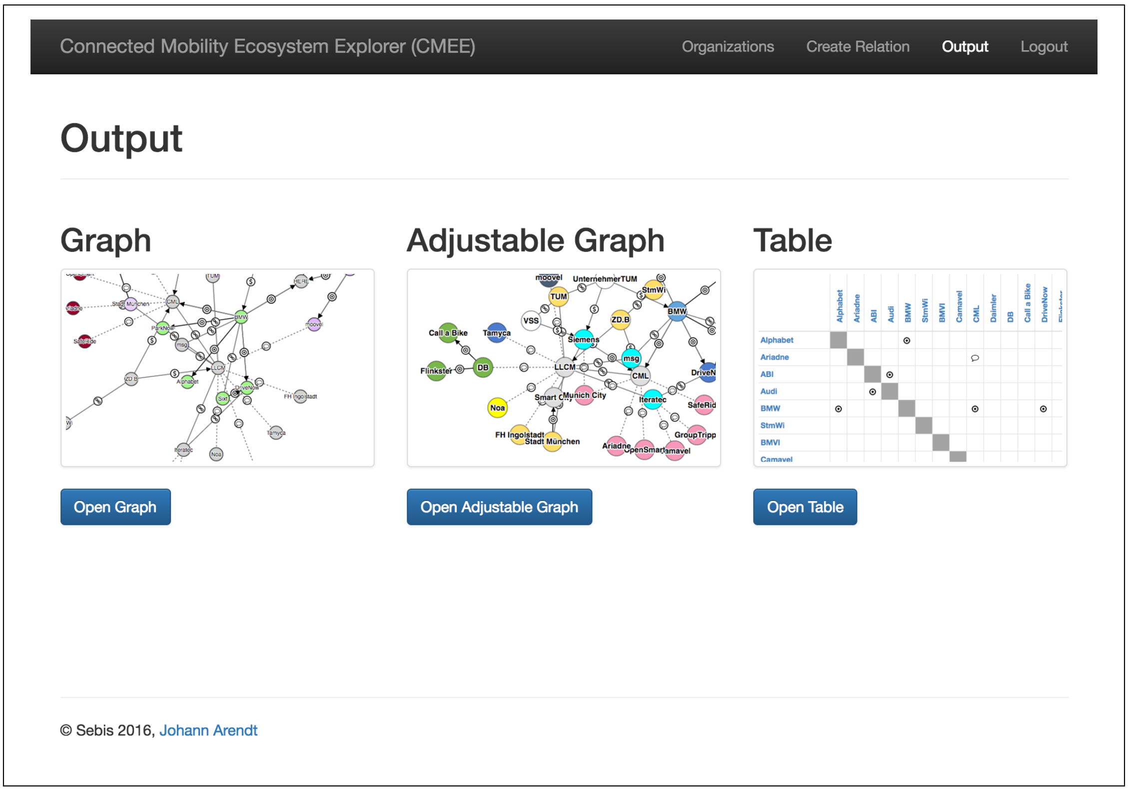


Figure 4.16.: Visualization Selection

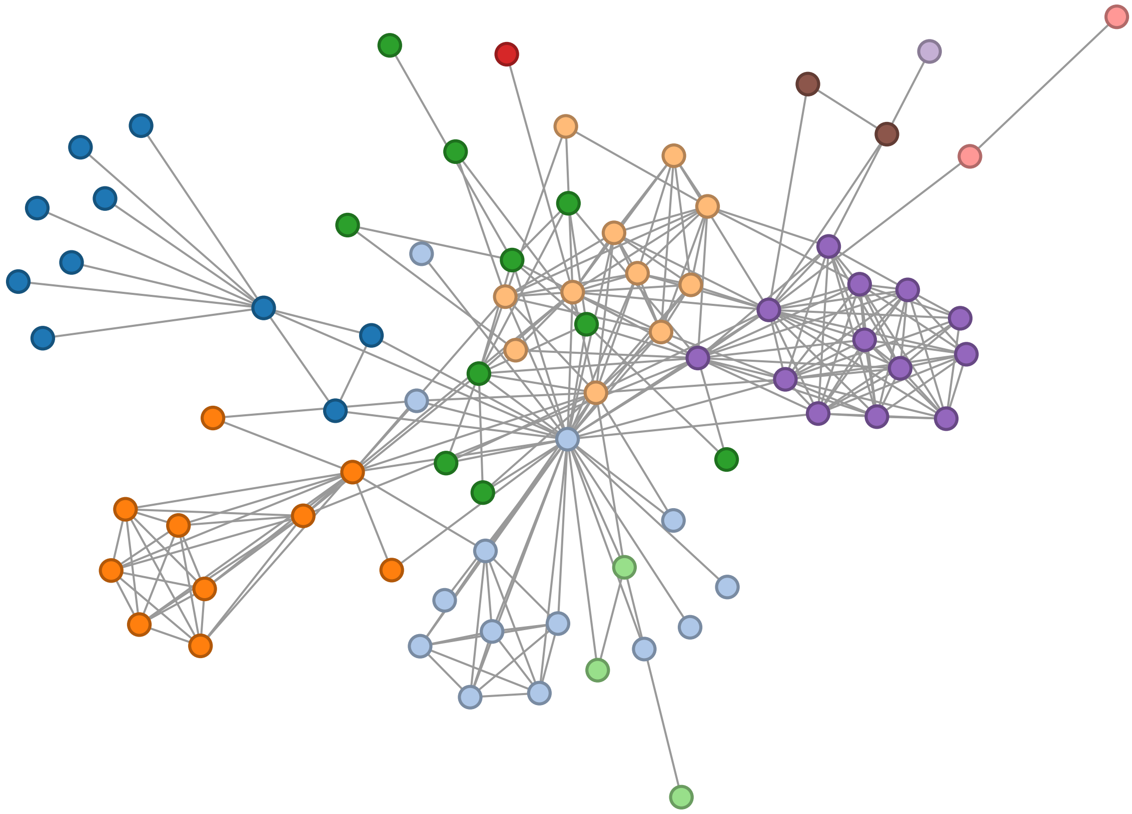


Figure 4.17.: Force Graph Example [Bos16]

data [Kai+12; Bas+16]. They derived three views for their ecosystem analysis: a list, a matrix and a network. A table structure was chosen for the CMEE web application for the ability to easily check certain relationships. The table view is suitable for this cause, as it can be sorted, whereas visually it is harder to locate a certain link (or absence of link) in a node-link graph. The table is more resilient to changes, and makes it easier for viewers to compare different states of the dataset. Since the graph would look different each time, comparing two graphs proved difficult. In the detailed look at both of these visualizations, the assumption is, that a graph $G = (V, E)$ is present as a dataset, where V are the vertices (nodes) and E the edges.

Since ideas diverged about how the graph visualization could look, two versions are offered to the users. Both try to generate an attractive graph. The regular graph is meant for being ready to view, while the adjustable graph relies on the user to position nodes to their liking. Both are instances of force directed graphs. Visualizations all employ hyperlinks to connect with SocioCortex. This allows users to click on the visualizations and be brought to the corresponding entity within SocioCortex.

4.4.1. Force Directed Graph

A force directed graph is created using an algorithm. The algorithm calculates the positions of nodes *N* by using multiple forces [Cri+11; KS12; Zab10]. On the one hand, an attractive force is applied between two nodes, if they are connected. On the other hand, a repulsive force is added between all nodes. Since the layout algorithm handles the positioning and no coordinates have to be specified, no special knowledge of graph algorithms is required in order to use it. This makes it a common choice to visualize data.

In each step of the simulation the positions of all nodes and links are calculated as a result of forces being applied on them. Each iteration of the simulation is referred to as "tick". The simulation is repeated multiple times, and terminates when the algorithm supposes a suitable state.

The D3[11] library enables data driven documents by providing means for developers to manipulate documents based on data. Its document manipulation tools allow developers to use any visualization technique, but at the same time simplify the development. For example it offers a declarative selection process, preventing the developer from having to write tedious imperative DOM API manipulations.

The force layout of D3 acts slightly differently than the typical force graph. An example of a graph created with the D3 force graph can be seen in Figure 4.17. It calculates node positions in each step of the simulation (called "tick"). Usually force graphs use a spring-like attractive force and a force similar to Coulomb's law to push nodes away from each other. D3 uses `charge` to describe the forces between nodes. A negative charge pushes nodes away, while a positive charge pulls them together. The distance a node is displaced in each tick, according to its position, its charge, and the position of all other nodes. The combination of these factors determine where the node will be on the next tick.

The distance between nodes is defined by a weak geometric constraint called `linkDistance`. The layout attempts to make the distances as close to the `linkDistance` as possible, but since the charge function affects the distance, even a constant `linkDistance` may result in non-constant lengths between nodes. In addition, D3 uses `friction` and `alpha` parameters to end the simulation. The `friction` parameter slows down the rate of travel with each tick. The `alpha` parameter decreases the forces acting on each node with each tick. If not for these factors, it would be impossible to end the simulation resulting in a usable layout for the graph. It should be noted that there is no guarantee the visualization resulting from a force layout will be optimal or free of intersections.

For the implementation of the explorer visualization, the `charge` and `linkDistance` parameters were adjusted. The goal was to move individual nodes to the outside of the graph, with shorter edges, while keeping the strongly connected nodes closer to the middle with longer edges, to prevent clustering. In order to calculate these adjusted values, the total number of edges was required. Each edge has a `from` and `to` node.

[11] `http://d3js.org/` [Online; accessed: 11-December-2016]

```
function calculateCharge(node) {
  return 50 * Math.tanh(node.neighbors.length / 4 - 2) - 400;
}
```

Figure 4.18.: Force Graph Charge Function

```
function calculateLinkDistance(edge) {
  var fromLength = edge.from.neighbors.length,
    toLength = edge.to.neighbors.length,
    maxLinks = Math.max(fromLength, toLength),
    minLinks = Math.min(fromLength, toLength),
    linkDiff = Math.max(1, maxLinks - minLinks);

  return 45 + maxLinks*7; + 1/linkDiff*5
}
```

Figure 4.19.: Force Graph Link Distance Function

Each node has a parameter `neighbors` which is an array of all neighbors. The `charge` function is shown in Figure 4.18. It resulted in nodes that were relatively close together, but the effect was enough to create an initial separation. The `linkDistance` function is shown in Figure 4.19.

Nodes can be moved using a drag function in the adjustable graph. Once an organization is moved, it is pinned in that location. Any remaining unpinned nodes will try to readjust in order to optimize the way the graph is displayed. If this process is repeated until all organizations have been moved, no recalculation is done. This method has the advantage of being able to manipulate the organizations into groupings the user desires, even if it is only the first step towards fully being able to explore the graph.

In the regular graph (Figure A.9, page 76) transitive relationships are encoded with the color instead. This was done in order to identify groupings amongst companies, in order to show their ownership affinity. These groupings did not have to be defined explicitly, because the graph nature of the data made it possible to identify them programmatically.

In the future it may be valuable to build on the work of Zhang, as they proposed a novel idea of constraining a force graph to any polygon [Zha14]. This could be used in order to prevent nodes from overlapping with the legend in the graph. Work needs to be done to improve the work of Zhang, in order to prevent edges to also overlap the polygon. This would result in lines also overlapping the legend in the Connected Mobility Ecosystem Explorer. The same result was achieved in the ecosystem explorer by altering the transformation function. Simple checks were added, in order to reposition nodes, if they would otherwise be colliding with the legend.

Figure 4.20 shows the latest version of the adjustable graph in the CMEE web applica-

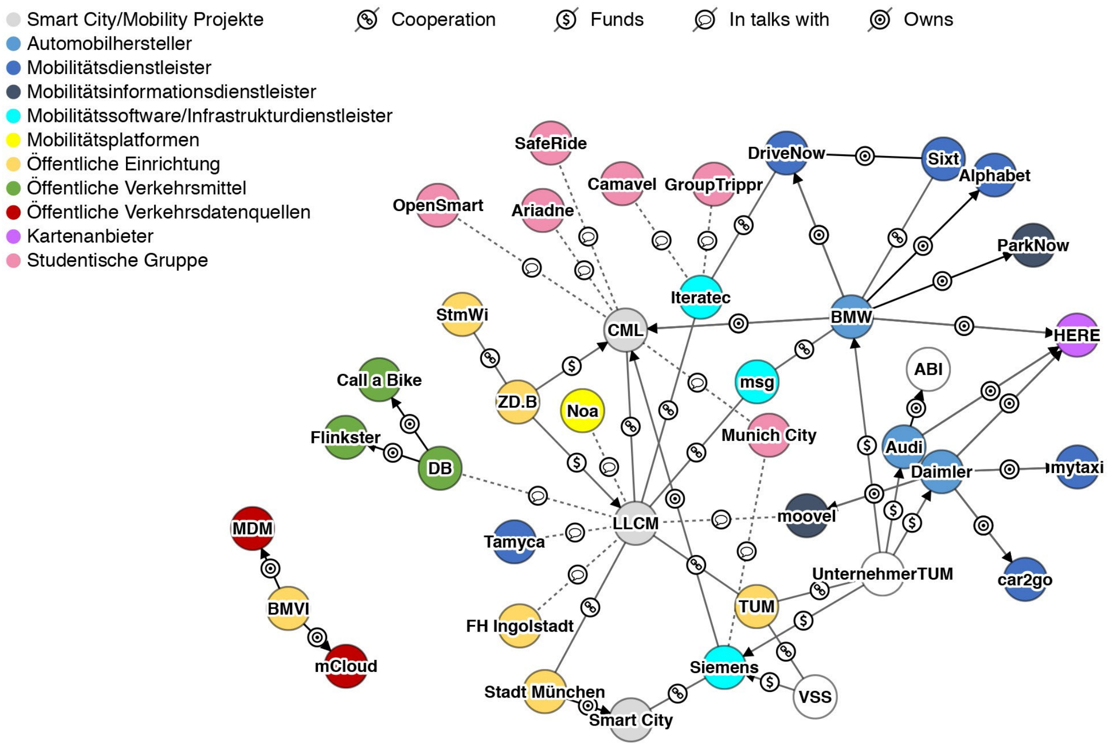


Figure 4.20.: Force Graph Export

tion. The category of organizations is encoded using the color. Relations are encoded by the links between organizations. Arrows indicate the direction of Relations where appropriate. The RelationType is encoded using the circular icons on relations.

4.4.2. Table

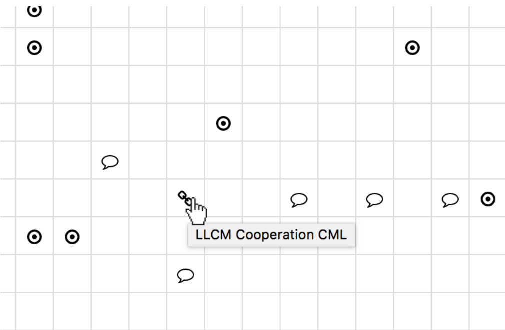
The table was inspired by an adjacency matrix. Let $|V| = n$ and $|E| = m$. The x-axis and y-axis were labeled with all V, making a $n \times n$ Matrix. A marker was places in the point $p(x_p, y_p) \iff (x_p, y_p) \in E \vee (y_p, x_p) \in E$ In the second case of the reversed occurrence, the direction of the relation had to be reversed. This was done by making use of the `inverseRelationType` explained in section 3.2. For example, if an "Owns" relationship was found in the opposite direction, it would be turned into an "Owned By".

Abbreviations were used for the names of organizations to increase the information density. In order to make interacting with the data possible, rather than just viewing information, basic methods of web documents were used. Organization abbreviations were linked to their dataset in SocioCortex. Users of the CMEE can profit from the SocioCortex integration. It is possible to view, edit and search for entities. Entity types can be edited and relationships explored. An example is shown in Figure 4.3, where all mobility providers are listed. Users can find this view, by navigating to the OrganizationCategory page "MobilityProvider". At the bottom of the page is a list of all

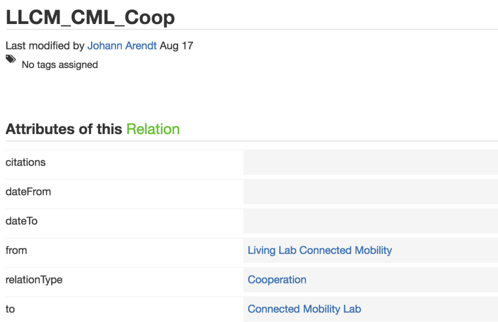
🔗 Cooperation $ Funds 💬 In talks with ⊙ Owns

	Alphabet	Ariadne	ABI	Audi	BMW	StmWi	Camavel	CML	Daimler	DriveNow	GroupTrippr	HERE	mytaxi	Iteratec	LLCM	Munich City	OpenSmart	SafeRide	Siemens	Sixt	FH Ingolstadt	TUM	UnternehmerTUM	VSS	ZD.B	car2go	moovel	msg	Tamyca
Alphabet					⊙																								
Ariadne								💬																					
ABI				⊙																									
Audi			⊙									⊙											$						
BMW	⊙							⊙		⊙		⊙								🔗			$					🔗	
StmWi																									🔗				
Camavel														💬															
CML		💬			⊙										🔗	💬	💬	💬	⊙						$				
Daimler												⊙	⊙										$			⊙	⊙		
DriveNow					⊙									🔗						⊙									
GroupTrippr														💬															
HERE				⊙	⊙				⊙																				
mytaxi									⊙																				
Iteratec							💬			🔗	💬				🔗														
LLCM								🔗						🔗							💬	🔗			$		💬	🔗	💬
Munich City								💬											💬										
OpenSmart								💬																					
SafeRide								💬																					
Siemens								⊙								💬							$	$					
Sixt					🔗					⊙																			
FH Ingolstadt															💬														
TUM															🔗								🔗	🔗					
UnternehmerTUM				$	$				$										$			🔗							
VSS																			$			🔗							
ZD.B						🔗		$							$														
car2go									⊙																				
moovel									⊙						💬														
msg					🔗										🔗														
Tamyca															💬														

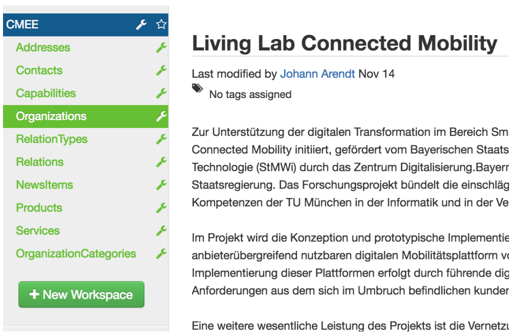
Figure 4.21.: Table View



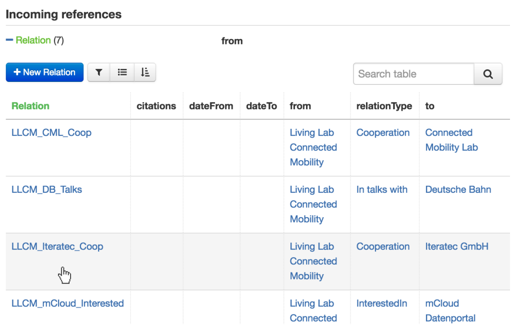
(a) Relation Hyperlink Clicked



(b) Relation in SocioCortex



(c) Organization in SocioCortex



(d) Relations of an Organization

Figure 4.22.: SocioCortex Workflow

incoming references, which is what can be seen in Figure 4.3.

Hyperlinks were attached to organizations and relationships in the table. This allows users to click either, and access the respective entity in SocioCortex. Use was made of the HTML `title` attribute to provide full organization names and relationship descriptions for the organization and relationships respectively.

Relationships are found in a fixed position. The table view proved useful when testing whether relationships were already in the CMEE. The matrix structure defines where relationships can be found. In contrast to the ever changing graph view, the relationship can be found in a specified place in the table, if present. Figure 4.21 shows how the table looks.

An example workflow can be seen in Figure 4.22.

- (a) shows how the user interacts with the table view. It is possible to see a brief summary of the relationship the user is exploring in the tooltip. The tooltip shows the organizations involved and the type of relationship. In the example it is possible to see "LLCM Cooperation CML".
- (b) shows what the relation entity looks like in SocioCortex. The attributes visible are defined by the schema. The user can navigate to the organization entity of the Living Lab Connected Mobility, by clicking on the name.
- (c) shows an organization entity, with unstructured wiki markup visible. On the bottom of the organization entity, the user will find any incoming and outgoing relations, shown in (d), just like on the relation entity.

5. Evaluation

An evaluation was conducted to test the success of the research and implementation of the CMEE. It was designed to test assumptions made during the development, as well as how the CMEE is perceived. Interest was placed on both the ability to modify and understand concepts, as well as perception of the visualization.

5.1. Technique

In order to evaluate the modeling efforts, as well as visualizations which were created, interviews appeared appropriate. The flexibility of interviews allow interviewees to focus on aspects that pertain to them. In order to be able to assess the CMEE, quantitative research methods seemed appropriate to roughly categorize the success achieved. On the other hand qualitative research methods would allow a deeper understanding of why participants reacted in a certain way. Additionally it opened up the possibility of requesting what could improve the CMEE in the future. These considerations fit semi-structured interviews. Participants were selected from outside the Connected Mobility Ecosystem, so that the results would convey whether the CMEE is a suitable way to convey information to potential startups.

5.1.1. Targeting

Participants are associated with nine different companies. Seven of them are stationed around the Munich area. The job titles of the participant include research associates, engineers, IT consultants, product managers and CEOs. By selecting people further away from the Connected Mobility Ecosystem, feedback would be less biased.

5.1.2. Semi-Structured Interviews

Semi-structured interviews adapted from Weiss were utilized to evaluate the prototype [Wei95]. This evaluation technique allows to integrate multiple perspectives. It also provided a learning opportunity to see how the CMEE was interpreted.

Participants were selected due to their expertise, feasibility as users, and experiences. In the case of the Connected Mobility Ecosystem Explorer, some participants were selected, that would likely be willing to use the system as soon as it becomes available. Others were selected from outside of the Connected Mobility Ecosystem, to evaluate the feasibility. This way, feedback can be obtained, how the existing prototype could be adapted to fit others needs. The added distance of some participants to the ongoings within the Connected Mobility Ecosystem will aid in objectively assessing the ideas and prototypes.

The format of semi-structured interviews adds the ability to vary the depth of topics [GL10]. Participants that are unable to, or choose not to engage are not inconvenienced as much, but it allows those that are capable and willing to, to engage in in-depth conversation. These conversations can bring to light undiscovered issues as well as solutions. At the same time, the semi-structured format will ensure, that some quantifiable data will be obtained as well. It will be less significant, due to the smaller number of participants, but at the same time provide a way to measurably test the hypotheses.

5.1.3. Preparation

In order to prepare the evaluation hypotheses were formed according to the methodology [GL10; Wei95]. Hypotheses were formed to regarding initial research questions (section 1.5), questions that came up during the development as well as the CMEE prototype. Next questions were formed to evaluate the hypotheses. The questions were phrased in a way that would entice answers that could be used to evaluate the research questions. A scenario was developed to give participants the same starting point and target. Before the interviews were conducted, an interview guideline was prepared as recommended by Gläser and Laudel [GL10]. This ensured that a structure was maintained in the interviews. The guideline was concrete enough to set common milestones in the interviews [GL10]. At the same time it is accepted that interviews may deviate from the guideline.

Research was focused on conversation techniques that would invite participants to cooperate [Hil+15]. This included being ready to perform white lies in order to convince participants of the shared common goal.

Hypotheses

The importance of companies and their relationships are known, but information systems are not being used to tackle this knowledge management problem

Figure 5.1.: Hypothesis 1

Hypothesis 1 (Figure 5.1) entails that knowledge management, in regards to companies and relationships between companies, is a common occurrence. It assumes that almost every person is affected by it. Additionally, it assumes that knowledge management is a task carried out mostly in peoples minds. Knowledge sources, such as newspapers, magazines and books may be used to satisfy the need for knowledge, but the assumption is, that people in general neither write this knowledge down (on a personal or company level) nor use information systems for this task.

In order to show Hypothesis 1, it must first be established that understanding companies and their relationships with one another is important. Second, one must show, that knowledge management issues arise as a result of the complexity and finally, it needs to be shown, that information systems are not actively used to support the task.

Having information on both organizations and their relationships is what makes a knowledge management system useful

Figure 5.2.: Hypothesis 2

Hypothesis 2 (Figure 5.2) states the assumption that a system that just stores information on organizations, or one that only stores information on relationship alone is not useful. Further it states that only a system that combines both opens up the possibility of exploring connections and utilizing the information system as a beneficial system.

Scenario

The scenario was developed to give different participants a level playing field. The idea was, to separate the experts from their daily tasks, and to all focus on the same goal. While there would remain a subjective perspective on the task at hand, it allows to compare different participants answers, for they are trying to reach the same goal. Figure 5.3 shows the description, as it was written in the guideline. Participants were read the scenario as printed, to try and keep word variations to a minimum. It should still be noted, that each interview set up would motivate different responses, before the scenario was stated.

> You are leading a research group that wants to rent out private vehicles, in the times that they are not being used (i.e. during the week while the owners commute by public transportation). Your investors want to see a prototype working in the real world, and it is your job to find companies which allow you to collaborate and realize this goal/desire. One of your first tasks is to analyze and contact potential partners. These could be competitors offering similar products, companies offering advice/parts or independent contractors.

Figure 5.3.: Scenario Description

5.2. Results

The interviews were conducted with $n = 10$ participants. Questions 1, 2, and 3 were answered by all 10. One participant felt unable to answer question 4, which explains why only 9 answers can be shown.

5.2.1. Quantitative

This section contains the results of the questions posed in the evaluation. When discussing the results the values are given for the mean μ, the variance σ^2, and the coefficient of variation c_v. The coefficient of variation is defined as:

$$c_v = \frac{\sigma}{\mu}$$

Participants of the interviews were introduced to the scenario. The four questions were all related to the scenario. Each question requested the interviewees to rate their agreement with statements.

Question 1: The organizational information: name, size, branch(es), and revenue, is useful for your task

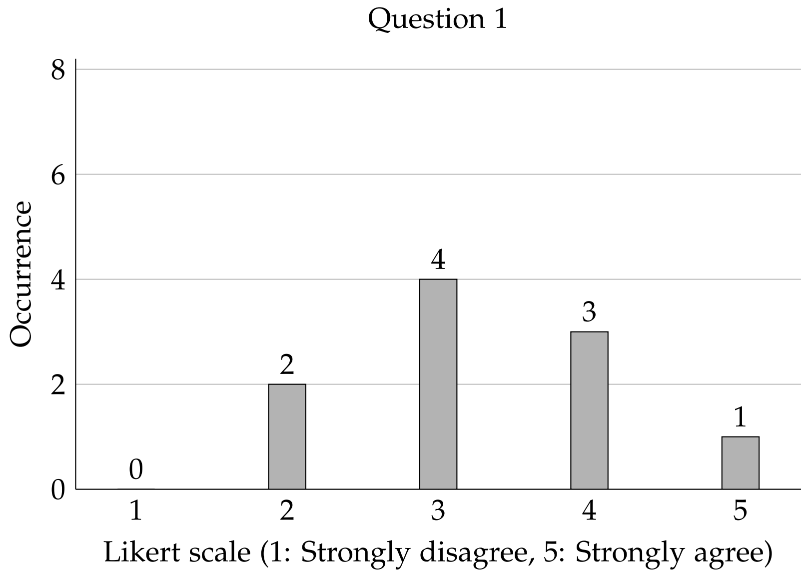


Figure 5.4.: Question 1: Results

Figure 5.4 shows the results for Question 1 with following properties:

$$\mu = 3.3, \quad \sigma^2 = 0.9, \quad c_v = 0.29$$

The results show something very near a normally distributed result. Mean, and variance show that the participants were indifferent towards having only organizations.

Question 2: Knowing links exist between companies, in the form of: cooperations, ownerships, funding, and communication, is useful for your task

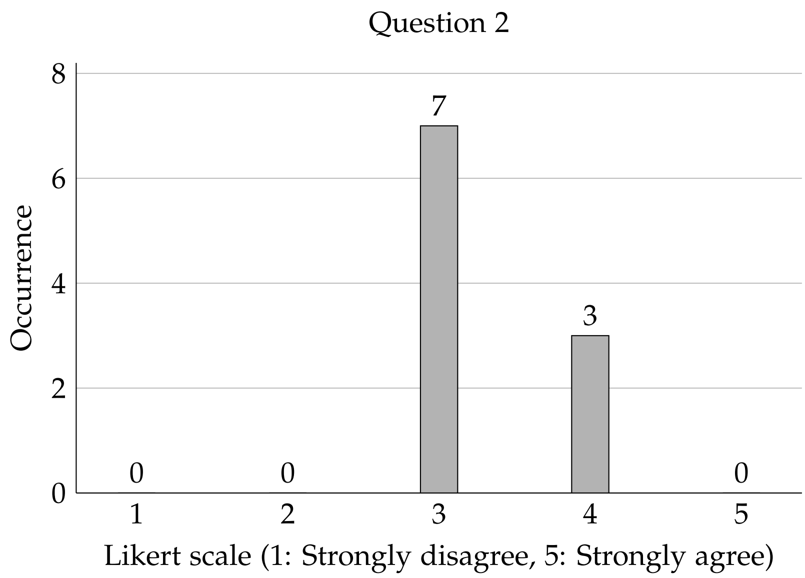


Figure 5.5.: Question 2: Results

Figure 5.5 shows the results for Question 2 with following properties:

$$\mu = 3.3, \quad \sigma^2 = 0.23, \quad c_v = 0.15$$

The results show that participants were much more certain of their indifference. The positive takeaway is that all members that were not entirely indifferent chose to respond positively to the suggestion. Yet the conclusion is that merely having relationships does not help participants in the given scenario.

Question 3: The combination of companies and relationships are useful for your task

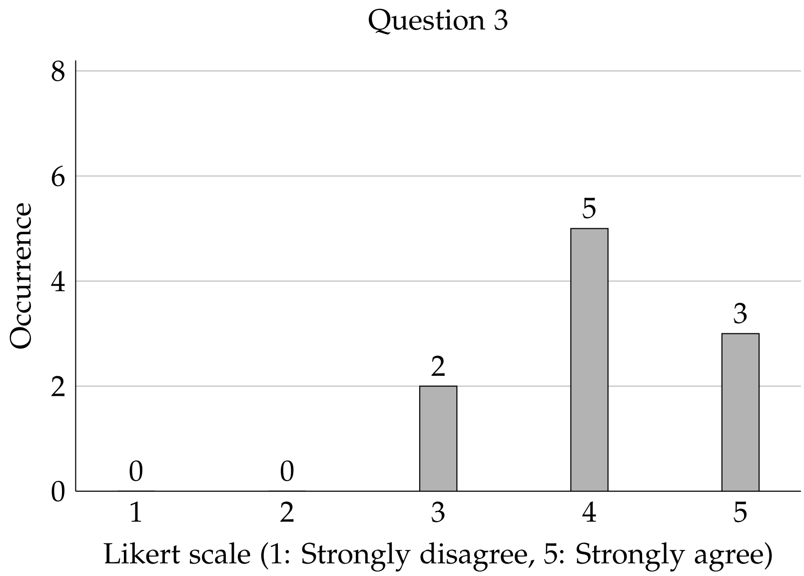


Figure 5.6.: Question 3: Results

Figure 5.6 shows the results for Question 3 with following properties:

$$\mu = 4.1, \quad \sigma^2 = 0.54, \quad c_v = 0.18$$

This shows that participants felt having organizations associated through relationships was useful in mastering the given scenario. This supports Hypothesis 2 (Figure 5.2).

Question 4: For a relationship between organizations to exist, please order the following factors by influence: People, Contracts, Departments, Company, Top Management

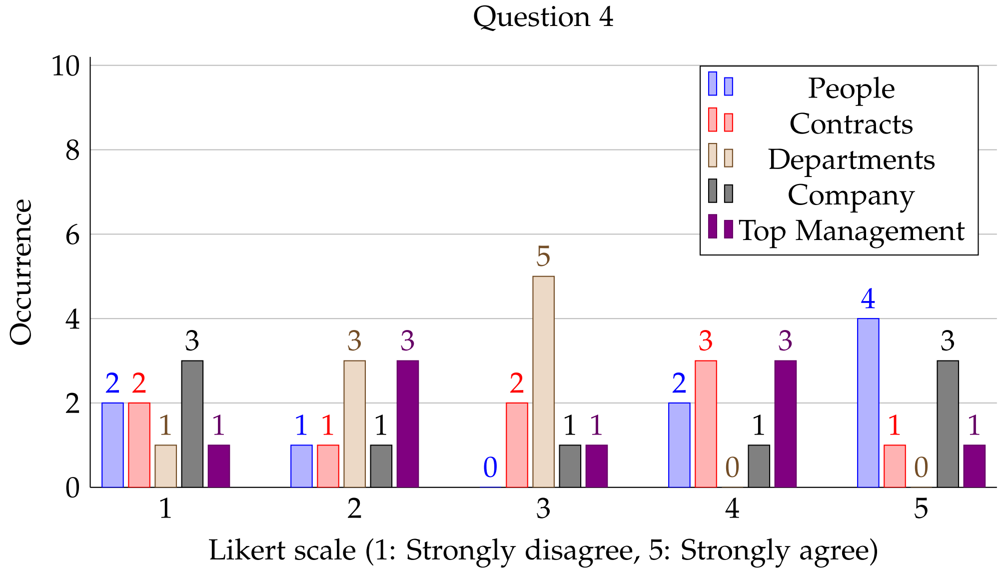


Figure 5.7.: Question 4: Results

The results are grouped by rating and shown in Figure 5.7. Using the mode of results obtained, following order seems most appropriate, ordered from most to least important:

Table 5.1.: Question 4 Tabular Results

		μ	σ^2	c_v
1	Company	3.00	3.25	0.60
2	Top Management	3.00	1.75	0.44
3	Departments	2.44	0.53	0.30
4	Contracts	3.00	2.00	0.47
5	People	3.56	3.03	0.49

The aim of Question 4 was to test whether the abstraction of the CMEE was sufficient. It was designed to show whether the CMEE needs to be accurate to a personal level. The results shown in Figure 5.7 and Table 5.1 show that it was not possible to confirm that People are the most important factors for relationships. The variance and distribution show that there are opposing points of view amongst the participants. Participants commented on the fact the question was difficult to answer. When prompted for their reasoning, the common answer was that organizations and relationships differ too much to generalize. In their opinion size and maturity of an organization affect the correct answer to this question.

5.2.2. Qualitative

After each response, participants were asked what were the defining factors for their choice. The most common use for this practice was in order to understand what additional information the model would require for questions 1 and 2, in order to be deemed useful. It was also used in order to evaluate why some participants chose to respond agreeably to question 1. The result of this particular question was always that having a contact inside the companies responsible for innovative inquiries was the defining positive aspect of the model.

It was remarkable to see how participants responded to the visualization. Many took a critical look at it after their initial impression, and most found particular connections interesting. Interviewees walked away from the interview having gained knowledge of the Connected Mobility Ecosystem. Some participants tried to apply aspects or the entire CMEE to their own struggles with knowledge management. One participant drew the analogies to the patent situation in the pharmaceutical industry. They remarked that it is very difficult to remember which company owns which patent, when it runs out, and who has bought rights to produce it.

Knowledge Management: A Familiar and Common Problem

The interviews showed that 10/10 participants considered knowledge management important. Every participant confirmed interest in relationships between organizations. Despite this, only 1/10 participant used software to assist the knowledge management process involving organizations. In that case, the participant used a spreadsheet to document existing organizations and startups. The CMEE development also included gathering data in spreadsheet format (see Figure A.2).

This showed that participants were familiar with the problem the CMEE tries to solve. Furthermore they understood both the problem and solution and recognized the potential of the CMEE.

Each Organization/Relationship: Unique and Hard to Classify

Participants frequently stated, that individual circumstances make most of the model questions impossible to answer accurately. They noted that the nature of some organizations can be vastly different to others. Examples mentioned included ones where the CEOs of two companies were close friends. This finding relates especially to their answers of question 4, as the variance shows participants uncertainty and opposing points of view.

Additional Knowledge Desired

Different participants expressed desires for new information. This included knowing organizations subcontractors and suppliers, as well as a finer segmentation of organizations into departments or work groups. Some interviewees also expressed desires to have more detail for existing relationships. For example, they wished to know exactly what type of funding was provided, and how much. Others wished to know the nature of cooperations, as they felt the term was too ambiguous.

Suggestions were also made to document money flow in the CMEE. This was mentioned as a way to authenticate that companies are legitimate and worth dealing with.

5.3. Limitations

The evaluation was only conducted with a very limited number of participants. The interviewing process was ended, when the time intensive interview process yielded no new information. Considering the limitations of the evaluation is a necessary step in order to test the findings.

5.3.1. Evaluation

The demographic of people interviewed was very limited. The majority was employed in managing positions, at companies located around the Munich area. Participants were familiar with the problems of knowledge management and trying to analyze other companies. This means, they understood the problem the Connected Mobility Ecosystem Explorer tries to solve. Nonetheless, only one participant had actively used an IS to better understand the company landscape. This leads to the assumption, that for the other interviewees, the problem either was not grave enough, or fixing it not profitable enough, to invest time in solving it. The results of the evaluation should be observed while considering participants may respond differently, if they knew more alternatives. Despite this, most members reacted very positively towards the provided solution. Especially the graph visualization focused peoples attention and imagination. Participants saw it and tried applying such a view to their field of interest. This resulted in suggestions regarding what the system could be adapted for.

Since the overall impression was, that the system would aid someone, given the scenario of innovative interest in finding business partners, it is important to put the results in perspective. Most members were familiar with the problems, but had not solved the problems before a potential solution was presented to them. Due to this, it seems plausible to assume participants were predisposed to respond positively. Additionally, response bias needs to be taken into account [GL10]. From a social point of view, interviewees would not want to make the interviewer feel like their time was invested badly in the solution. This makes them tend towards answering in a way they believe to be expected to answer. Resulting from this, perhaps the evaluation merely tested, whether the solution sounds feasible, and not whether it actually is a good solution.

5.3.2. Data Maintenance

Even if it will be possible to obtain the relevant sets of data in the first place, it will be very difficult to maintain the system and its data. Based on the assumptions and choices, the resulting Connected Mobility Ecosystem Explorer has to be maintained manually. This leads to difficulties with data entry and updating it, because the manual labor required is extremely high and in most cases will lead to mistakes. At the same time, it is unclear whether members will (continue to) provide data required for an accurate representation in the system, and as a result it is impossible to guarantee the freshness of data. Perhaps a system needs to be established in order to validate the data.

Quality Management

Ensuring the quality of data will be an important aspect. During the prototype phase, only members of the chair had access to enter and modify data into the System. For future developments, a process needs to be developed, in order to enforce the quality of information in the CMEE.

Future research can be conducted to evaluate different systems. Current suggestions include an administrated or community managed CMEE. The prototype stage was not able to show strengths or weaknesses regarding the quality management.

5.3.3. Model

The visualization presented in the Connected Mobility Ecosystem Explorer relies on the underlying data model. It is possible to adapt the source of data to a different model, but binding between visualization and SocioCortex limits the freedom to modify the models. The implicit model binding means that changes in the model result in the need to update the views. Failing to do so results in unintended side effects, as were observed during the CMEE development, when model updates were carried out.

The domain model currently does not distinguish between departments or even smaller work-groups. For the prototype of the CMEE, the value of doing so did not justify the effort.

In the future, it may be interesting to be able to show which organization purchases or consumes which product or service from which other company. In order for this to succeed, it would be good, if the relationships were not limited to organization levels, but rather if they the from and to parts of relationships were not typed. This would allow services to be connected to organizations, and used by other organizations. The result could then imply a connection on the organizational level, however it would be nice, if this would not have to be created explicitly.

6. Conclusion and Future Work

As a closing of this work the research questions will be related to the research that has been done. Finally an outlook will be provided for the work done in the future.

6.1. Conclusion

While the evaluation had its limitations, it was continued until no further information could be obtained. The evaluation was questioned extensively in subsection 5.3.1.

1. **How can existing knowledge about the Connected Mobility Ecosystem be aggregated and documented in a reusable fashion?**

Research Question 1 was addressed by identifying members of the Connected Mobility Ecosystem, gathering information, and developing a model for it. A SocioCortex instance was populated with the data, allowing it to be used and reused. The evaluation was conducted to assess how successful this process was. Feedback from the evaluation was used to improve the model without needing to write code. The ability to evolve the model was tested successfully. The data that was obtained is shown in 4 different views: two graphs, a table, and the SocioCortex views. Additionally, it can be queried via the API using both the native API as well as MxL. The development iterations have shown that this model of documenting knowledge can be used

3. **Which types of relationships exist between Connected Mobility Ecosystem members and how can these be documented?**

Research Question 2 was addressed by gathering information about company to company relationships. A model was developed, which mapped these relationships to a relational database. At the same time care was given, to make sure new types of relationships could be added without needing to change the system. Afterwards this proposed solution was evaluated. The evaluation revealed the need for further types of relationships which were since added to the system. The fact that people unfamiliar with the CMEE were able to add new RelationTypes validates the proposed solution.

4. **How can the acquired knowledge from 1. and 2. be visualized?**

Research Question 3 was addressed by creating two new visualizations for the data collected in the previous steps in the SocioCortex instance. There were multiple iterations, in which feedback shaped the visualizations. Additionally all the views already present in SocioCortex were presented in order to interact with the knowledge. The evaluation revealed that the visualization triggered critical thoughts about what the visualization should look like for the interviewee. The outcome of the evaluation was that users desire tailored visualizations based on the same set of data. Additionally they want to slice and visualize the data in their own respective ways.

In summary, models were created based on the data that was collected. The models were initially not detailed enough, but were designed to be easy to change. This proved advantageous when feedback reshaped them, which could be accomplished with ease. Interacting with the collected data was a primary interest for people. People appreciated the capabilities SocioCortex offered in this regard and how easy it was. Based on the overall feedback, the CMEE showed a promising signs of being adopted and continued.

6.2. Future Work

In the future, further aspects of the existing data could be evaluated. For example, it may be useful to cluster nodes into communities [Kai+12]. This could reveal groupings among organizations. Knowing these groups could enable members to reach out to partners of their friends. It could be possible to find partners which are more likely to cooperate.

A car manufacturer from the Connected Mobility Environment will evaluate the CMEE in some variation as an internal tool. Two use cases are planned at the moment. First it will be used as a tool for competitor analysis. Second it will be used as a knowledge management tool for departments, in order to optimize processes.

The research at the sebis chair will be continued in addition to that. The next step includes the possible scenario of using the system to judge companies and as a tool to help decide which companies to invest in.

6.2.1. Data entry

It would be a requirement for this system to be used productively, that data entry is less cumbersome. Manually having to insert and categorize data makes the potential of active adoption look very bleak. This could be accomplished in several ways.

Perhaps a system could be envisioned, where data would be gathered about companies and individuals the same way that Open-source intelligence (OSINT) works in practice. In addition, the data would need to be updated and kept at the current state.

Alternatively a system could be opened to outside proposals of information. This would turn the knowledge management process into a collaborative effort, and distribute the workload on multiple parties.

6.2.2. Declarative View Model

Figure 6.1 shows, how the process could be envisioned. A common data source is used. Each user is able to select the data desired from the data source via queries. Rules

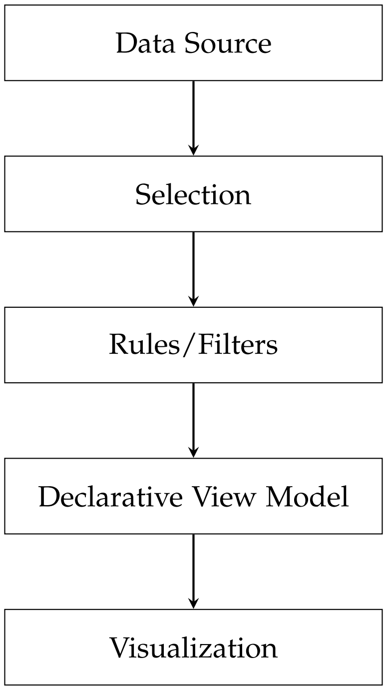


Figure 6.1.: Proposed Declarative Process

and filters can be applied to the data in a second step. This could include rounding or transforming data. In the next step, a declarative view model encodes the input. This allows users to declare how information shall be displayed. What results is the final visualization.

This technique has the advantage, that different users can view different aspects of the same set of data. It allows different interests to work on the same maintainable set of data. Due to the nature of the view model, changes can be taken into account, in any visualization. As a result, changes to the data can affect all visualizations, which encode it.

The declarative view model can be created as a web form. This will allow novices to engage and create visualizations. This suggestion is inspired by the Vega[1] toolkit. It uses a JSON schema consisting of data and view model to create different types of visualizations.

[1] `https://vega.github.io/vega/` [Online; accessed: 11-December-2016]

A. Appendix

A.1. Prototype Iterations

A.1.1. Paper Prototype

Figure A.1 shows the first paper prototype. Interestingly, it already includes different types of relationships. It also illustrates the difficulties of trying to draw a graph in a limited amount of space. As an early prototype it contains a decent amount of data already, but is undoubtebly hard to reuse.

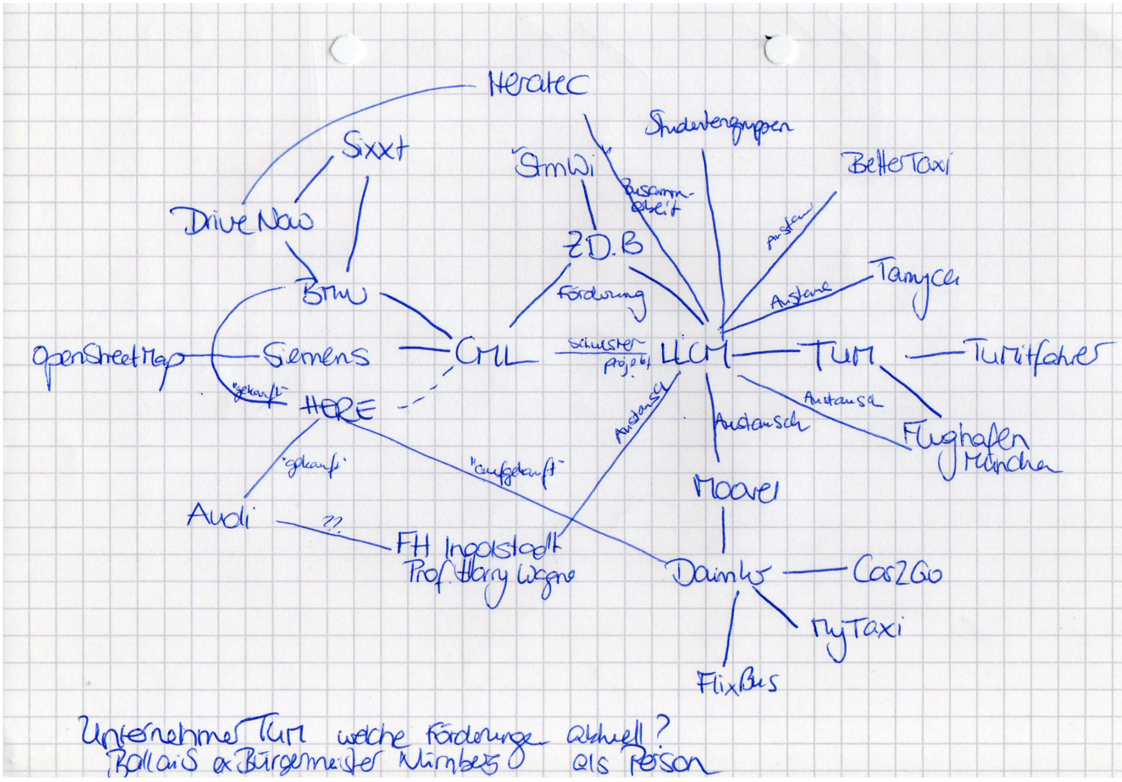


Figure A.1.: Sketched graph

A.1.2. Excel data collection

Figure A.2 shows the next step, where data was gathered in a spreadsheet. This was better for manipulating organizational data. Typical spreadsheet functions like sorting and filtering could be applied to the organizations, making it easier to maintain them. In order to keep track of relations, an adjacency matrix was started on the right side of the same spreadsheet. It was difficult to maintain, and hard to extract the important information.

	A	B	C
1	Type	Subject	Name
2	Public Institution	Public Institutions	Landeshauptstadt München
3	Public Institution	Public Institutions	Zentrum Digitalisierung.Bayern
4	Public Institution	Public Institutions	UnternehmerTUM
5	Organisations/Initiatives	Network	Capgemini - German Innovation Lab
6	Established Player	Automotive	BMW Group
7	Established Player	Conglomerate Railwail vehicles	Siemens AG
8	Platform Provider	Platform Provider	SmartLane
9	Supplier	Consulting & Software Supplier	msg systems
10	Supplier	Software Supplier	iteratec
11	Mobility Service Provider	Mobility interface	Moovel
12	Mobility Service Provider	Private CarSharing	Tamyca
13	Mobility Service Provider	(Individual) RideSharing	BetterTaxi

Figure A.2.: Excel data collection

A.1.3. Graph database representation

Figure A.3 shows, how the information gathered can be represented in Neo4J. The types of links between nodes is the same as the proposed RelationTypes of CMEE. The graph database was nicer to view, but it was harder to check whether a certain entry existed.

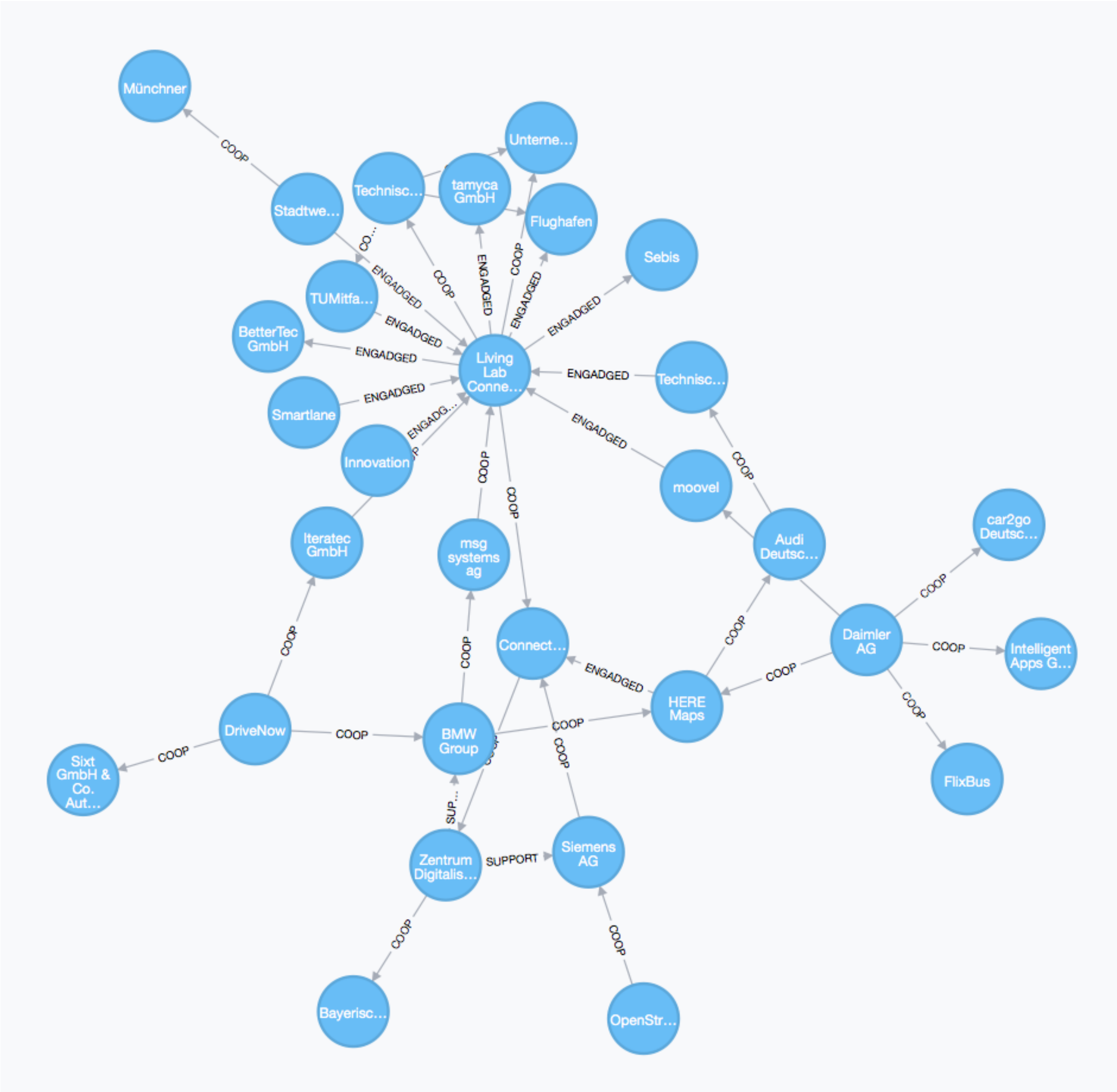


Figure A.3.: Data in Neo4J

A.1.4. SocioCortex

Figure A.4 shows Organizations entered into SocioCortex. Figure A.5 shows Relation-Types entered into SocioCortex. The `inverseRelationType` shows the dependencies within the RelationType EntityType.

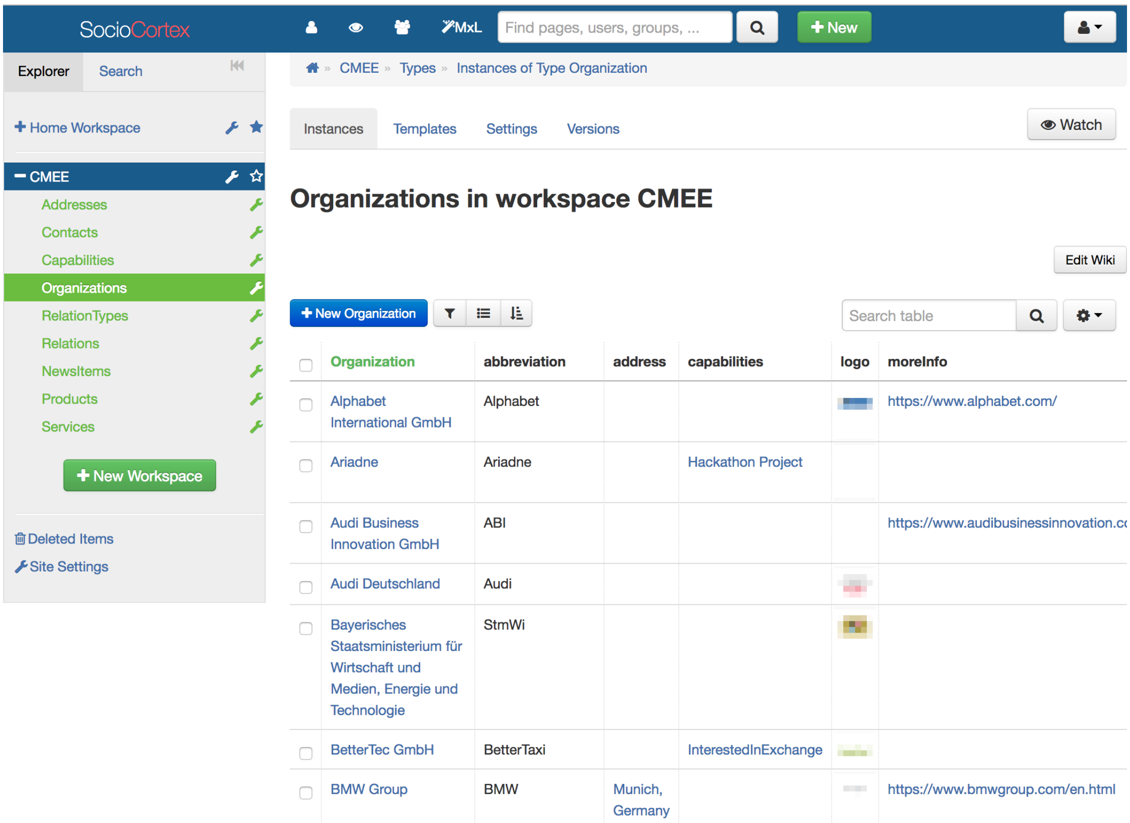


Figure A.4.: Data in SocioCortex

RelationType	enumName	img	inverseRelationType
Cooperation	Coop	link.svg	Cooperation
Funded by	Funded	dollar.svg	Funds
Funds	Funds	dollar.svg	Funded by
In talks with	Talks	comment-empty.svg	In talks with
InterestedIn	Interested	help.svg	InterestedInBackwards
InterestedInBackwards	InterestedBack	help.svg	InterestedIn
Owned by	Owned	dot-circled.svg	Owns
Owns	Owns	dot-circled.svg	Owned by
Partially owned	PartialOwned	dot-circled.svg	Partially owns
Partially owns	PartialOwns	dot-circled.svg	Partially owned

Figure A.5.: RelationTypes in SocioCortex

Features

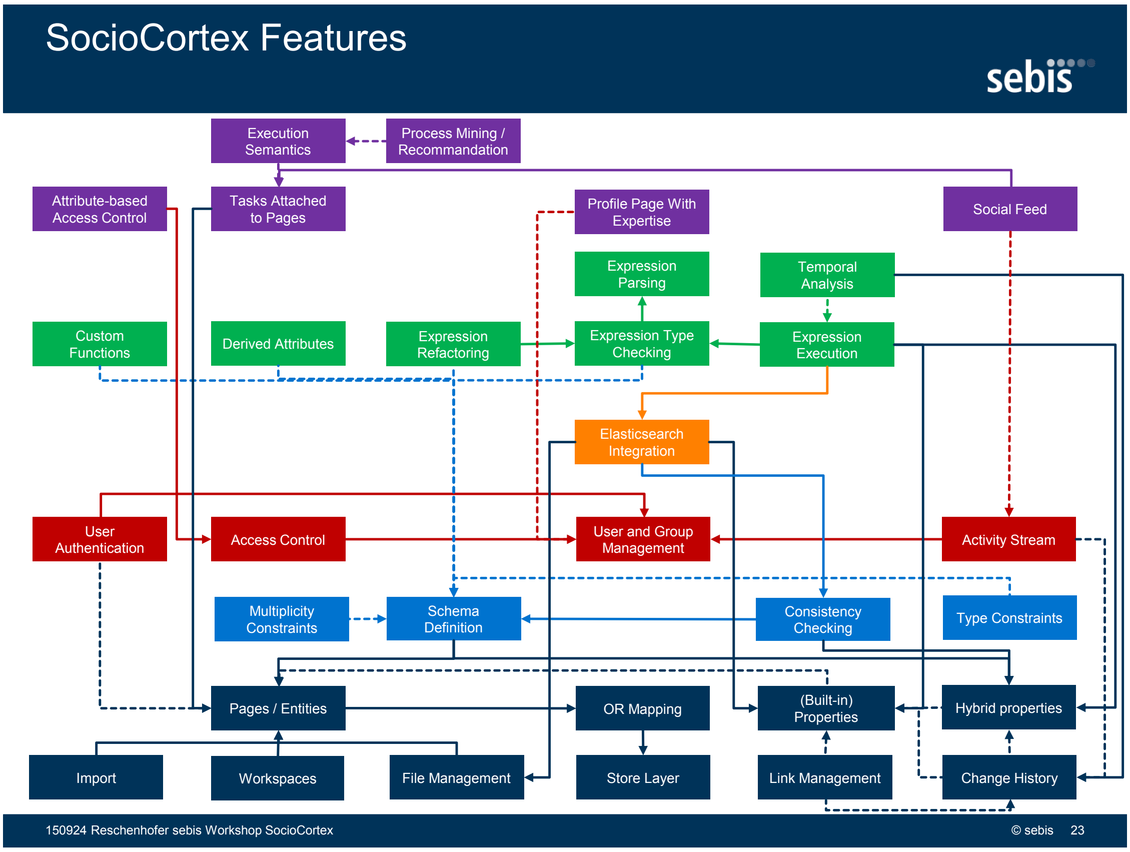


Figure A.6.: SocioCortex Features

Figure A.6 was taken from the last page of "Slide Deck From the sebis Day 2015"[1], from the SocioCortex website. The intent of showing it here is to provide an overview of the features SocioCortex offers.

A.1.5. Networks

This section shows the stages of visualizations of the networks.

Force graph with curved lines

Figure A.7 shows an early protoype of the force graph layout. The bidirectional arrows were thought to clarify both "Owns" as well as "Owned By" relations. It achieved the contrary, because the arrows confused users. The curved nature also meant it took

[1] `http://www.sociocortex.com/files/150924%20Reschenhofer%20sebis%20Workshop%20SocioCortex.pdf` [Online; accessed: 10-December-2016]

longer to accurately pinpoint where the connected organization was. This situation worsened over time, as more organizations and relations were added.

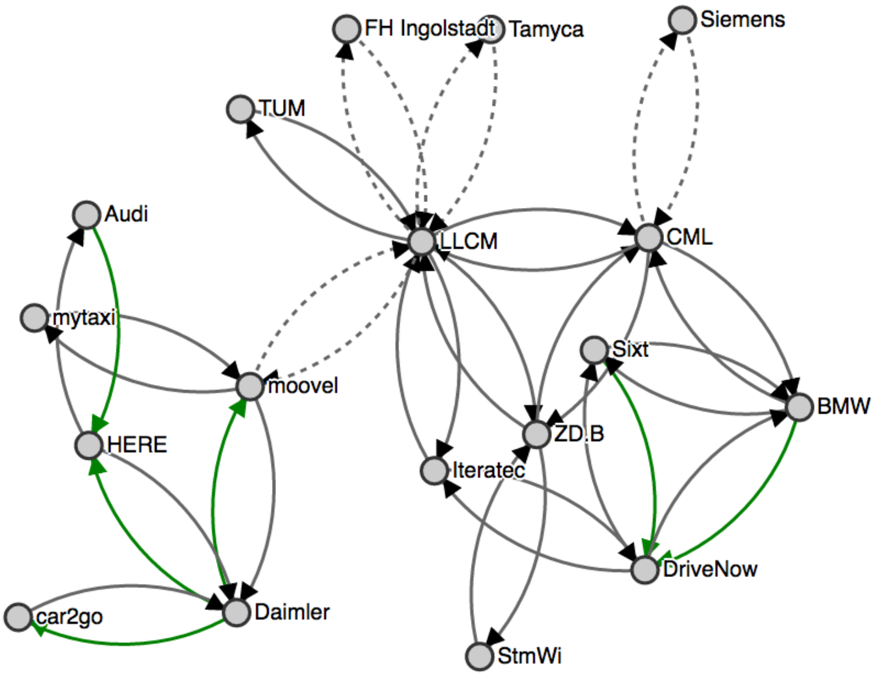


Figure A.7.: Early force graph prototype

Force graph

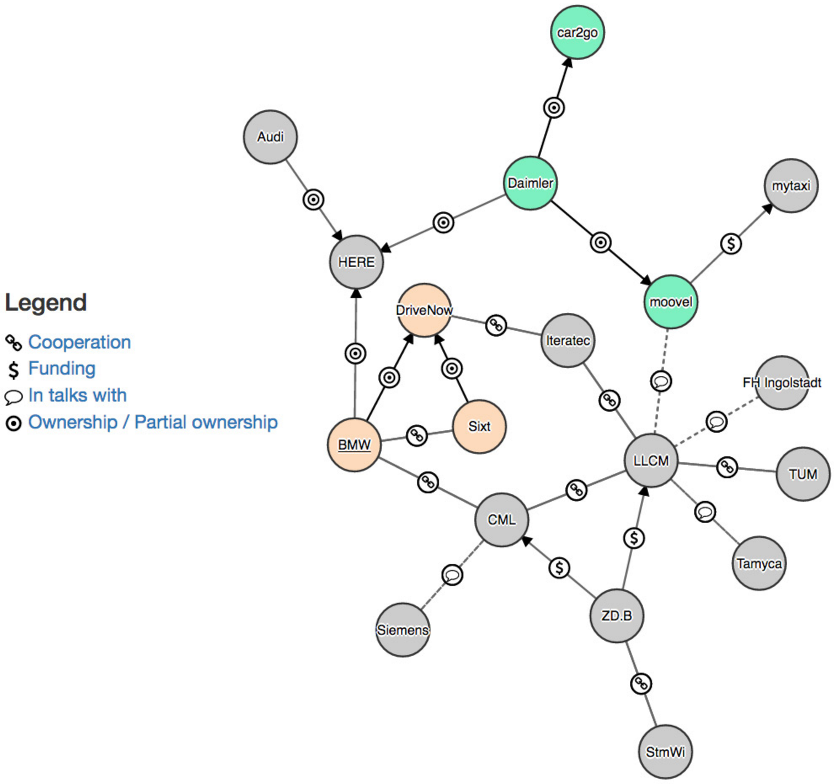


Figure A.8.: Early stage of force graph view

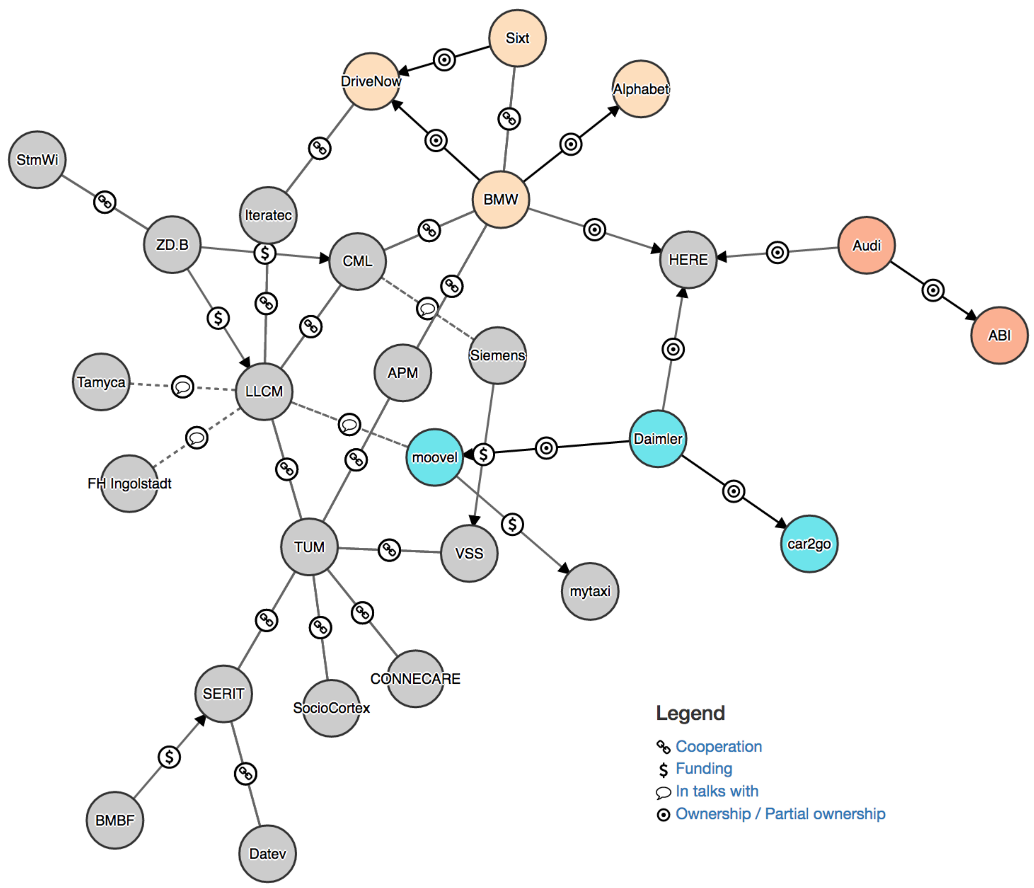


Figure A.9.: Intermittent stage of force graph view

A.2. Web Application Dependencies

The development of the CMEE web applications depends on following software:

```
{
  "node": "^4.2.1",
  "del": "^2.2.2",
  "express": "^4.14.0",
  "gulp": "^3.9.1",
  "gulp-clean-css": "^2.0.13",
  "gulp-concat": "^2.6.1"
}
```

Figure A.10.: CMEE Development Dependencies

Additionally the frontend used the libraries shown in Figure A.11. Names are the packages as they appear in the npm[2].

```
{
  "jquery": "1.11.2",
  "bootstrap": "3.3.1"
  "angular": "1.3.0"
}
```

Figure A.11.: CMEE Client Libraries

In addition to the libraries shown in Figure A.11, following non-npm libraries were used:

- `angular-sc`[3] (v0.9.0)
- `ngMessages`[4] (v1.3.0)
- `ngStorage`[5] (v0.3.11)
- `ngResource`[6] (v1.3.0)
- `AngularUI Router`[7] (v0.2.18)
- `D3.js`[8] (v3.5.17)
- `angular-d3`[9] (v0.0.0)
- `UI Bootstrap`[10] (v0.14.3)
- `RandomColor`[11] (v0.4.4)
- `Modernirz`[12] (v2.8.3)
- `Respond.js`[13] (v1.4.2)

[2] https://www.npmjs.com/ [Online; accessed: 11-December-2016]
[3] https://github.com/sebischair/sc-angular [Online; accessed: 11-December-2016]
[4] https://docs.angularjs.org/api/ngMessages/directive/ngMessages [Online; accessed: 11-December 2016]
[5] https://github.com/gsklee/ngStorage [Online; accessed: 11-December 2016]
[6] https://docs.angularjs.org/api/ngResource/service/$resource [Online; accessed: 11-December 2016]
[7] https://github.com/angular-ui/ui-router [Online; accessed: 11-December 2016]
[8] https://d3js.org/ [Online; accessed: 11-December 2016]
[9] https://github.com/beefsack/angular-d3 [Online; accessed: 11-December 2016]
[10] https://github.com/angular-ui/bootstrap [Online; accessed: 11-December 2016]
[11] https://github.com/davidmerfield/randomColor [Online; accessed: 11-December 2016]
[12] https://modernizr.com/ [Online; accessed: 11-December 2016]
[13] https://github.com/scottjehl/Respond [Online; accessed: 11-December 2016]

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