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Bachelor's Thesis

A Recommender Framework for Skills Management

In Cooperation With SinnerSchrader

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Abstract

TODO rewrite

Contents

1 Introduction

1.1 Motivation

Project driven organisations have to face the problem of constantly needing to put teams together based on the members' skills, experience and preferences. In many businesses, there is no sophisticated source of information about those data which makes finding the right person with a specific ability even more complicated. A popular approach to this problem is using computer programs to find an employee skilled in a given set of tasks in all availble employees.

SinnerSchrader, a hamburg based web agency that will serve as the practical context for this thesis, decided to launch an internal application for skills management that is meant to solve the aforesaid problems. This thesis will deal with the design and implementation of such an application.

1.1.1 SinnerSchrader

The SinnerSchrader Group is a full service web agency based in Hamburg aggregating the subcompanies SinnerSchrader Deutschland, SinnerSchrader Content, SinnerSchrader Commerce and SinnerSchrader Swipe. The broad spectrum of expertise, including, but not limited to, digital communication strategies, visual and interaction design, technical architecture, full stack development, editorial services, content production, E-Commerce, mobile app development, hosting, and maintenance, allows SinnerSchrader to serve all needs regarding their customers' digital transformation. The combination of all said competencies under one single roof reduces organisational friction between the discipline-specific teams because they all share the same vision of the big picture they are creating. This does not only lead to faster development cycles, but also to a more coherent and unified product.

Project-Driven Business

As a web agency, it is clear that SinnerSchrader has to operate in a project-driven way. This means there no continuous stream of recurring work repeating constantly, but many different projects for different clients, each one dealing with varying challenges and questions. From a technical point of view, the diversity of know-how needed for each project is extremely huge since every application uses its own dedicated stack of technologies. As a consequence, the developers' skill sets are based on the combination of projects they

have worked on and their general field of interest. This results in one problem: Managers frequently have to put teams together based on the members' skills with respect to the individual requirements of the project.

Matrix Organisation

The personnel of SinnerSchrader are divided into two different types of teams: functional teams of employees sharing the same specialization, e.g. backend development, frontend development, design, or concept, and project teams of people from different functional teams working collaboratively on the same project. This structural model is called a matrix organisation [Ber16, P. 75]. The organisational head of functional teams will further be called the *supervisor* the pendant for project team will be mentioned as *team manager*.

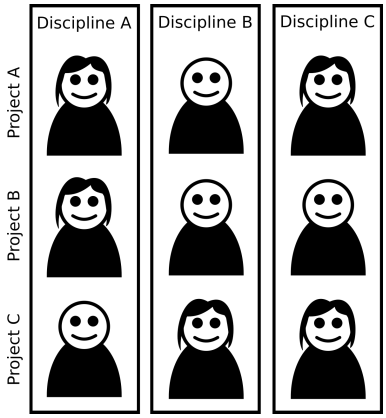

Figure 1.1: Illustration of a matrix organisation

1.2 Leading Goals

This thesis will discuss the requirements a skills management software will have to fulfill in order to be advantageous to SinnerSchrader. Existing solutions will be examined and evaluated regarding those requirements. The outcome of this analysis will lay the foundations for the design and concept of a skills management web application custom-tailored to SinnerSchrader's individual needs. The backend part of said application will be implemented and evaluated.

2 Related Work

Skills management is a trending topic in today's management world, as it is a vital part to the success of a modern business. Darvish et al. highlight the importance of knowledge management in various forms of institutions and compare different knowledge management strategies. Furthermore, the authors show how enterprises can introduce tools and mindsets to use the positive effects of knowledge management in their organizations [DAQ13], but do not discuss concrete software tools. A market analysis by Lehner [Leh04], however, compares multiple commercially available software systems for skills management and provides information adapted in 3.3.
Beck outlines a case study that deals with the introduction of a skills management system at *Putzmeister GmbH* [Bec03] and reveals important success factors of such a software, e.g. ways to motivate employees to provide a sufficient amount of data, legal concerns and cooperation with the industrial council (*Betriebsrat*), obstacles that occur in the maintenance phase of the system's lifecycle, and usability requirements.
In contrast to the systems analyzed by Lehner and Beck, the application that this thesis will deal with does not only show the information saved in its database, but also provides a powerful search function and recommends employees based on the combination of multiple personal factors including their motivation. Canos-Daros introduced an algorithm to measure employees' motivation [Can13] and highlights aspects the algorithm used by the application should include.
Spoonamore et al. created an algorithm that deals with the matching of peronnel to open positions in the *United States Navy* [SSH07]. An adaption of this algorithm lays the foundation for the scoring algorithm used in this application (see 4.1.4). Futhermore, the authors describe non-technical requirements an algorithm which ranks personal abilities has to meet in order to be accepted by the target audience that will be scored by it.
This thesis does not cover the visual concept and implementation of the applications graphical user interface, since Strecker's bachelor's thesis adresses this filed of functionality [Str17].

3 Functional Objectives and Exisiting Solutions

3.1 Usage Scenarios

3.1.1 Asking for Help

Having the possibility to ask for help is a vital part of the working culture in many knowledge driven businesses, so collaboration and the sharing of ideas are a major factor in the company guidelines of SinnerSchrader. The application is supposed to act as a central repository for knowledge and contacts, enabling employees to find someone who can help in order to answer questions and find solutions to domain-specific problems.

3.1.2 Finding Potential Team Members

Team managers constantly face the problem of reassembling parts of their teams, forming new teams for new projects, and disbanding teams whose projects have ended. As there is no unified source of information about all employees, managers often do not find the best suitable team member to fill an open position because they simply do not know each other yet. The tool will give managers the opportunity to search the entirety of employees at SinnerSchrader and find one meeting all requirements of the open position, thus making collocating teams easier and more efficient.

3.1.3 Collecting Information

The application will give employees the possibility to provide information about their personal knowledge regarding their skills. Furthermore, they can assign a will value for every skill that describes if they prefer doing the implicitly linked activity or working with the tool described by said skill. That is, people can define what they want to do and what tasks they would like to refuse.
As employees continually enlarge their knowledge while their fields of interest shift towards new technologies, tools or even functional divisions, providing data about their skills and preference once will lead to the system being filled with obsolete information. The quality of the search results and suggestions heavily relies on the fidelity and volume of the underlying data about the employees, hence keeping said information up to date is crucial to the performance of the application.

Biannual Feedback Meetings

Every employee has biannual meetings with their respective supervisor to interchange bidirectional feedback, define personal goals, and negotiate possible changes of salary. Part of the feedback given by the employee are subjects they learned or enhanced their knowledge about, and newly developed interests. These insights are documented and registered in the employee's personnel file. This meeting will be the regular occasion for supervisors and employees to refine the data saved in the application and to add newly gained skills to it. The supervisor is advised to address discrepancies between the employee's and their own estimations of skills to accomodate the human factors of self-perception. A case study performed by Beck indicates that this approach to collect information about the employees' skills generates a sufficient amount of data to run such a system [Bec03].

3.1.4 Notifications by Supervisors

Employees and supvervisors are encouraged to be in rich contact with each other in order to deliver continous feedback about the individual person's needs, impediments, and the status of their current projects. As a result, supervisors can identify appropriate moments for reevaluating the skills and preferences saved in the application and notify the employee.
For example, according to Tuckman's team development model, the so called *adjourning* phase of a project is an occasion for "recognition of individual achievements and reflection on how far the team has come" [Wil10, P. 3] and thus is a convenient chance to add new skills acquired during the project and to refine the existing data.

Automatic Notifications

In contrast to the supervisor, the application cannot be able to find the best situations to notify employees to maintain their skill profile, so sending automatic notifications will not be nearly as effective as being reminded by the supervisor. Furthermore, according to the Direct Marketing Association (UK), only about one in five automatically generated e-mails will be opened [DMA14], which reflects SinnerSchraders expieriences with email reminders. Those facts justify the decision, that the system will not send any notification to its users.

Intrinsic Motivations

In addition to the mentioned reasons for employees to provide data about their skills which are all extrinsic motivations, there also exist intrinsic motivations to do so. Being motivated intrinsically is defined as "doing something because it is inherently interesting or enjoyable" [RD00]. As people are motivated to focus on tasks they fancy, they are also motivated to voluntarily keep an eye on the quality of the data that is used to determine the tasks they will have to perfom.

3.2 Requirements

3.2.1 Functional Requirements

- Accessible to all Employees
  Every employee must be able to use the application regardless of their equipment or used operating system.

- User Profiles
  Anyone can see another user's profile consisting of basic information about the user such as name, location, e-mail and personal skills. Personal skills are composed of a name, a skill level and a will level, both on a scale from one to four.

- Provide/Edit skills
  Users can add new skills from a pool of known skills to their own profile. Already added skills can be edited and removed from the profile.

- Search
  A search function can be used to find people who have added one or more specific skills to their profile. When searching for multiple skills, only persons matching all of them will will be displayed.
  - Ranking
    By default, the search results order should be defined by a score aggregating the individual employee's skill level, will level and grade of spezialization in the searched skills.
  - Sorting
    The user should be able to sort the search results not only by said score but also by knowledge and will level.

- Management of known skills
  New skills can be added to the set of known skills in the application. Existing skills can be edited and removed. Users' personal skills are automatically updated when a skill has been edited so that the integrity of the user profiles is maintained at all times.

3.2.2 Non Functional Requirements

TODO: Klären und formulieren

- Desktop/Devices
- Browsers
- Scalability
- Load/Response Times

3.3 Commercial Solutions

Three commercial skills management applications have been picked randomly for further examination: *Skills Base*, *engage! Talent Management* and *SkillsDB Pro*. A more detailed analysis by Lehner shows that most tools, provide a spectrum of features and limitationss very similar to the examined solutions, so that the selection is assumed to be representative to the market [Leh04].

3.3.1 Skills Base

Skills Base[1] offers the required features, but also includes a large number of functionality SinnerSchrader does not need and ist not willing to use. This includes assessments, the categorization of skills, and a role model for advanced access rights configuration. The search function does not provide searching for multiple skills. Furthermore, the sorting of results found cannot be customized. A central point of the application are dashboards displaying information about the most popular skills in the organisation and long term statistics.

3.3.2 Talent Management (engage!)

Talent Management[2] is a module for Infoniqa's management software engage![3]. It offers advanced features for managers such as a powerful search function controlled via a special query language. It also includes data about the employees' salaries, feedback protocols and certificates. It can only be used in combination with engage!, a complete human resources management solution including features like time tracking, e-learning, applicant management and payroll accounting.

[1] http://http://www.skills-base.com/
[2] http://www.infoniqa.com/hr-software/skill-management
[3] http://www.infoniqa.com/hr-software/personalmanagement

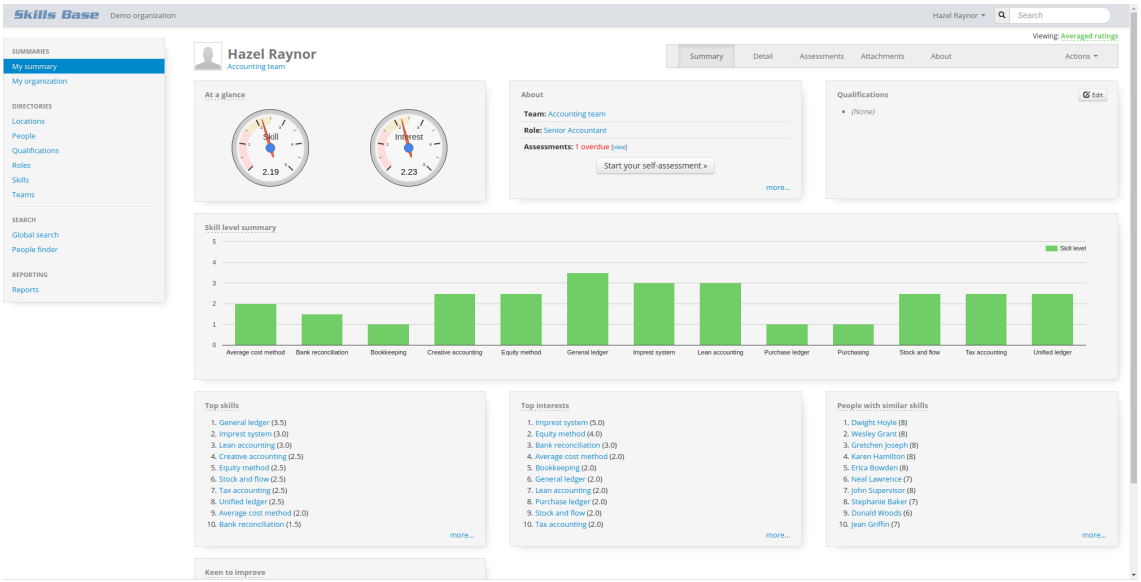

Figure 3.1: SkillsBase Dashboard

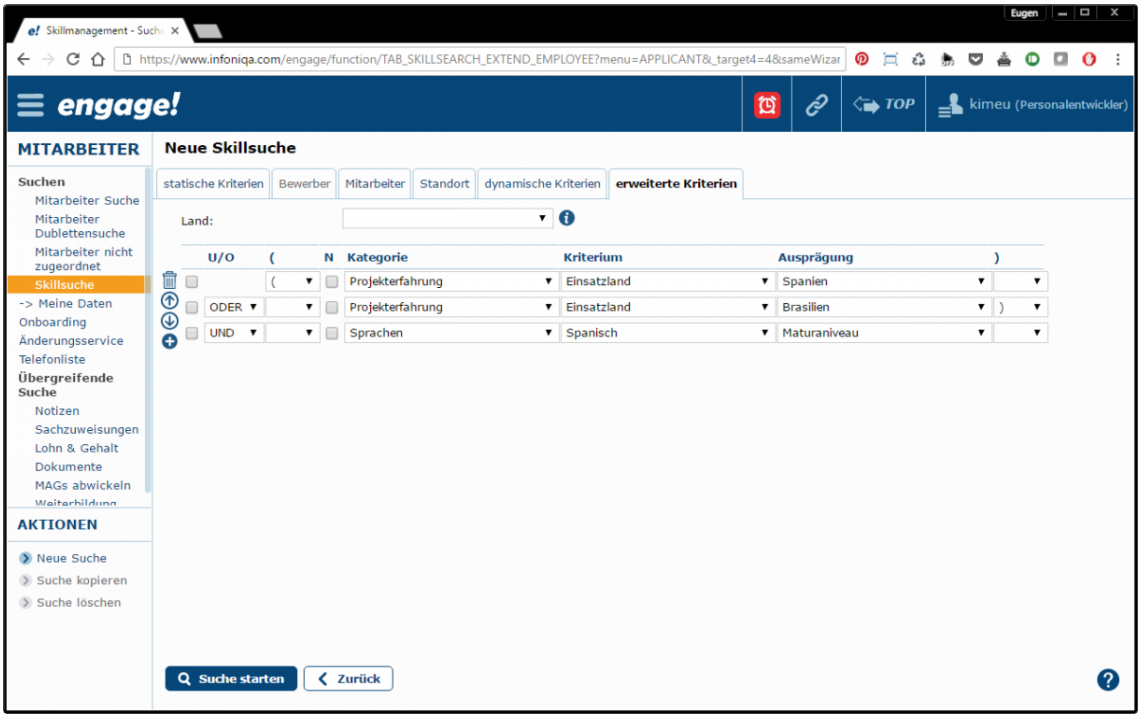

Figure 3.2: Talent Management Search

3.3.3 SkillsDB Pro

SkillsDB Pro[4] is an application designed to serve as a database in an organization providing an overview about every person's own skills and and trainings only to themselves and their manager. The search function is capable of searching for multiple skills combined with different logical operators which enables users to enter very sophisticated queries. Not only can users provide information about their skills, but managers can also do this with the limitation that no employee can see their manager's rating about themselves. Furthermore, only managers can search for persons. Taking into consideration that SinnerSchrader needs a tool to enable everyone to find someone with a specific skillset, this is a serious disadvantage. SkillsDB also offers features SinnerSchrader does not intent to use including, but not limited to, the automatic generation of project reports based on plan succession and demands for assessments.

3.3.4 Conclusion

None of the analyzed softwares offers all features required, but all of them include various functions SinnerSchrader does not intend to use, which brings undesired complexity into the applications. One of the most critical features, sorting the search results by best match, is not offered by any of the commercial solutions. Furthermore, all those systems differentiate between employees and their supervisors and thus restrain transparency. The application is not supposed to be used for monitoring and rating employees, but should give employees the possibility to find each other; categorizing them would clearly defeat this purpose.

Pain Point Fitness Scoring

As shown by Canós-Darós, motivation is a vital factor regarding any employee's performance and quality of work [Can13]. Although motivation is a complex construct of many highly diverse dimensions, the overlap of a person's interests and their duties is a key aspect to it. Assuming that every member of the company has some skills they prefer to employ over others, matching people to tasks that require the exact same abilities they are interested in employing will lead to more motivated employees and thus have a positive impact on the overall productivity. Consequentely, when searching for persons having specific skills, the application should not only take into acount the employees' skills but only their preferences in order not to find the most skilled, but the best fitting one. Unfortunally, none of the examined applications does provide a way to aggregate both, skills and preferences, into a single score indicating the overall grade suitability of a person relative to the searched skills.

[4] http://www.skillsdbpro.com

4 Concept

The application should be accessible to all employees of SinnerSchrader. Due to the heterogeneity of the the users' computer setups running *Windows*, *macOS* and *Linux*, creating a native application supported by everyone's system is a rather complicated task. A web application using standard technologies does not only solve this problem, but can also be used from mobile devices such as smart phones and tablets. Furthermore, there is no need to manually install and update the software so that it can be assumed that all users use the latest version of the application. This is a positive factor regarding the overall usability of the system and assures bugs and security issues are eliminated the moment a fixed version of the software is deployed. All those advantages compared to native clients and the fact that SinnerSchrader's expertise lies in the development of web applications lead to the decision, that such an application would be the appropriate choice.

4.1 Person Search

The central feature of the application is the search function that returns a list of all persons matching the entered set of skills. By default, the results are ordered by a fitness score which describes how well a person matches into the set of searched skills. As a consequence of this sorting, the application implicitly recommends the best matching person to the user, thus it falls within the group of *recommender systems*.

4.1.1 Recommender Systems

Recommender systems "are information filtering systems that deal with the problem of information overload by filtering vital information fragment out of large amount of [...] information" [IFO15] which are commonly used to recommend an item to the user based on their previous interactions with other items. For example, recommender systems are used to predict products a customer might want to buy based on the ones they already bought in order to present those items more prominentely than articles the customer is unlikely to buy. In this application's context, the recommender system will filter the set of all employees and recommend better results by showing them first.

4.1.2 Techniques of Content Filtering

As described by Isinkaye et al., filtering techniques used in recommender systems are divided in three classes: model based, memory based and hybrid. Each of this classes relies on a different approach for gaining data to filter the information by [IFO15].

Content Based Filtering

The content is filtered by examining its attributes in order to find items that are contentually similar to the one the user is currently or has previously been interacting with.

Collaborative Filtering

Collaborative filtering techniques rely on the assumption that users can be divided into groups of *neighbors* that behave similarly, so that reccommendations are decutable from ohter users' former interactions.

- Model Based Filtering
  Model based filtering applies methods of machine learning and data mining to learn a pre-computed model which predicts the users' interactions.

- Memory Based Filtering
  Memory based filtering techniques employ the saved interaction history and generate recommendations based on it. In contrast to model based filtering, memory based filtering does not learn a given model but operates directly on the known data.

  – User Based Filtering
    The user's interactions with items are examied in order to find neighbors that share a similar activity history. Once neighbors are found, the system combines their interaction histories in order to find items to user is likely to appreciate getting recommended.

  – Item Based Filtering
    Item based filtering combines all users' interactions and creates a model describing which items are similar to another. This model is then used to recommend items similar to the ones the user has given positive feedback for.

Hybrid Filtering

Hybrid filtering combines two or more filtering methods either by aggregating their respective results into a single set of recommendations preferring the items multiple methods recommend, or by bringing content based aspects into the approach of collaborative filtering and/or vice versa.

4.1.3 Search Algorithm

In the context of the search function, all employees are searchable items. Their attributes include name, location and their respective skills structured as pairs of skill level and will level. This data will be used in an content based filtering approach that not only finds suitable employees, but also ranks them by their fitting into the searched skill set. Other users' interactions with search results, for example the opening of a found person's profile, will not be taken into account, since there is no direct connection between these actions and the person's fitness. Furthermore, a system based on the user's former selections would be inadequate, because the application is meant to give managers the ability to find employees they did not already have contact with; recommending persons the searching user had interacted with would thus be counterproductive.

Outline

The basic structure of the search function will be:

1. Create a list of all employees
2. Filter by Skills
   Remove all employees from the list that do not have all skills the user searched for. At this point, only the presence of the skill in the employees' profiles is taken into account; skill/will levels are ignored.
3. Filter by Location
   If the user specified a location to search for, remove all employees from the list that do not match it.
4. Assign Fitness Scores
   Assign a fitness score to all remaining employees. This fitness score takes into account the user's skill/will levels and their specializations.
5. Sort by fitness score
   The results will be sorted by fitness score. The employee with the best fitness score will be shown first in the list of results, so an implicit recommendation is made by the system.
6. Return Results

Pseudo-Implementation

```
function search(searchItems, searchLocation) {
  var results = getAllEmployees()

  for (Employee e in results) {
    if (e.skills does not contain all elements of searchItems) {
      results.remove(e)
    }
  }

  for (Employee e in results) {
    if (e.location is not searchLocation) {
      results.remove(e)
    }
  }

  for (Employee e in results) {
    e.assignFitnessScore()
  }

  results = results.sortByFitnessScore()

  return results
}
```

Figure 4.1: Pseudo-Implementation of the search algorithm

4.1.4 Scoring Algorithm

The application will sort all found persons by their fitness into the searched skill set; so there has to be an algorithm that can assign a score describing said fitness to every person.

Requirements

According to Spoonamore et al., an algorithm that matches persons to positions based on their skills has to meet more demands than solely the functional ones [SSH07, P. 14]. They define the specific requirements such an algorithm assigning naval personnel to positions on a ship as follows:

- Easy to implement and maintain
- Fast to execute, so as not to become a computational bottleneck
- Takes into account factors: rating, pay grade and NECs[1] and future taxonomies characterizing required knowledge, skills and abilities

[1] Navy Enlisted Classifications

These qualities include factors very specific to the US Navy and thus will have to be evaluated and traslated into SinnerSchraders field of operation, but general requirements such an algorithm has to meet can be deducted: It may not be too complex as employees must be able to understand the system they are rated by, it should take into account different groups of factors and must be easy to adjust in order to keep the system maintainable.

Factors to Include

An estimation of a concrete person's fitness into a position described by the searched skill set needs not only to take into account the matching of offered and required skills, but also the employees motivation to apply said skills derived from their preferences and their personal specialities and expertise. The latter can be described as the skill and will levels that are significantly higher than the person's average level. So the important factors to be included in the algorithm are:

- Average level of knowledge regarding the searched skills.
- Average level of will regarding the searched skills.
- Specialization in the searched skills, including:
  - Specialization in knowledge about the searched skills.
  - Preference of the searched skills over others.

Proposed Fitness Score Algorithm

Skill and will levels are described as integer values on a scale form zero to three. This scale, called V, can be expressed as

$$V = \{x \in \mathrm{N}_0^+ \mid 0 \leq x \leq 3\}$$

All existing skills are accumulated in the set S. The employee's skills are represented by E which is a subset of S. The search items are defined as Q.

$$S = \{java, ruby, ...\}$$
$$E = \{x \in S \mid \text{employee has skill x}\}$$
$$Q = \{x \in S \mid \text{user searches for skill x}\}$$

The functions v_s and v_w assign a level of skill/will to each value in E.

$$v_s : E \mapsto V$$
$$v_w : E \mapsto V$$

The averages of the employees' skill/will values of the searched skills are defined as a_s and a_w. The variables s_s and s_w describe the employee's specialization in the searched items and are defined as the difference of the average skill/will level of the searched items and the average level of all other items. A person with maximal interest and knowledge in all searched items and an infinite number of skills with the minimal value of zero would have the greatest specialization possible and thus get assigned a value of one.

$$a_s = \left(\sum_{x \in E \cap Q} v_s(x) \right) \cdot \frac{1}{|E \cap Q|}$$
$$a_w = \left(\sum_{x \in E \cap Q} v_w(x) \right) \cdot \frac{1}{|E \cap Q|}$$

$$s_s = \frac{|V| \ + a_s - \left(\left(\sum_{x \in E \setminus Q} v_s(x) \right) \cdot \frac{1}{|E \setminus Q|} \right)}{2 \, |V|}$$
$$s_w = \frac{|V| \ + a_w - \left(\left(\sum_{x \in E \setminus Q} v_w(x) \right) \cdot \frac{1}{|E \setminus Q|} \right)}{2 \, |V|}$$

The resulting fitness score f is a weighted mean of the introduced facors. The weights w_{as}, w_{aw}, w_{ss}, w_{sw} sum up to one.[2]

$$f = \frac{w_{as} \cdot a_s}{|V|} + \frac{w_{aw} \cdot a_w}{|V|} + w_{ss} \cdot s_s + w_{sw} \cdot s_w$$
$$w_{as} + w_{aw} + w_{ss} + w_{sw} = 1$$

[2]Mathematically, this is not neccessary, but it results in much more human readable fitness score values between zero and one.

Example Caculation

Let there be three example employees, Alice, Bob, and Charlie, having the same three skills each. (Notation: skill level/will level)

Person	Java	Ruby	C++
Alice	2/1	2/2	3/3
Bob	2/3	0/3	0/1
Charlie	3/3	2/1	1/2

Applying the algorithm with $w_{as} = w_{aw} = w_{ss} = w_{sw} = 0.25$ to a search for the skills *Java* and *Ruby* results in the following values[3]:

Person	a_s	a_w	s_s	s_w	f
Alice	2	1.5	0.33	0.25	0.44
Bob	1	3	0.67	0.83	0.71
Charlie	2.5	2	0.75	0.5	0.69

Ranking the employees only by the average value of skill regarding the two searched items would result in Charlie being preferred to Alice and Alice being preferred to Bob. Sorting them using the proposed fitness score, however, would result in Bob being recommended as the best match, because his relatively high interest in the searched skills and his specialization in them compensates his low average skill. Interestingly, Alice has the best average skill level but nonetheless gets scored the worst due to her obvious specialization in C++. In real life usage, the weighting constants w_{as}, w_{aw}, w_{ss} and w_{sw} might need to be adjusted so that the average skill plays a bigger role in the resulting score.[4]

[3] Values have been rounded off to two significant digits.

[4] The need to adjust the weights should not be considered a design flaw, since the algorithm has been intentionally designed to be customizable to the users' needs as defined in 4.1.4.

4.1.5 Example Search

For this example, let the set of employees be Alice, Bob, Charlie, Donald, and Erika, and the set of all known skills be Java, Ruby, and C++. The assignment of skill/will levels and the respective locations are:

Person	Location	Java	Ruby	C++
Alice	Hamburg	2/1	2/2	3/3
Bob	Hamburg	2/3	0/3	0/1
Charlie	Hamburg	3/3	2/1	1/2
Donald	Hamburg	3/3	-	2/2
Erika	Frankfurt	1/1	2/3	3/1

Applying the algorithm and searching for employees knowing Java and Ruby in Hamburg:
(Let the weights used in the fitness score be $w_{as} = w_{aw} = w_{ss} = w_{sw} = 0.25$)

- Create a list of all employees
  $\Rightarrow$ Alice, Bob, Charlie, Donald, Erika

- Filter by skills: Donald gets eliminated because he does not have the skill *Ruby*
  $\Rightarrow$ Alice, Bob, Charlie, Erika

- Filter by location: Erika works in Frankfurt and thus will be excluded
  $\Rightarrow$ Alice, Bob, Charlie

- Assign fitness scores[5]
  $\Rightarrow$ Alice (0.44), Bob (0.71), Charlie (0.69)

- Sort by fitness score
  $\Rightarrow$ Bob (0.71), Charlie (0.69), Alice (0.44)

4.2 Search Suggestions

After entering an item into the search bar, the user will be presented other items they are likely to enter next. This minor feature can be seen as another recommender system, because it recommends the next item from the set of all available search items and thus matches the definition given in 4.1.1. This recommender system has to deal with other limitations than the one used for the main search function. It filters a completely different set of data, namely all skills instead of all persons, and uses a different filtering approach.

[5]The calculation of the fitness scores can be seen in 4.1.4

4.2.1 Available Data

Distinguishable Users

Since it is not planned that users will have to log in before performing a search, there is no user context that can be used examine a person's former interactions in order to predict their next ones and recommending it.
As the system is designed to be a web application, a cookie holding an unique identifier could be stored on the client device. The application would then use this ID to aggregate interactions made by the same person. Unfortunally, this method cannot itentify a known person using another device as multiple devices will not share the same ID. Furthermore data collected about a user will be discarded if they delete their devices cookies or change browsers. This approach would also need the application to inform the user that data will be stored on their devices as stated by Article 15(3) of the Telemediengesetz (TMG). The user has to give their approval and must be able to refuse the saving of their data (BDSG, Section 4a).
There also exist various methods to identify users without the need to store any data on their devices by examining and recognizing their devices attributes. The collected data can include factors like language settings, the used browser and its version, and the devices hardware components. All this data combined can be used to form an almost unique fingerprint which can be used to recognize a device [WGGK16].
Another possibile method would be to recognize users by examining their very own usage behaviour such as typing patterns or mouse strokes. This approach called *user fingerprinting* does not depend on the users device and thus can be used to identify people across multiple devices and browsers. On the downside, this method can only differntiate between users typing the same word and needs a multitude of samples of each user in order to be able to recognize them [AJL+05]. Although device and user fingerprinting is not prohibited by law, the *Opinion 9/2014 on the application of Directive 2002/58/EC to device fingerprinting* by the EU's *Article 29 data protection working party* states that a user must be informed about the fingerprinting process and be able to deny this. To sum up, the described methods to identify unique persons create an exorbitant computational effort and/or have high error rates for not being able to determine a single user across multiple devices. For the further design of the skill search recommender system, it will be assumed that there is no data about unique users, but about their entirety.

Skill Attributes

The skills are planned to be saved as simple names not enriched with any metainformation, so using content based filtering is not a trivial task. One possible approach would be to use linguistic methods to find similarities in names of skills in order to form clusters of related skills. Unfortunally, most of the skills' names are arbitrarily chosen or acronyms, so that this form of analysis will fail to detect any menaingful attributes.
Regarding the concept of the suggestion engine, the assumption is made, that there is no context to the skills and that the only information about any skill is its name.

Aggregated Search History

Tracking which skills have been searched together can be implemented easily and creates a fair amount of data to generate potentially useful suggestions. Legally, this is not problematic if the application does neither save personal data about the users (Article 15 Telemediengesetz), nor stores information that could potentially be used to create personal usage profiles that can be matched to specific persons (Article 15(3) Telemediengesetz). Grouping skills that have been searched jointly does not stand in conflict with those regulations and requires no information about distinguishable user, so the application will store the search history.

4.2.2 Choosen Appoach

Assmuning that no user profiles exist, user based filtering and model based filtering cannot be applied. Due to the lack of metadata about the skills, content based filtering can also be eliminated as a possible approach. Item based filtering, however, does not require any data that is not available, so this approach will be used for the recommender system.

4.2.3 Concept

The application has access to the list of skills the user already entered and to a repository of all previous searches. Having this information, the system will use a markov chain to predict the next item that the user is likely to entered and recommed it to them.

Markov Chains

Markov chains are a relatively simple tool for predicting future states of systems based on the current state. In fact, makrov chains rely on the fact, that the next state of the system is only dependent on the current state, which is called the *markov property* [Sie]. In the context of the skill management application, we assume this to be true because only two states will be examined: the current state is represented by the set of all items entered in the search field; the future state is skill set of the current search plus one more item. The basic concept is to store all possible states of the system and the respective probability

of switching between from any state to any other one. Knowing the current state one can easily deduct the most probable future state. When a state transistion occurs, the outgoing probabilities of the origin states can be adjusted accordingly in order to factor the transition into the prospective projections.

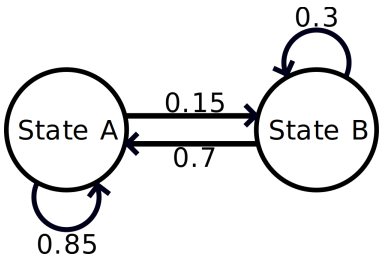

Figure 4.2: A simple markov chain displayed as graph. The states are represented as vertices. All possible transitions between states are denoted as edges. The edge weights define the probability of the transition relative to all other outgoing edges of a node.

Data Structure and Algorithm

In order to get the best results, the recommender system should save all combinations of items that have previously been searched for together and then recommend the next one based on this exact starting point. On the downside, this would result in a lot of different origin states that contain very few possible future states due to being to specific to a single search. The stored data can only be used if the exact same combination of skills is entered again.

Another way to implement such a recommendation system would be to only inspect the last entered search item and ignoring all other ones. Given n known skill items, all probabilities for the future state could be saved in one single $n \times n$ matrix saving only n^2 values. This solution would disregard the whole context of the search item.

As a tradeoff, the system will generate predictions for each skill in the search query independently and aggretage these predictions afterwards. For each skill, a list of possible recommendations paired with the total count of searches for both will be stored. The recommendation lists of all skills combined represent the transition matrix. Instead of transition probabilities, the total number of searches is saved in order to simplify the aggreation of multiple suggestions.

The recommender system will concatenate the suggestion lists of all items in the current search query and add up the counts of skills appearing in multiple suggestion lists. Then, all elements of the combined list that are part of the search query will be removed, the result is a list of suggestions for the whole search query.

4.2.4 Pseudo-Code

```
var knownSkills = [
  {
    name: "java",
    similar: [
      {
        name: "php",
        count: 3
      }, {
        name: "ruby",
        count: 2
      }
    ]
  }, {
    name: "php",
    similar: [
      {
        name: "java",
        count: 5
      }, {
        name: "ruby",
        count: 2
      }
    ]
    name: "ruby",
    similar: [
      {
        name: "java",
        count: 0
      }, {
        name: "php",
        count: 5
      }
    ]
  }
]
```

Figure 4.3: Pseudo-Implementation of the known skills' data structure

```
function suggest(searched) {
  var accumulated = {};

  for (s in searched) {
    for (t in knownSkills.getByName(t).getSkillsSearchedWith()) {
      if (accumulated.getByName(t) exists) {
        accumulated.getByName(t).count += t.count
      } else {
        accumulated.getByName(t) = t.clone()
      }
    }
  }

  for (t in accumulated) {
    if (searched contains t) {
      remove t from accumulated
    }
  }

  return accumulated.getHighestCount();
}
```

Figure 4.4: Pseudo-Implementation for the suggestion of a known skill based on a set of already searched items

4.2.5 Example

Transition Matrix:

	Java	PHP	CSS	COBOL
Java	-	7	3	1
PHP	7	-	9	5
CSS	3	9	-	8
COBOL	1	5	8	-

Using the given transition matrix and the seaerch query “Java, PHP”, the algorithm works like this:

1. Retrieve suggestion lists for each search item
   ⇒ PHP (7), CSS (3), COBOL (1), Java (7), CSS (9), COBOL (5)
2. Aggregate lists (combine counts)
   ⇒ PHP (7), Java (7), CSS (12), COBOL (6)
3. Remove suggestions that are part of the search query
   ⇒ CSS (12), COBOL (6)
4. Suggest item with the highest total count
   ⇒ CSS

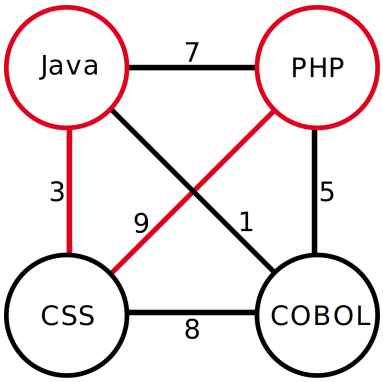

Figure 4.5: Markov Model used in the example. The two origin states and the transitions that form the end result are highlighted red.

4.3 Visual Concept & Wireframes

The application should be as simple as possible and usable for everyone, in order to provide an efficient and fast tool. Thus, it will be designed as a single page application based around a people search that provides a way to input the skills needed and returns all persons offering said skills. After entering a search, the user can select any of the found colleagues and view their personal profile showing extended information like contact details, more skills the user did not search for, and the employee's location. This profile will also include links to directly contact the inspected person via Email or Google Hangouts[6]. Unlike the considered commercial solutions (see 3.3), this tool will not include features like creating statistics, assessments, applicant management, or any dashboard other than the basic search view. Furthermore, there will not be any different roles with different access rights for employees and their managers, since this application is meant to be a tool enhancing collaboration, not supervision. More information about the concept behind the visual design and the frontend's implementation is provided by [Str17].

[6]https://support.google.com/hangouts/answer/2944865

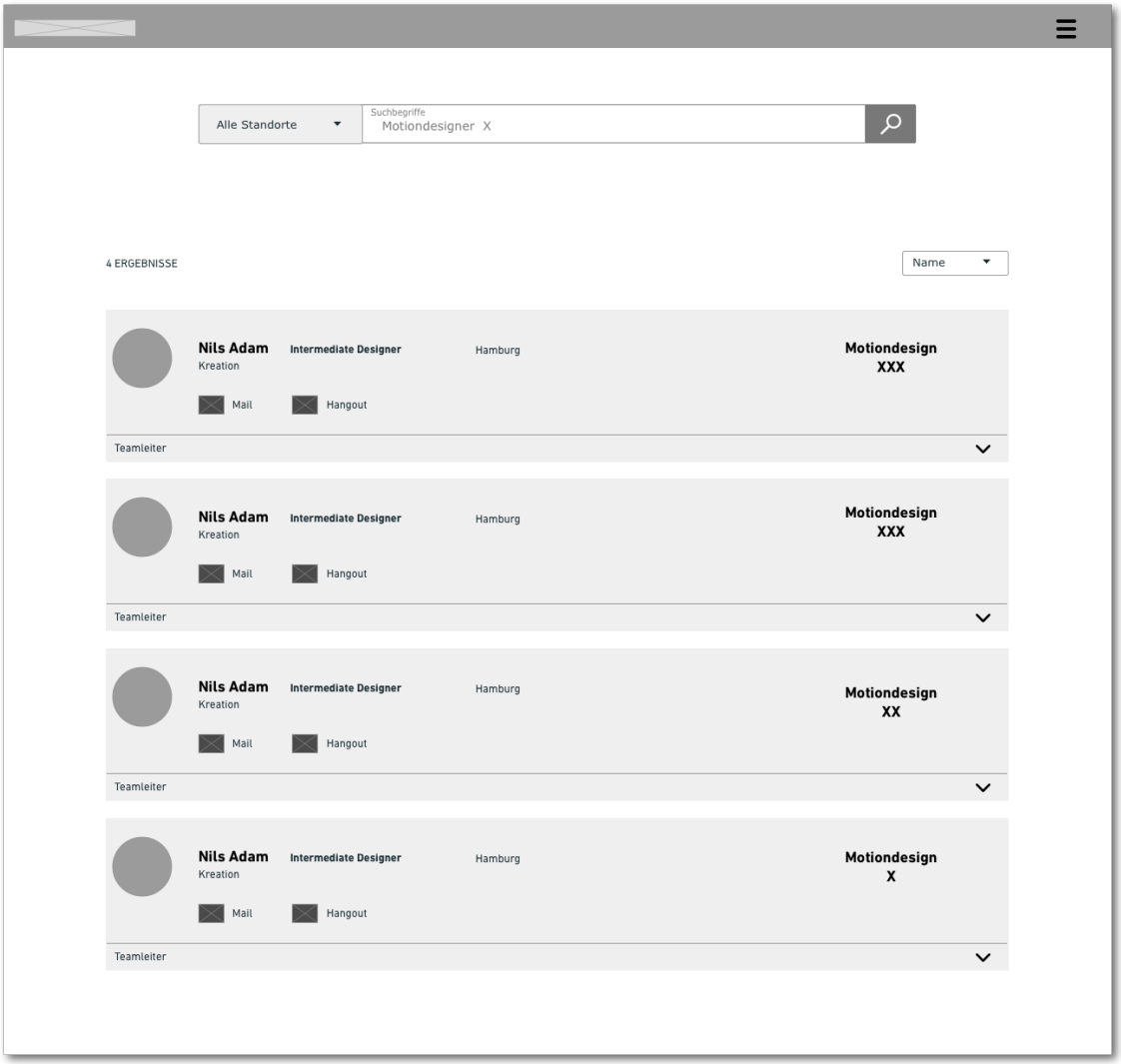

Figure 4.6: Wireframe of the search result view

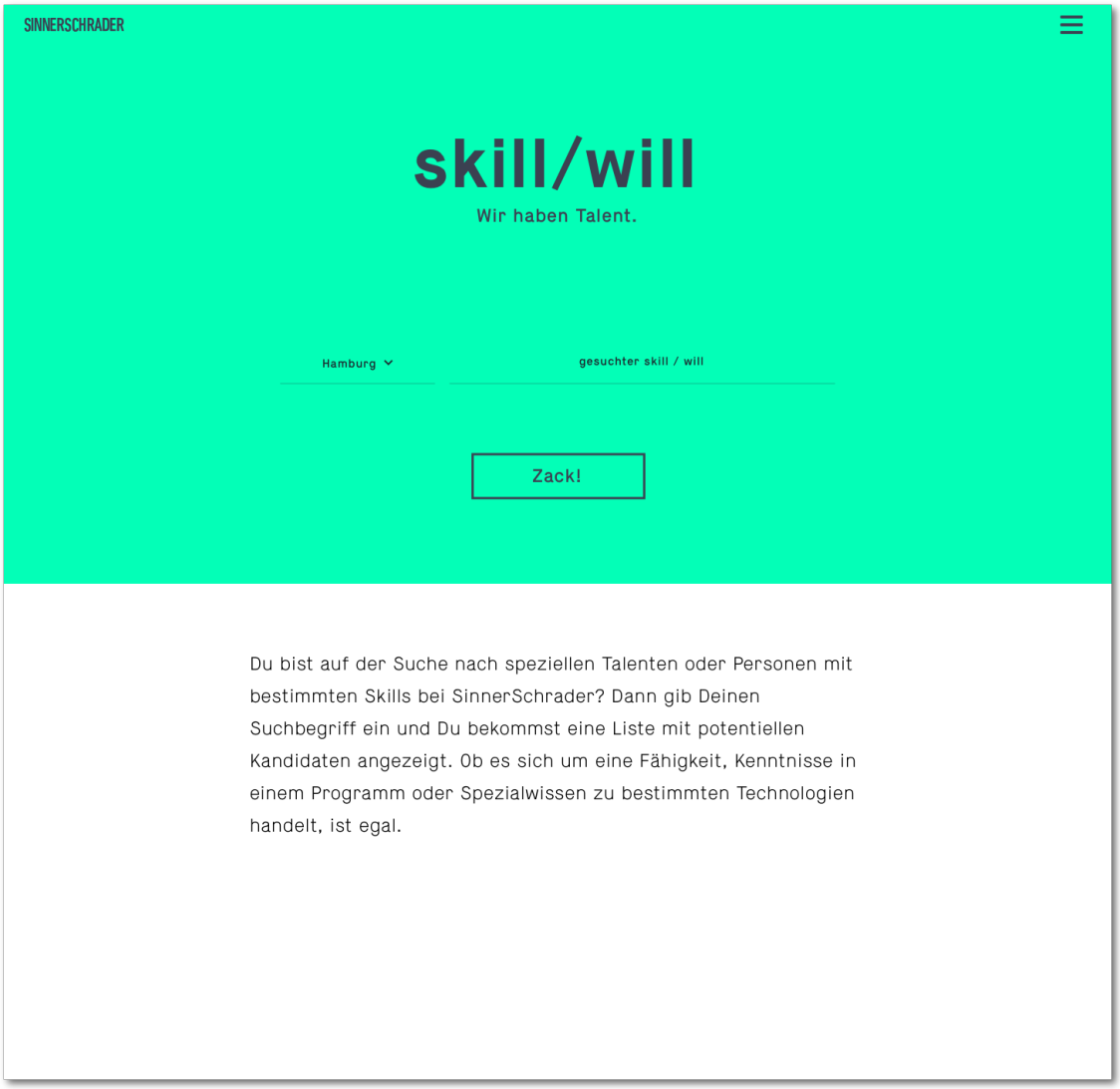

Figure 4.7: An early prototypical design for the search view

4.4 Legal Concerns

Nearly all of data fall into the category of personal data (*Personenbezogene Daten*), which is defined as "any information concerning the personal or material circumstances of an identified or identifiable individual (the data subject)" (BDSG, 3(1)). The personal data will be collected (BDSG, 3(3)), processed (BDSG, 3(4)) and transfered (BDSG, 3(3)) to other employees of SinnerSchrader. Generally, this does not violate any law, since the "collection, storage, modification or transfer of personal data or their use as a means of fulfilling one's own business purposes shall be admissible" (BDSG, 28(1)), but some restrictions apply: the data subjects have to be informed about the processing of their personal data, must be able to deny their consent (BDSG, Section 4a), and the personal data shall not be made public. To ensure the latter, the application must not be accessible to persons that do not work for or on behalf of SinnerSchrader. Technically, this will be arragned by making the application attainable from SinnerSchrader's internal network only, which can only be used by employees and authorized persons.

5 Implementation

5.1 Application Structure

The application consists of two main components: the frontend that presents the user with a graphical interface and the backend that provides data and actions on it to the frontend. The user's browser connects to a web server that acts as a reverse proxy and not only provides static resources like HTML and CSS files which resemble the frontend, but also acts as a SSL endpoint. Requests for dynamic data and actions that are handled via the REST API provided by the backend are passed on to it, its response will then be directed through the reverse proxy to the client. To store and read data, the backend connects to a MongoDB Database. User details are synced from the existing LDAP server which acts a central repository for personal information of all employees.

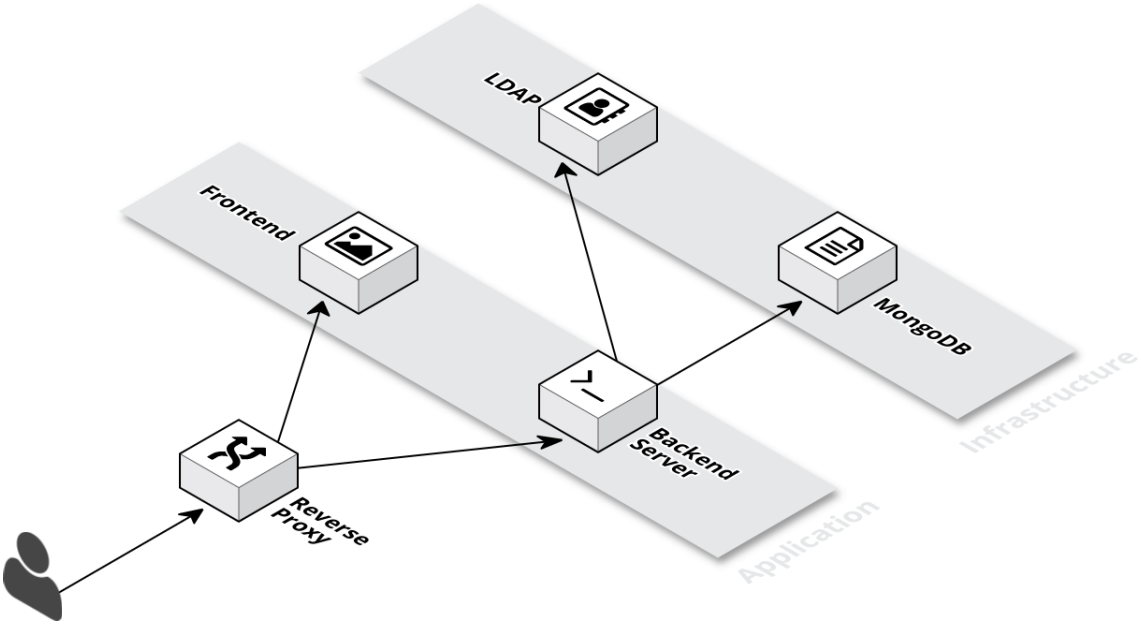

Figure 5.1: The system's architecture. Created with *https://cloudcraft.co*.

5.2 MongoDB

MongoDB[1] is a popular non-relational NoSQL Database that aims to be fast and easy to use [HMPH15, p. 10]. To increase performance, like many NoSQL databases, it does not provide ACID[2] transactions which are a well-known feature of relational database management systems (RDBMS). This, however, simplifies horizontal scaling since new machines can easily be inserted into an existing cluster of database servers without the need to be in sync [HMPH15, p. 3].

5.2.1 BSON

In contrast to relational databases that store all data in tables, MongoDB uses a document-orient data structure saving every element in the Binary JSON[3] (BSON) format. This approach allows complex data to be stored as one object rather than having to dissect its elements and storing them in separate tables. As a consequence, retrieving an object from the database is much more efficient than it would be using a RDBMS, as the latter needs to join the tables storing the object's nested sub-objects and compose the requested element whereas MongoDB has it stored in the exact same form it is requested [HMPH15, p. 10].

5.2.2 Data Structure

The application stores three diffenrent object classes in the database: Skills that are known to the system, persons with their individual contact data and skills, and sessions used to authenticate users that wish to modify their profiles. In order to instanciate the elements as java objects, Spring Data[4], the framework used for database access, also stores the class name the object needs to be mapped to as a field inside of it. Furthermore, every item has the field *version* which holds a version number used to resolve writing conflicts that may occur when multiple threads access the same object simultaneously.

[1] https://www.mongodb.com
[2] (Atomicity, Consistency, Isolation, Durability
[3] Javascript Object Notation
[4] http://projects.spring.io/spring-data/

Known Skills

Skills known to the system consist of a uniqe name and a list of suggestions that themselves are expressed by a name and a total count of searches of the respectice suggestion together with the skill.

```
{
  "_id" : "Java",
  "_class" : "[...].skills.KnownSkill",
  "suggestions" : [
    {
      "name" : "AEM",
      "count" : 1
    }, {
      "name" : "jquery",
      "count" : 1
    }
  ],
  "version" : NumberLong(3)
}
```

Figure 5.2: Data strucutre of a skill stored in the database

Sessions

Sessions are used to authenticate users that wish to modify their personal profile. The client has to authenticate the user with their credentials; if this is successful, a new session holding a unique id, the point of time it will expire, and the id of the authenticated user, will be created and stored in the database.

```
{
    "_id" : "87163f310f124830bac677fe31484262",
    "_class" : "com.sinnerschrader.skillwill.session.Session",
    "username" : "foobar",
    "expireDate" : ISODate("2017-01-09T08:36:40.128Z"),
    "version" : NumberLong(1)
}
```

Figure 5.3: Data structure of a session stored in the DB

Persons

The documents that represent persons contain the respective person's id[5], their personal data like first and last name, telephone number, e-mail address, office location, job title[6], and a list of the person's skills. Each of those skills consists of a name, a level of skill and a level of will.

```
{
  "_id" : "foobar",
  "_class" : "com.sinnerschrader.skillwill.domain.person.Person",
  "skills" : [
    {
      "_id" : ".NET",
      "skillLevel" : 1,
      "willLevel" : 2
    },{
      "_id" : "Scrum",
      "skillLevel" : 3,
      "willLevel" : 1
    }
  ],
  "version" : NumberLong(1),
  "ldapDetails" : {
    "firstName" : "Fooberius",
    "lastName" : "Bartels",
    "mail" : "foobar@mail.org",
    "phone" : "+49 12 345678 901",
    "location" : "Hamburg",
    "title" : "Development"
  }
}
```

Figure 5.4: Data structure of a person stored in the DB

[5]Each employee gets assigned an internal id ("Benutzerkürzel") that is globally used to uniquely identify a person.

[6]The job title data is not maintained consistently in the LDAP, so that, unfortunately, it is not suitable to be used in the person search.

5.2.3 Queries

As shown in 5.2.1, the document based data structure of MongoDB allows the database to efficiently perform complex requests. Furthermore, it provides simple and straightforward search queries to retrieve objects based on their attributes. For example, getting all users who offer the skill *Ruby* from the collection *person* can be done with this straightforward query:

```
1 db.person.find({ "skills._id" : "Ruby" })
```

Figure 5.5: MongoDB query to retrieve all users with the skill *Ruby*

5.3 LDAP

SinnerSchrader runs a LDAP server which acts as a centralized source of personal information of all employees. The application connects to this server in order to retrieve contact information to display in users' profiles. In comparison with having the users to enter their data manually, this methods has the benefit that the users' data will be kept in sync across all internal services, and that it reduces the effort a user has to spend to create their profile.

5.4 Reverse Proxy

Between the client and the backend, an intermediary web server that acts as a reverse proxy is switched in. Its main purpose is the distinguising between requests for static files, like HTML and CSS content that will be directly delivered by said server, and API calls that are redirected to the backend. This increases the system's security by protecting the backend server's identity and presenting an additional defense layer [NGI]. Furthermore, this server can handle SSL encryption between the application and the client, and, if multiple backend servers are needed, balance the workload between them while presenting them as one uniform service.

5.5 API

To exchange data between the backend and the frontend, a Representational State Transfer (REST) API is provided by the backend. Its endpoints are called by the fronted code to either request data or to command the backend to perform modifying operations on it. The used HTTP method is the main indicator of the action to perform: GET is used to retrieve data, POST to insert new elements, PUT to modify existing ones and DELETE to remove them. The URLs of the individual action express the entity on which the action will be performed. All API endpoints are listed in table 5.1.

URL	HTTP Method	Non-URL Parameters	Return Status	Comment
/login	POST	username, password	200, 401, 500	Try to login a user; returns session key
/logout	POST	session	200, 401, 500	Logout a session
/skills	GET	search	200, 500	Search for autocompletion; returns all skills if search is empty
/skills	POST	name	200, 400, 401, 500	Add new skill with the given name
/skills/next	GET	search	200, 400, 500	Suggest a skill based on the comma separated list of skills (parameter: search)
/skills/{skill}	DELETE		200, 400, 401, 404, 500	Remove the skill with the given name
/skills/{skill}	PUT	name	200, 400, 401, 404, 500	Rename the skill
/users	GET	skills, location	200, 400, 500	Get all users matching the searched skills in the given location (parameters may be empty)
/users/{user}	GET		200, 404, 500	Return the specified user
/users/{user}/skills	POST	session, skill, skill_level, will_level	200, 400, 401, 404, 500	Create new skill/modifiy existing personal skill
/users/{user}/skills	DELETE	session, skill	200, 400, 401, 404, 501	Remove the skill from the users profile

Table 5.1: All API endpoints provided by the backend

5.5.1 API Responses

The API returns data in the JSON format, which is one of the two de-facto standards for data exchange on the web[7], because it is part of the Javascript (JS) language [Smi15, p. 37]. Approximately 94% of all websites use JS [QS]; since JSON directly represents JS objects and is both easy to parse and human-readable, it became the leading data format for web applications. For every HTTP request, the backend will return a JSON response, notwithstanding the request may not demand data to be returned. In this case, the response will contain status information about the success of the requested action.

```
{
    "id" : "foobar",
    "firstName" : "Fooberius",
    "lastName" : "Bartels",
    "mail" : "foobar@mail.org",
    "phone" : "+49 12 345678 901",
    "location" : "Hamburg",
    "title" : "Development",
    "skills" : [
        {
            "name" : ".NET",
            "skillLevel" : 1,
            "willLevel" : 2
        }, {
            "name" : "Scrum",
            "skillLevel" : 3,
            "willLevel" : 1
        }
    ]
}
```

Figure 5.6: Example JSON response by the api for the request */users/foobar*. For comparison, the corresponding database entry is shown in 5.2.2.

```
{
    "message" : "logout successful"
}
```

Figure 5.7: Example JSON response for a request that does not demand any data.

[7] The other one is *XML* used by the *Simple Object Access Protocol*

5.6 Backend

The backend component ist implemented in Java 8[8] using the Spring Boot framework[9]. Maven[10] is employed to manage the build process and run unit and integration tests.

5.7 Architecture

The software architecture consists of three main categories of classes: services handling data manipulation and filtering that hold the business logic, repository objects that wrap the database operations into easy-to-use handlers, and domain specific data types. Additionally, numerous helper classes like custom exception types, comparators and general utilities are implemented.

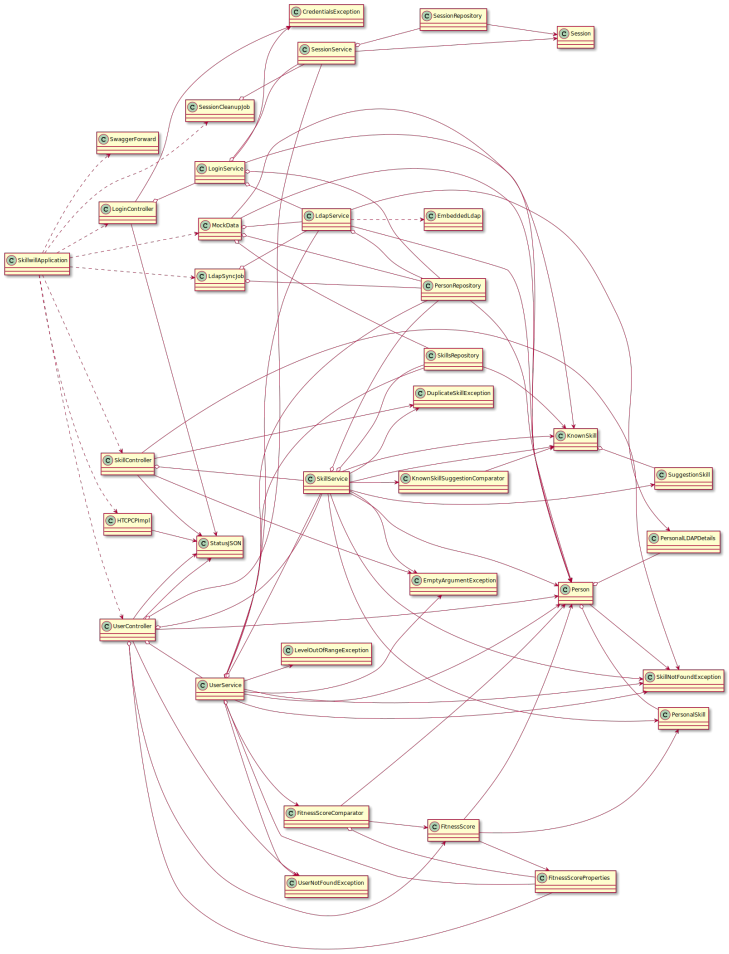

Figure 5.8: UML class diagramm of the backend.

[8]https://go.java/
[9]https://projects.spring.io/spring-boot/
[10]https://maven.apache.org/what-is-maven.html

5.7.1 Spring Boot

Spring Boot is a highly sophisticated web framework that provides numerous features to create web applications including, but not limted to, annotations to expose java methods as HTTP request endpoints, an embedded webserver to run the application on, a modular design to extend its features, and annotation based dependency injection. It is used because its credo to provide default configurations where possible and thus reduce the need to write infrastructure code simplifies the applications structure [Gut16, p. 6]. For example, a controller that returns a static response can be created using two annotations: *@Controller* to make spring boot identify the class as a resource that will listen to HTTP calls, and *@Request* to specify the URL and HTTP method to use. Unlike most other web frameworks, spring boot does not require any more configuration or dispatching classes.

```
@Controller
public class HTCPCPImpl {

    @RequestMapping(path = "/coffee", method = RequestMethod.GET)
    public ResponseEntity<String> coffee() {
        StatusJSON json = new StatusJSON("I'm a teapot \u2615");
        return new ResponseEntity<String>(
      json.toString(),
      HttpStatus.I_AM_A_TEAPOT
    );
    }

}
```

Figure 5.9: Example controller using Spring Boot

5.7.2 Spring Data Repositories

Spring Data[11] is a module for Spring Boot that streamlines the way elements can be accessed from a database. The component mainly used in this application are CRUD[12] repository objects that enclose the database connections and serve simple java methods as an interface. To create such a repository, a java interface defining the stored data type and custom database queries has to be constructed. No actual implementation of the interface has to be created since it will be generated automatically by Spring Data. The parameters needed to connect to the database have to be configured in any source of properties known to Spring Boot, e.g. in *src/main/resources/application.properties*.

```
1 public interface PersonRepository
2     extends MongoRepository<Person, String> {
3
4     Person findById(String id);
5
6     @Query("{ skills._id : ?0 }")
7     List<Person> findBySkill(String skillName);
8
9 }
```

Figure 5.10: Example for a repository interface managing person objects stored in the database

```
1 spring.data.mongodb.host=127.0.0.1
2 spring.data.mongodb.port=27017
3 spring.datasource.driverClassName=com.mongodb.Mongo
```

Figure 5.11: All configuration parameters needed to run Spring Data

5.7.3 LDAP Connection

To connect to the LDAP server, the *unboundid* library is used in the class *LdapService*, It provides methods to open a TCP connection to the server, make requests, and parse the server's response. The connection to the LDAP server will be kept alive and is reused for all operations, so that the effort to open a new connection is eliminated.

[11] http://projects.spring.io/spring-data/
[12] Create, Read, Update, Delete

```
@Service
@Scope("singleton")
@EnableRetry
public class LdapService {

    private static Logger logger =
    LoggerFactory.getLogger(LdapService.class);

    // [fields not used in this example]

    private static LDAPConnection ldapConnection;

    @Autowired
    private PersonRepository personRepo;

    // [methods for user sync and connection handling]

    public boolean canAuthenticate(String username,
            String password) {
        try {
            BindRequest bindRequest = new SimpleBindRequest(
                "uid=" + username + "," + ldapBaseDN, password);
            BindResult bindResult =
                ldapConnection.bind(bindRequest);
            if (bindResult.getResultCode()
                    .equals(ResultCode.SUCCESS)) {
                return true;
            }
            return false;
        } catch (LDAPBindException e) {
            return false;
        } catch (LDAPException e) {
            logger.error("Failed to authenticate: LDAP error");
        }
        return false;
    }
}
```

Figure 5.12: LDAP user authentiction using the unboundid library. Note: parts of the code have been removed for this example.

5.7.4 Swagger

Swagger[13] is an open-source framework for creating documentations of REST APIs. Its annotation based java integration is heavily used to generate an interactive overview of the API endpoints provided by the backend. This overview is automatically served by spring boot and contains a list of all URLs to make requests to, HTTP response codes to expect, the content type of the response and an built-in form to make example requests. The main advantage of this approach is that the code and its documentation are located at the very same place and that parts of the documentation are automatically gernerated, so that the both are maintained synchronously, thus avoiding the documentation differing from the implementation.

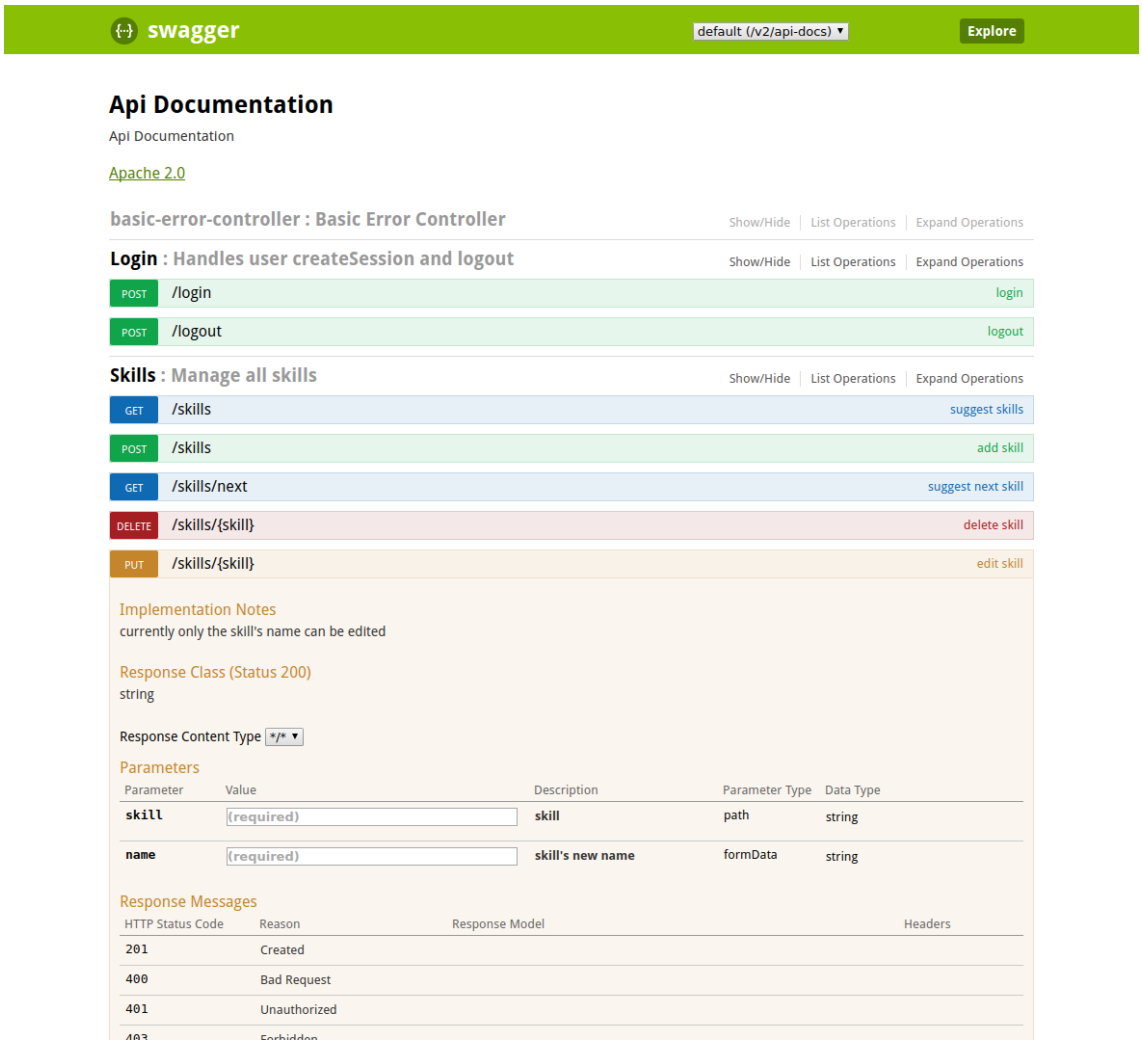

Figure 5.13: Interactive API documentation generated by Swagger

[13] http://swagger.io/

5.7.5 Testing

As a part of the build process, automatic tests are run using the JUnit[14] framework. Two types of tests are employed to ensure the proper working of the software: unit tests that validate isolated segments (java classes), and integration tests that simulate calls to the controllers and test the interplay of the individual components.

```
@RunWith(SpringJUnit4ClassRunner.class)
@SpringBootTest
public class KnownSkillSuggestionComparatorTest {

    @Test
    public void testNoneStarts() {
        KnownSkill a = new KnownSkill("Wurstwasser");
        KnownSkill b = new KnownSkill("foo");

        List<KnownSkill> toSort = new ArrayList<KnownSkill>();
        toSort.add(a);
        toSort.add(b);
        toSort.sort(new KnownSkillSuggestionComparator("42"));

        assertEquals(a, toSort.get(0));
        assertEquals(b, toSort.get(1));
    }

    @Test
    public void bothStart() {
        KnownSkill a = new KnownSkill("foobar");
        KnownSkill b = new KnownSkill("foowurst");

        List<KnownSkill> toSort = new ArrayList<KnownSkill>();
        toSort.add(a);
        toSort.add(b);
        toSort.sort(new KnownSkillSuggestionComparator("foo"));

        assertEquals(a, toSort.get(0));
        assertEquals(b, toSort.get(1));
    }

}
```

Figure 5.14: Example unit test using JUnit

[14] http://junit.org

Embedded Services

During the integration test phase, external services like LDAP and a database have to be accessed in order to ensure the proper working of the interfaces connecting to them. Using the real services, however, is not an option as it cannot be assumed that the machine that runs the tests has a connection to them, and because the tests have to take control over the state of the services. To solve this, a LDAP server and a MongoDB are embedded into the application and will be used during testing. The embedded database is the MongoDB implementation by *flapdoodle*[15], which has the advantage of being effortlessly deployed by importing it; all further configuration and setup happen automatically. As an embedded LDAP, the implementation created for the *unboundid* framework[16] is used.

5.8 License

The software is licensed under the MIT license [Mas88] which is considered one of the most popular open source licenses, mainly because it grants a high level of freedom to modify and use the software under the sole condition that a copy of the original license is distributed algonside the software.

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[Mas88]

[15] https://github.com/flapdoodle-oss/de.flapdoodle.embed.mongo
[16] https://www.ldap.com/unboundid-ldap-sdk-for-java

6 Evaluation

6.1 Fitness Score Algorithm

6.1.1 Uniform Distribution of Score Values

The scores calculated by the algorithm should be distributed uniformly in the complete range of possible values, because this does not only generate the best search results, but also is an indicator for the algorithm's fairness. To test this, one hundred persons have been fed into the system. Each test person has been assigned a random number of skills between zero and 17, with random skill and will levels each. A search for any skill will return a list of up to one hundred persons sorted by their fitness score. The search results for the skills *Atomic Design*, *Datenbanken*, *Funkspots*, *hybris*, *Kommunikation*, *MySQL*, *Sktech* and *Text* have been analyzed, because those have the highest number of results (33 each); all results can be found in table 6.1. Ideally, the scores in each result list decline linearily from one to zero. The ideal value for the n-th result value is:

$$v_{Ideal}(n) = 1 - \frac{n}{33}$$

The distribution of the score values for every respective search is shown in figure 6.1. Figure 6.2 illustrates the average of all eight scores for each postion in the search result lists, the maximum value found at this position, and the respective minimum value. It shows that the average score declines linearily, which means that the score values are distributed uniformly thorough the result lists. In figure 6.1, every result function shows a variance from the ideal value; the average value in figure 6.2, however, deviates signifitantly less from the ideal than any of the isolated data rows. This leads to the conclusion that the drift from the ideal that occurs when observering one single set of data for one specific search is based on the small amount of examined values (33 data points). The average fitness score shows an average error of approx. 6% (see figure 6.3). The maximum error in the given set of data is 27%. This leads to the conclusion that the fitness score algorithm generates uniformly distributed score values with an acceptable error.
Interestingly, the maximum error seems to have a declining trend; the small amount of examined data does not provide a solid basis for assumptions about whether there is a systematic reason for this, and, if so, whether it could have a negative impact on the proper working of the system. Unfortunately, there is no authentic usage data yet, so that this question will remain unanswered and might be subject to further research.

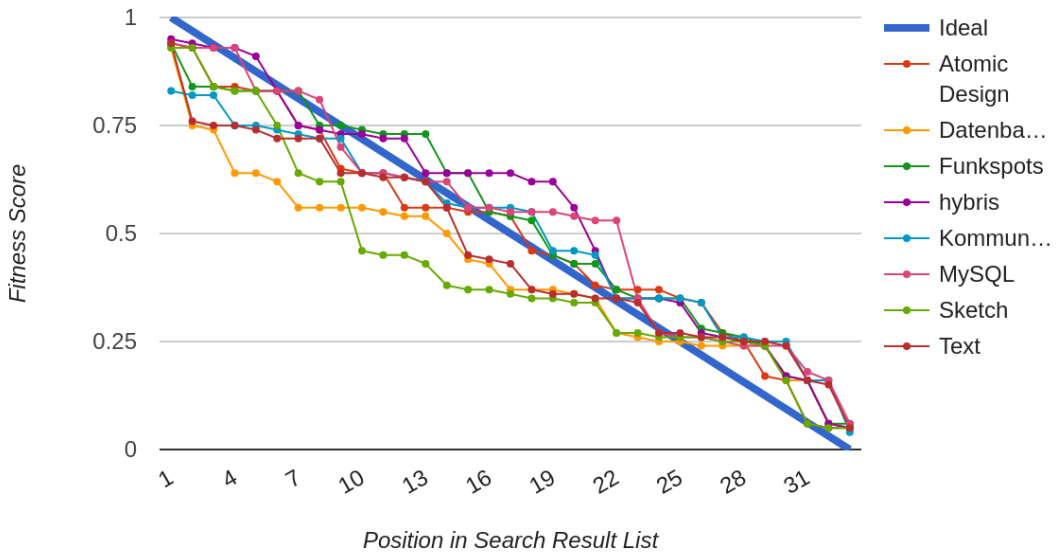

Figure 6.1: All search results and the ideal value.

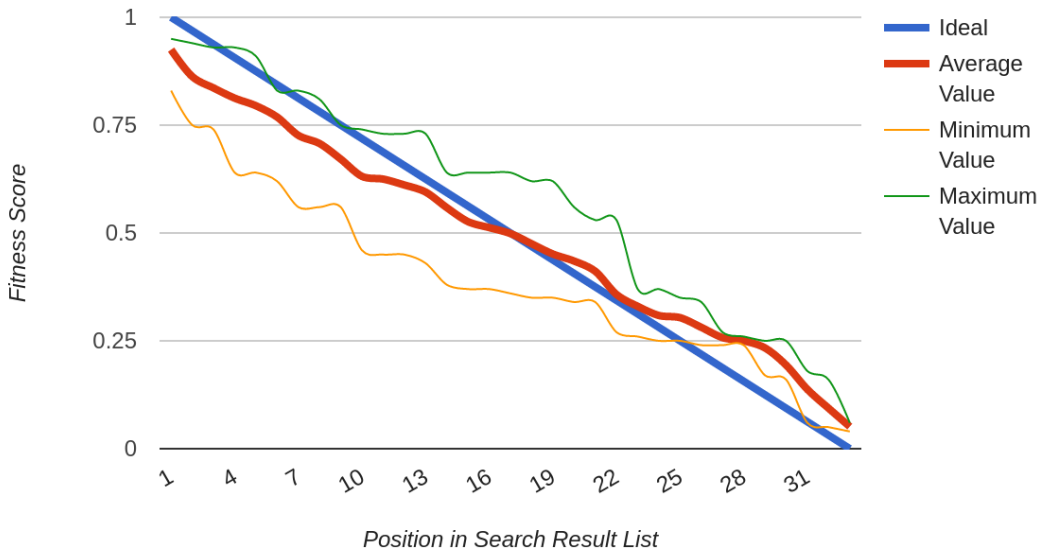

Figure 6.2: Average, maximum and minimum score for earch position in the respective search result list.

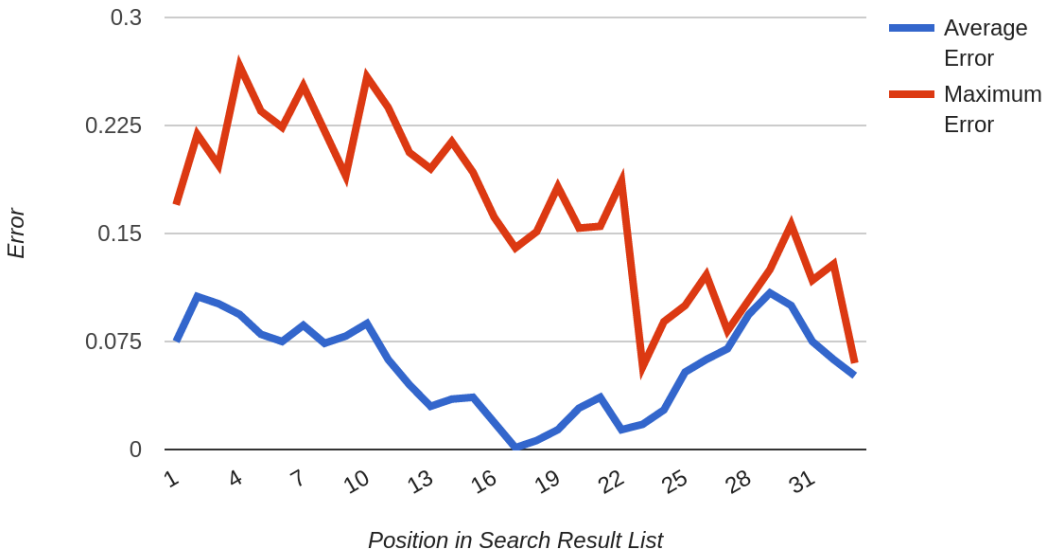

Figure 6.3: Average and maximum error (Difference between respective score value and the ideal value)

No.	v_{Ideal}	A.D.	DBs	Funk.	hybris	Kom.	MySQL	Sketch	Text	Avg. Val.	Min. Val.	Max. Val.	Avg. Err.	Max. Err.
1	1	0.94	0.93	0.94	0.95	0.83	0.94	0.93	0.94	0.925	0.83	0.95	0.075	0.17
2	0.96875	0.93	0.75	0.84	0.94	0.82	0.93	0.93	0.76	0.8625	0.75	0.94	0.10625	0.21875
3	0.9375	0.84	0.74	0.84	0.93	0.82	0.93	0.84	0.75	0.83625	0.74	0.93	0.10125	0.1975
4	0.90625	0.84	0.64	0.83	0.93	0.75	0.93	0.83	0.75	0.8125	0.64	0.93	0.09375	0.26625
5	0.875	0.83	0.64	0.83	0.91	0.75	0.83	0.83	0.74	0.795	0.64	0.91	0.08	0.235
6	0.84375	0.83	0.62	0.83	0.83	0.74	0.83	0.75	0.72	0.76875	0.62	0.83	0.075	0.22375
7	0.8125	0.75	0.56	0.83	0.75	0.73	0.83	0.64	0.72	0.72625	0.56	0.83	0.08625	0.2525
8	0.78125	0.74	0.56	0.75	0.74	0.72	0.81	0.62	0.72	0.7075	0.56	0.81	0.07375	0.22125
9	0.75	0.65	0.56	0.75	0.73	0.72	0.7	0.62	0.64	0.67125	0.56	0.75	0.07875	0.19
10	0.71875	0.64	0.56	0.74	0.73	0.64	0.64	0.46	0.64	0.63125	0.46	0.74	0.0875	0.25875
11	0.6875	0.64	0.55	0.73	0.72	0.64	0.64	0.45	0.63	0.625	0.45	0.73	0.0625	0.2375
12	0.65625	0.56	0.54	0.73	0.72	0.63	0.63	0.45	0.63	0.61125	0.45	0.73	0.045	0.20625
13	0.625	0.56	0.54	0.73	0.64	0.62	0.62	0.43	0.62	0.595	0.43	0.73	0.03	0.195
14	0.59375	0.56	0.5	0.64	0.64	0.57	0.62	0.38	0.56	0.55875	0.38	0.64	0.035	0.21375
15	0.5625	0.55	0.44	0.64	0.64	0.56	0.56	0.37	0.45	0.52625	0.37	0.64	0.03625	0.1925
16	0.53125	0.55	0.43	0.55	0.64	0.56	0.56	0.37	0.44	0.5125	0.37	0.64	0.01875	0.16125
17	0.5	0.54	0.37	0.54	0.64	0.56	0.55	0.36	0.43	0.49875	0.36	0.64	0.00125	0.14
18	0.46875	0.46	0.37	0.53	0.62	0.55	0.55	0.35	0.37	0.475	0.35	0.62	0.00625	0.15125
19	0.4375	0.45	0.37	0.45	0.62	0.46	0.55	0.35	0.36	0.45125	0.35	0.62	0.01375	0.1825
20	0.40625	0.43	0.36	0.43	0.56	0.46	0.54	0.34	0.36	0.435	0.34	0.56	0.02875	0.15375
21	0.375	0.38	0.35	0.43	0.46	0.45	0.53	0.34	0.35	0.41125	0.34	0.53	0.03625	0.155
22	0.34375	0.37	0.27	0.37	0.35	0.35	0.53	0.27	0.35	0.3575	0.27	0.53	0.01375	0.18625
23	0.3125	0.37	0.26	0.35	0.35	0.35	0.35	0.27	0.34	0.33	0.26	0.37	0.0175	0.0575
24	0.28125	0.37	0.25	0.35	0.35	0.35	0.27	0.26	0.27	0.30875	0.25	0.37	0.0275	0.08875
25	0.25	0.35	0.25	0.35	0.34	0.35	0.26	0.26	0.27	0.30375	0.25	0.35	0.05375	0.1
26	0.21875	0.34	0.24	0.28	0.27	0.34	0.26	0.26	0.26	0.28125	0.24	0.34	0.0625	0.12125
27	0.1875	0.27	0.24	0.27	0.26	0.26	0.25	0.25	0.26	0.2575	0.24	0.27	0.07	0.0825
28	0.15625	0.25	0.24	0.26	0.25	0.26	0.24	0.25	0.25	0.25	0.24	0.26	0.09375	0.10375
29	0.125	0.17	0.24	0.24	0.24	0.25	0.24	0.24	0.25	0.23375	0.17	0.25	0.10875	0.125
30	0.09375	0.16	0.16	0.17	0.17	0.25	0.24	0.16	0.24	0.19375	0.16	0.25	0.1	0.15625
31	0.0625	0.06	0.16	0.16	0.16	0.16	0.18	0.06	0.16	0.1375	0.06	0.18	0.075	0.1175
32	0.03125	0.05	0.06	0.06	0.06	0.16	0.16	0.05	0.15	0.09375	0.05	0.16	0.0625	0.12875
33	0	0.05	0.05	0.06	0.05	0.04	0.06	0.05	0.05	0.05125	0.04	0.06	0.05125	0.06

Table 6.1: Fitness score values that have been selected for this test.

6.2 Implementation

6.2.1 Scalability

A software system has to be able to scale according to the number of its users in order to be future-proof, as the current trend to dynamically scalable cloud solutions and server-less web architecture approaches highlights. There are two concepts or preparing an application for an higher workload: vertical scaling and horizontal scaling. Vertical scaling is done by providing more resources, e.g. Memory and CPU power, to the machines running the applicaions. Horziontal scaling, however, means setting up more machines providing the same service, so that workload can be distributed between them [Bea]. In contrast to vertical scaling, horizontal scaling has vital advantages: the application will be more robust since the crashing of one machine can be compensated by others [Fed16], the capacity of the system can, theoretically, be unlimited, and it is cheaper, because instances can be created dynamically if needed and then be destroyed in times of low workload, whereas the resources given to a machine that has been scaled vertically will remain unused.

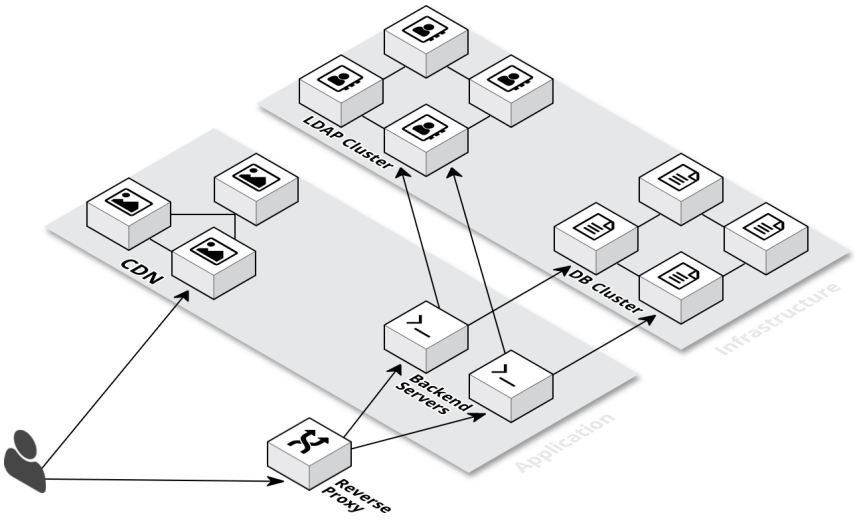

Figure 6.4: A possible approach to scale the system using multiple backend servers, a CDN, and multiple clustered database and ldap servers. Created with *https://cloudcraft.co*.

MongoDB

MongoDB is meant to be scaled horizontally and supports the adding of new instances to a running cluster of databases out-of-the-box [HMPH15, p. 19]. So, new machines running the database as a cluster will be created, if needed. As shown in 6.4, the backend servers can be connected to any of the database servers in order to request data. If the demanded document is not found on the instance the backend is connected to, MongoDB will handle the lookup in the cluster; to the application, the cluster is completely transparent and appear as if it was one machine.

LDAP

The LDAP servers[1] can also be run as a cluster in order to improve response times and prevent data loss by replicating the stored information [Fou]. In fact, the LDAP is currently being provided by six servers that represent the service. As illustrated in 6.4, the backend servers can connect to any of the LDAP servers; the data replication and synchronization is handled transparently.

Static Content

The static content files like HTML, CSS and JS files, that altogether represent the frontend, are served by the reverse proxy web server. In the event of an increasing number of requests that cannot be handled by the single server, a *Content Delivery Network* (CDN) could be deployed. A CDN is a network of webservers that provide static content and large files. The reverse proxy would redirect the URLs for those files, so that the users' browsers will connect directly to said network in order to retrieve the assets.

Backend

The backend application itself does not save any data on the machine it is running on, but connects a database server (see 5.6). As a result, any number of backend instances can be set up. In contrast to the other services, the backend servers do not have to synchronize. In order to receive HTTP requests, the reverse proxy must be configured so that it redirects API calls to the backend servers. This is called *load balancing* and is supported by many modern web servers such as *nginx*, *Apache* and *Tomcat*.

[1] SinnerSchrader is running *OpenLDAP* (http://www.openldap.org)

6.2.2 Conclusion

In theory, the application should be able to scale according to the number of its users. Practically, only the running of multiple backend and LDAP servers has been tested successfully. Running multiple database instances has not been tested; since MongoDB has been designed to be horizontally scalable and comes to use in various companies like *Github*[2], *eBay*[3], and *Otto*[4], it can be assumed that this can be done successfully for this application, too. Deploying a CDN that serves the static content has not been evaluated, as the implementation of the frontend was not part of this thesis, but has been worked on by [Str17].

[2]https://www.mongodb.com/presentations/mongosv-2012/mongodb-analytics-github
[3]https://www.mongodb.com/presentations/mongodb-ebay
[4]https://www.mongodb.com/industries/retail

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