



FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master's Thesis in Informatik

**Implementation and Evaluation of a
Context-Aware Mobile Shopping
Recommender System**

Yurong Tao





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**Implementierung und Evaluierung eines
kontextsensitiven mobilen
Einkaufsempfehlungssystems**

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| Author: | Yurong Tao |
| Supervisor: | Prof. Dr. Johann Schlichter |
| Advisor: | Béatrice Lamche, M.Sc. |
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Yurong Tao

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Abstract

This thesis presents a context-aware mobile shopping recommender system that integrates contextual information into an existing recommender system that was built using active learning strategies. The methodology introduced in paper [4] was adopted and adapted to guide the development of the system.

The system integrates the contextual information into an existing recommendation process using a case-based recommendation approach that recommends clothes items bought by other users under contextual situations similar to the one the current user is in.

Before the system was built, the influence of different context factors on different clothes types was quantitatively assessed first. Following the methodology introduced in paper [5], a user study was conducted where the influence was rated by the participants through imagining themselves being in different context conditions. The assessed influence was used as importance weights in the similarity metric for retrieving cases.

The cases are retrieved using a similarity metric designed and developed from the Euclidean Overlap Metric (HEOM). The system recommends based on a case base that can be set up using expert-driven approach. To overcome the static suggestion problem of case-based recommendation, a collaborative filtering approach was adopted to provide an effective way for knowledge engineering, in which user's purchased items together with the contextual information can be added as a new case to the case base.

The Android application integrating the developed system was developed on a baseline system developed in paper [20]. It was evaluated mainly qualitatively with a diverse set of people with different backgrounds. It was shown to perform better regarding prediction accuracy, decision effort and general satisfaction compared to the baseline system that is not context-aware. Users also showed a good understanding of the benefits of using contextual conditions.

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1. Introduction

In this Master's Thesis, a context-aware mobile shopping recommender system is implemented and evaluated. A methodology for building context-aware recommender systems was adopted and adapted to the system. Following the methodology, a recommendation approach and the reasoning behind why this specific approach was chosen will be given. The development and design process together with the evaluation process will be presented.

This chapter will shed light on the motivations behind the developed system and the goals set out to meet. The last section will give a brief outline on how this thesis is structured.

1.1. Motivation

In this thesis a mobile shopping recommender system developed for recent touch-based Android phone handsets will be displayed. In this system, contextual information was integrated into the recommendation process so as to provide context-aware recommendations.

Mobile platform was selected in this thesis because it is the trend. Mobile computing has caught the attention of the research community for quite some time. Many experimental systems and applications have been developed but were not vastly put in real use because of the limitation of the mobile devices and the infrastructure outside. However, around six years ago, the introduction of new mobile platforms such as iPhone and Android changed everything drastically. The new touch-based interaction method and the improvement of the computing power of mobile devices bring new possibilities to application development. The constant development of wireless network bandwidth and the decrease in the price of both the mobile devices and the network fee help to create a large customer base for developers. The reduce in the size of mobile devices also makes it easier to carry them around. According to reports from Market Research firm Gartner, by the year 2016, an estimated 310B downloads and \$74B in revenue is predicted from app stores [37].

In particular, Android was selected as the target mobile platform in this thesis. Android is the most popular mobile platform and is still growing very fast - every day more than one million new Android devices are activated worldwide [2]. The

openness and the powerful development framework make Android applications be deployable across a wide range of devices. On the other hand, from the developer's perspective, the Android development tools offer a full Java IDE with advanced features for developing, debugging, and packaging Android apps that can efficiently facilitate the development.

In addition, mobile devices are generally becoming an essential part of people's daily life. People can carry them around and have access to internet anywhere at anytime. Mobile devices have simplified and changed the way people do business, do shopping, travel and communicate. This feature of mobile also draws the attention to context-aware systems. Especially for recommender systems, which and to what degree can context factors affect people's perception of the recommended items and how can contextual information be effectively integrated into existing recommender systems need to be further studied.

In mobile exploratory scenarios, the user does not know exactly what she/he is looking for, or she/he might have a general idea of the product to buy (e.g., buy clothes for sports purpose). In the ideal case, the system should be designed not to require any query input from the user at the start of the recommendation session. Instead, to best predict user's preference, a diverse set of items will be presented so as to ensure that the user can start general and determine the direction to go. However, if the diversity of items increases, further personalization is required for initial recommendation to ensure the accuracy and efficiency of the system. At this time, context-aware information such as weather, budget and shopping intent can be important clues to predicting user's current interest.

As a result, the focus of this thesis shifted to implementing and evaluating context-aware recommender systems using Active Learning strategies on mobile platforms. To be more specific, a clothes shopping scenario was used in this thesis because it was not much studied but is closely related to people's daily life.

1.2. Goals

Few studies have been done on the integration of context-aware information into an active learning mobile recommender system [4, 33, 29]. The goal of this paper is to explore if the integration of context-aware information using case-based recommendation approach can improve the user experience of mobile recommender system that uses a conversation-based Active Learning strategy.

The system designed should be flexible enough to include different types of mobile contextual information. In this thesis, four types of context should be considered: physical context, social context, interaction media context and modal context.

The interaction design of the system will follow the Android Design Principles [1] to ensure an integrated experience and user's acceptance of the system. In mobile shopping scenario, users are believe to be less patient, mostly on the move and likely to be distracted easily, contextual information retrieval, thus, should be kept as simple as possible and not too much user input should be required. If possible, automatic detection can be used to minimize user input.

To successfully design and develop the context-aware recommender system, a methodology for developing context-aware recommender system [4] should be used and adapted to the current system. Firstly, context factors relevance will be assessed using a web tool developed for that. Then a case-based recommendation algorithm will be designed and developed based on that. After that, a context-aware mobile recommender system that utilizes the developed algorithm will be developed and evaluated.

1.3. Outline

The thesis is divided into five chapters. The current one (chapter 1), introduces the ideas, motivations and goals behind this thesis.

The second chapter lays a foundation for the system developed in this thesis. It gives a general introduction to recommender system, case-based recommender system, active learning recommender system and context-aware recommender system. The baseline system used for evaluation in this thesis is also introduced in this chapter. Finally, a methodology adopted in this thesis for developing context-aware recommender system is introduced.

The third chapter follows the methodology in chapter two and explains step by step how the system was built. First, an experiment for acquiring context relevance is explained. Then a proposed approach together with the algorithm for integrating contextual information into existing recommender system using Active Learning strategies is explained. Finally, the developed context-aware mobile recommender system prototype Shopper is introduced.

Shopper is evaluated in chapter four. It shows that Shopper received a better evaluation in prediction accuracy, decision efficiency and general satisfaction compared with the similar, but not context-aware baseline system introduced in chapter three.

The thesis ends with a summary of the achievements and discussion of possible directions for future work.

2. Foundations

Based on the motivations and goals discussed in the previous chapter, this chapter will start with a detail discussion of the recommender system researches that informed the design, implementation and evaluation of the developed system.

2.1. Recommender System

With the development of information technology, people can now have access to various kinds of product and services all over the world using internet without any difficulty compared to limited choices in the local shops in the old days. At the same time, people are overwhelmed by the number of options to consider. Thus Recommender Systems (RSs) as a decision support tool has become an important topic in the research study.

Recommender Systems are software tools and techniques providing suggestions for items to be of use to a user [30]. RSs try to provide personalized recommendations based on user preferences and constraints which can be either explicitly expressed as, e.g., ratings of products, or implicitly inferred from, e.g., user actions or context around. For instance, user's navigation to a particular product page can be interpreted as user's interest in that product. With the introduction of the concept of context-aware recommender system, context such as location, weather, company can also be used for recommendation prediction.

Different recommendation techniques are used for recommendation and they are usually categorized into three categories [22, 30]:

- **Collaborative Filtering:** RSs using collaborative filtering approach recommend to the active user items that are liked by other users with similar tastes in the past.
- **Content-based:** RSs using content-based approach recommend items that are similar to the ones the current user liked before.
- **Knowledge-based:** RSs using knowledge-based approach exploit knowledge about the customers and the application domain to reason about the items that might be of interest to the user.

In collaborative RSs, recommendation depends on the information of current user and a large amount user/system interaction data is needed to find similar users and thus relevant items to recommend. In content-based RSs, only the current user information is exploited for recommendation and since content-based RSs are usually implemented as classifier systems based on machine learning research, a large enough number of user ratings is needed to train the prediction model. Both techniques are faced with a cold-start problem: not until enough examples (product ratings or pattern of user preferences) are known, the recommendations can not be useful for the user [22, 9].

This problem is even worse for clothing recommender systems. If we look into Amazon website, we can find that there are far fewer ratings for clothes than for other products like cameras or mobile phones. It is because clothing product is featured with fast updating and diverse styles. It is unrealistic to have enough ratings for all the clothing for recommendations in a short period of time. As for the application in this thesis, where a clothing recommendation system for offline shopping scenario was built. Different from online shopping, offline shopping is limited with location and space, which will drastically cut down the number of examples. On the other hand, user's clothing shopping preferences change a lot with the current contextual conditions like weather, temperature, mood or budget and it is difficult for content-based and collaborative RSs to adapt quickly to those changes. All these considerations motivated the adoption of the third approach, knowledge-based approach. Knowledge-based RSs help to solve all these challenges by exploiting existing knowledge about the specific product domain and explicit user requirements. There is no cold-start problem because all requirements are directly elicited within a recommendation session.

There are two types of knowledge-based RSs: case-based recommender and constraint-based recommender [17]. Case-based recommenders determine recommendations based on past similar cases or in other words, successful solutions, while constraint-based recommenders determine recommendations by exploiting predefined knowledge bases that contain explicit rules about relationship between customer requirements and item features.

2.1.1. Case-Based Recommender System

Case-based reasoning (CBR) is a problem solving methodology that tries to solve new problems by re-using or adapting past solutions stored in past similar cases [19]. A case models a past experience, storing both problem description and solution applied in that context. A case can be as simple as a product. It can also include a product and the context in which the product is bought. All the cases are stored in a case base. In a typical CBR process, when the system is given a new problem to solve, it first searches in the case base for previous similar cases, then reuses or adapts the solutions in those

cases to the current problem. After that, the solution together with the problem are retained as a new case in the system case base for the use of future recommendation.

In paper [22], a methodology was introduced to help with applying CBR steps to the recommender systems, in which a framework was created for building CBR RSs. In this framework, a typical case-based recommendation process is composed of six steps: retrieval, reuse, revise, review, retain and iterate, which is similar to the CBR process. Each of these steps will be explained separately below so as to provide a better understanding of this framework.

Retrieval: Retrieval phase, as the first step of the recommendation cycle, is also the main phase and the majority of CBR recommender system. Cases with similar problem descriptions are retrieved in this step using different retrieving strategies.

Reuse: The cases retrieved in the last stage are evaluated and reused in the current problem in this step. There are various ways to reuse the cases. In the simplest cases, the solutions in the retrieved cases will be directly applied to the current problem. In more advanced cases, the retrieved cases can be used as reference set to rank candidate items [29].

Revise: In the revise stage, the reused cases are adapted to better fit to the current problem. For example, if the recommended travel location in the previous case is already closed or is too far away for the current user, then the system can replace it with another similar place that is still open or is nearby.

Review: In the review stage, user can customize or critique the recommended items. For example, the user can tell the system what she/he likes and doesn't like about a recommended clothes item.

Iterate: Usually in a conversational recommender system, the critiques and customization in the review stage will be given as a feedback to the system so that the system can iteratively update its recommendations to better fit the users' preferences.

Retain: Finally, at the end of a recommendation session, e.g., an item is bought or an item's page is viewed, a new case will be created and retained in the case base for future use.

Case Modeling

A case base CB can be decomposed into four sub-components:

$$CB \subseteq X \times U \times S \times E$$

where X is the product/content model, U is the user model, S is the session model and E is the evaluation model. Each case $c = (x, u, s, e) \in CB$ in the case base is consist of four sub-elements x, u, s, e which are instances of the spaces X, U, S, E respectively. However it's not a must that every case base contains all four components.

Content model (X): The content model describes the product recommended or to be recommended and is usually represented as feature vectors. For example, a clothes item to be recommended in the case base can be represented as an n -dimensional vector space $X = \prod_{i=1}^n X_i$. Each X_i represents the set of possible values for a product attribute [24]. An attribute could be the color or price or clothes type.

User model (U): The user model contains the user information, such as, name, address, age or user's past interactions with the system, such as, the products bought before or the products liked before.

Session model (S): The session model usually contains the information about the recommendation session. It can be the contextual information, such as, weather, temperature, budget, shopping intent, etc.

Evaluation model (E): The evaluation model describes the outcome of the recommendation (e.g., user's rate).

Similarity Assessment

Retrieval is the majority of case-based recommendation in which cases similar to the current problem will be retrieved. Thus the definition of similarity and the approaches to similarity assessment becomes an important topic and affects the retrieval strategy. For example, if the user submits a query to find similar clothes to the current selected one, the products' features in each case will be compared to the selected product to determine the similarity. However, if the user submits a query to find clothes to wear in the current season (e.g., summer), then the season information contained in session model in each case will be compared to the current season to determine the similarity.

Similarity assessment between cases or between user query and a candidate case is usually calculated as a weighted sum of similarity between individual feature pairs as is shown in Equation 2.1:

$$Similarity(t, c) = \frac{\sum_{i=1} w_i * sim_i(t_i, c_i)}{\sum_{i=1 \dots n} w_i} \quad (2.1)$$

where the similarity between target query t and candidate case c is calculated as weighted sum of the individual similarities between the corresponding features of t and c , namely t_i and c_i . A unique weight is defined for each feature according to its level of importance in the current problem and a unique similarity function $sim_i(t_i, c_i)$ is defined for each feature according to the property of the feature. For example, considering a numeric feature such as clothes size, the maximum similarity is achieved when the size in the target query matches the one in the candidate case. The desirability of the size will decrease equally if it goes either larger or smaller. In this case, the size feature can be measured by symmetric similarity metric like the one in Equation 2.2 [7]:

$$sim_{size}(s_t, s_c) = 1 - \frac{|s_t - s_c|}{range(s)} \quad (2.2)$$

On the other hand, considering a numeric feature such as price, if the user queries for clothes of price €50, it means that the user can also afford clothes with price lower than €50, but it may not be the case for clothes with price higher than €50. Thus the price feature can be measured by asymmetric similarity metric like the one in Equation 2.3 [38]:

$$sim_{price}(p_t, p_c) = 1 - \frac{|p_t - p_c|}{max(p_t, p_c)} \quad (2.3)$$

To evaluate the similarity of non-numeric features usually requires additional domain knowledge and hard coding the knowledge into the system using a proper a structure, e.g., an ontology.

2.1.2. Active Learning Recommender System

Traditionally, recommender systems present items to users because those items are thought to be of interests to the users. However, RSs can also intentionally influence the presentation of items to users so that more user preferences can be elicited and learned. Active Learning (AL) helps to fulfill this goal through actively influencing which items the user is exposed to and learning from user's feedback [31]. For example, a movie recommender system can first let the user select the genre the user is interested in and then recommend more movies from the genres selected by the user or it can first display a diverse set of movies from different genres and let the user rate or critique on them to get the user's preferences.

Usually three situations can occur when a user is searching for a product: the user knows exactly what to buy; the user has a desire (e.g., want to buy clothes for work) but does not have a clear objective in mind; the user does not know precisely what to buy [22]. For users in the second and third situation, RSs augmented with AL help the user become more self-aware of their own interests and at the same time collect more information about the user that can be used for better recommendation.

AL is the process of actively selecting training points so as to observe the most informative output. AL methods can be categorized based on their primary goals:

- **Uncertainty-based Active Learning:** This approach selects training points so as to reduce uncertainty in, for example, output values, the model's parameters or a decision boundary, etc.
- **Error-based Active Learning:** This approach selects training points so as to reduce the predictive error.

- **Ensemble-based Active Learning:** There are usually advantages and disadvantages for each single model. Thus a combination of different models can give a better result through compensating the disadvantages of each other.

2.1.3. Conversation-based Active Learning

Different from standard AL methods in which the goal is to obtain ratings of representative items from users so as to improve the prediction accuracy of underlying model for the entire data set, conversation-based AL first starts with a general set of items and then iteratively narrows down the scope of candidate items through a series of interaction cycles in which user's preferences are elicited and learned in various ways until a final desired item is found [31]. A typical example is to first present the user with a diverse set of items and iteratively update and adapt the recommendations based on user's critiques on item features [20]. In each iteration, the scope of candidate items is narrowed down, because user's queries are becoming more and more concrete. This process will keep going until the scope is narrowed down to a single item or the user finds the desired item.

This cycle-based conversational approach usually works because it mimics the behavior of offline shopping guide. People are usually unaware of their own interests and don't know what is out there in the market. Through a conversational interaction, people can first explore the available products and then refine and form their preferences over each cycle. This process is also self-explained enough because user can see how the final recommendation is reached. Such conversational systems include AL by design because user preferences are learned through active interaction. There are three main approaches to perform conversation with the user [31]:

- **Case-based Critique:** This approach searches for cases similar to user's query and then updates the recommendations based on user's critiques. During the initialization of the recommendation, no user preference initialization is required. In each iteration, a list of cases will be retrieved and be ranked according to the similarity to user's current query. The user can then critique on the attributes of the recommended items to further filter out irrelevant items or narrow down the scope of candidate items. There can be positive or negative critiques. Positive critiques can be something like "I like color red.", while negative critiques can be something like "I don't like jacket."
- **Diversity-based:** Although cases are retrieved based on their similarities to the current user's query, diversity is also an important consideration. In each cycle of the recommendation, the system should present the most representative items in the current search space. If the recommended items are too similar to each other,

it might be the case that the user dislikes all of them and have to use more steps to find the items she/he likes. Thus the system should also consider diversity in each iteration and let the user choose the direction to go in the next step. It is especially important when the user's preference is still not clear.

- **Query Editing-based:** This approach allows users to repeatedly edit and submit the query in order to get better recommendations. In order to make this process be more efficient, usually, the system can make predictions of the next query or make editing suggestions to the current query so as to save user's exploration time and help the user to narrow down to their interest area sooner.

2.1.4. Context-Aware Recommender Systems

In traditional cases where people talk to each other, context helps with increasing conversational bandwidth [1]. The current time, the location where the two people meet each other, the gestures, or the companion are all influential factors of the conversation. However, this important ability of context is largely neglected when it comes to human-computer interaction.

With the development of portable computers and wireless network, people can now carry their personal devices and have access to the internet anywhere at anytime. Instead of being used in a steady environment with a predictable environment, the software systems now will be installed on different devices and be used in different environments. With traditional human-computer interaction paradigms, it becomes more difficult for human and computer systems to talk to each other. Also since the customers now can be accessed at anytime through either apps on the mobile phone or other mobile devices like wristband and intelligent glasses, companies now must deliver not just competitive products but also unique, real-time customer experience which leads to the study of context-aware recommender systems (CARS) [26].

Among the researches that have been done in recommender systems, most existing approaches recommend most relevant items to users without taking into account the current context of the user, such as time, location or purpose. However, for recommender systems and especially those on mobile devices, it might not be sufficient to just consider item and user when making recommendations for items in specific fields like vacation package, retailing or movies, because users' preferences may often change according to the current context. For example, users may prefer to visit indoor sight spot when the weather is raining and may prefer to visit museums when they are with their young children. Similarly, in the case of clothes shopping, a user may want to buy coat when the weather is cold even though the user generally like skirt the best. A user may even don't know what kind of clothes to buy for a certain context

(e.g., what clothes to buy for hiking and what clothes to buy for running) and needs the recommender system to assist them in making purchasing decisions. Thus, it is important to incorporate the contextual information into the recommendation process so as to provide better recommendations in different circumstances.

Many researches have already laid the foundations and shown the importance of context in recommender systems. Findings in behavior research show that decision making is contingent on the context of decision making [3]. Therefore, to increase user satisfaction and prediction accuracy, RSs need to capture the real-time user preferences by integrating context into the recommender systems. Also, a number of ubiquitous computing researchers also share the hypothesis that enabling devices and applications to automatically adapt to changes in context will help to improve the user experience [15]. For example, paper [4] assessed the influence of context factors to user ratings and integrate the contextual information in a mobile travel planning tool. It shows that the context-aware recommender system was preferred to a similar variant that did not exploit contextual information in terms of efficiency, general satisfactory and serendipity.

What is Context

Context is a multifaceted concept and has been studied in various fields like computer science, cognitive science, psychology, etc. In each field, context has its own definition. To better understand how we can effectively use context in the mobile recommender systems, we need to find out the accurate definition of context in this field but not just borrow it from other areas.

According to *Webster's New Twentieth Century Dictionary* (1980), context is the "whole situation, background or environment relevant to some happening or personality." This definition is too general and can not be effectively used in context-aware recommendation systems. In previous researches in context-aware computing, context is usually defined either through enumerating through examples of contextual information or through categorization.

Initially, context was defined as the location of the user, the identity of people near the user, the objects around and the changes in these elements [35]. After that, more factors were added to this definition. For example, Brown et al. [8] include the time of day, the season, and the temperature. Ryan et al. [32] add the physical and logical attributes of interest for a user. Dey et al. [13] include the user's emotional and mental (focus-of-attention) status.

In paper [4], the author focused on mobile context and divided mobile context into four categories:

- **Physical context:** This includes the physical status of or around the entities and

can be the time, position, activity of the user, weather, light or temperature. For example, the weather of the day might affect the travel plan of the user.

- **Social context:** This category includes the social status of the entities and can be the presence and role of other people around the user, or the relationship among different items. For example, a movie a user wants to see with her/his boy/girlfriend might be different from the one when she/he is with her/his parents. Also a system can recommend a user a scarf nearby that can be matched to the sweater the user just bought because of the matching relationship between the scarf and the sweater.
- **Interaction media context:** This category includes the device the user is currently using, or the item the user is currently browsing or have bought.
- **Modal context:** This category includes the states of mind of the user and can be the user's purchasing goals, current mood, etc.

On the other hand, in paper [16], the author gives a more operational definition of context: Context is any information that can be used to characterize the situation of entities (i.e., person, place, or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity, and state of people, groups, and computational and physical objects.

There is an argument among researchers whether context should only include information that is automatically obtained. Although, ideally, it is hoped that no manual input is required from the user which is the best from for the sake of user experience. Many researches have also been done on automatic prediction of user's context. For example, in paper [6], the author tried to use time and location to infer user's current activity. However, up till now, the techniques for automatic context detection are still unmaturred and require further research. So here a more inclusive definition was opted and contextual information that are either manually obtained and automatically obtained were both accepted.

Context-aware Computing

Context-aware computing is a mobile computing paradigm in which systems can retrieve context either explicitly or implicitly and utilize contextual information to provide relevant information or services to the user, where relevancy depends on the user's task [10, 14].

In summary, context can be used in three different ways in different applications [15]: The first way is to present information and services. It refers to the systems that

present the contextual information directly to the user to help with the decision making of the users or the systems that propose appropriate selections of actions to the user. For example, in paper [34], a context-aware system was developed to present a choice of printers close to the user, but the system did not automatically book the printer or print the document for the user. The second way is to automatically execute a service. It refers to the systems that act or make decisions on behalf of the user based on the current context or context changes. For example, the Google Self-Driving Car uses various detectors and sensors like laser to collect and generate data (e.g., maps) that is needed to allow the car to drive by itself [39]. The third way is to attach the contextual information for later retrieval. It refers to the systems that tag captured data with relevant contextual information so that the data can be retrieved in a different way using context.

In this thesis, these three approaches were combined. The detected contextual information is presented to the user so that she/he can decide which context factors are important in her/his decision making process. Then the system will automatically recommend clothes items based on user's context settings. Once the user purchases an item, the system will record the context and the bought item as a case so that it can be used for future recommendations.

Context and Reasoning Processes

After the discussion of the importance and definition of context, this chapter shows how the contextual information can be most effectively used by the system through studying how context affects people's reasoning processes. Paper [27] analyzed this from the psychological perspective. Psychologists Stanovich and West claims that there are two systems operating in the mind: system one operates subconsciously with little or no effort in solving the problem and system two allocates attention to the effortful mental activities that demand it. System one always works under a certain context. It will generates a likely context if no context exists. For example, the music most recently played will affect your evaluation of the music you are currently listening. You may prefer music with similar style to th last one because you are in a certain mood or you may prefer a music with different style because you want to try something new. In traditional recommender systems, recommendation quality is often measured by utility. If we look from the utility perspective, we can see that for the user, the quality of a recommender system depends on three factors [27]:

- **Expected Utility:** What you expect an experience will make you feel.
- **Experienced Utility:** The way an item (movie, travel, etc) makes you feel in the moment.

- **Remembered Utility:** Once you have an experience (e.g., a movie), future choice will be based on what you remember about that.

These three factors are produced, measured and utilized at different stages of the recommendation. The recommender systems predict recommendations based on the remembered utility data. Users accept or reject based on expected utility. Users' experienced utility after consuming the item will be transferred into remembered utility and be used for the next round of recommendation. So, in order to predict more precisely how likely a user may like an item, the system should know how to accurately measure these three types of utilities.

Researchers show that those utilities are affected and can be measured by some basic rules:

- **Peak-end Rule:** D.Kahneman shows that what we remember about an experience is determined by how it felt when it was at its peak and how it felt when it ended [27]. People rely on this summary later to remind how the experience felt and decide whether to have that experience again. Based on this rule, the recommender system should be able to detect and record users' feelings at the peak and at the end either explicitly or implicitly. For example, the system can ask for rating after the user have bought and tried the clothes as an end feeling and the system can record the purchasing of an item as the peak feeling. Those records can then be used as measurements of the utility of this item.
- **Anchoring:** People measure the expected utility of an item by comparing it to some other items. For example, shops always put clothes with original prices beside clothes with discounts. Although most people will choose to buy those discount clothes, the clothes with original prices actually act as anchors against those discount clothes and make the prices of those discount clothes cheaper and more reasonable. So the recommender system should utilize this psychological rule and try to explain their recommendations in a more efficient way to increase the users' expected utility. For example, the system can put the original price of a clothes item when it is on sale at a more conspicuous place.
- **Opportunity Cost:** Once you make a choice from several options, opportunity cost is the opportunities you need to give up if you choose a different option. Economists point out that the quality of any given option can not be assessed in isolation from its alternatives. For example, when recommending a discount clothes, the system can show some other similar clothes that do not have discounts to make the current recommendation be more appealing. Or the system can use some special icons to differentiate the items recommended for special contexts

from other recommendations to decrease the opportunity cost. For example, in paper [4], the author marked some of the recommendations with an icon showing a small clock and a green arrow to show that these recommendations are especially suited for the current context.

Obtaining Contextual Information

The contextual information can be obtained in various ways including:

- **Explicitly:** For contextual information that can not be detected automatically, the system can directly ask for it or elicit it from relevant people or other sources.
- **Implicitly:** For contextual information that can be automatically detected, there is no need for the system to interact with the user or other contextual information for the data. The system can just implicitly gather the information without disturbing the user.
- **Inferring:** The contextual information can also be inferred from other existing data known about the users and other entities. It may help with enhancing the user experience because it reduces the manual input the user needs to provide. However, this approach requires a predictive model which needs to be trained on appropriate data. There are already some researches in this area. In paper [33], the form of transportation can be inferred by the speed of the user using a decision tree (DT) followed by a first-order discrete Hidden Markov Model (DHMM). For clothes shopping recommender systems, user's location (e.g., which area of the store the user is in) and movement can be used to detect user's current interest like whether or not she/he wants buy male or female clothes or whether she/he wants to buy sports clothes or formal clothes. However, because the indoor location detection technology is still in it's early stage, it is put as future work in this thesis.

Relevance of Contextual Information

It was pointed out in paper [3] that not all contextual information is relevant or useful for recommendation purposes. It varies for different applications and for different users and it is usually unclear which contextual factors are more important and to what degree.

There are several approaches to determining the relevance of context factors. It can be either done manually, e.g., through utilizing the domain knowledge of the recommender system's designer or the market expert, or automatically, e.g., through analyzing existing ratings using approaches from machine learning, data mining and

statistics during the data preprocessing phase. This thesis followed the second approach mentioned above and adopted the methodology in paper [5] to quantitatively assess the relationship between contextual factors and user's intention to purchase. Traditionally, user's evaluations are collected in real situations which is time and energy consuming because enough data need to be collected in different context settings and it is not always the case that the ideal context situation will appear. In this methodology, contextual situations are simulated to more easily capture the data where users are asked to judge whether a contextual factor will affect their intention to purchase the item given a certain contextual condition. Details about how the relevance of context factors were determined in this thesis using this methodology, please refer to section 3.1.

Incorporating Context into Recommender Systems

In paper [3], different approaches to incorporating contextual information into recommender systems are categorized into two groups:

- Recommendation via context-driven querying and search: This group refers to the systems that use contextual information and/or user's specified interests to query or search a repository of resources (e.g., movies) and present the most appropriate result to the user. The contextual information is obtained directly from the user or the environment. The resources in the repository are tagged with contextual information while collecting them.
- Recommendation via contextual preference elicitation and estimation: This group refers to the systems that try to model and learn user preferences. Based on the data collected through observing user behaviors or from user's preference feedback on previously recommended items, the system tries to model user's context-aware preferences and generate recommendations either through applying traditional recommendation approaches (e.g., context-based recommendation or collaborative filtering) or through applying various data analysis techniques from data mining or machine learning.

2.1.5. Mobile Recommender System

With the increasing of the computation power of mobile devices and the improvement of mobile network technologies, mobile phones are becoming a primary platform for obtaining information [28]. The problem of information overload from PCs is also emerging in mobile devices and is becoming even more serious. Thus more and more researches have been done on deploying and developing recommender systems on

mobile platforms so as to increase the usability of mobile systems through providing personalized and more focused content and to solve the information overload problem.

However, existing recommendation approaches can not be directly applied to mobile platforms because of two main reasons. Firstly, mobile devices provide a different computing environment compared to PCs and has a lot of limitations and potential disadvantages. Mobile devices are of a smaller size compared to PCs and thus have limited screen size, computing power and data storage. Although users can read and understand the content displayed on small screens, it is still difficult for them to finish a recommendation session on those screens [28]. Users of mobile phones are usually less patient and be on the move, and thus have unstable network connections. They tend to spend less time on mobile applications compared to PC softwares. So how to help users reach their goals in a short period of time efficiently is important for mobile systems.

Secondly, mobile devices provide some extra characteristics and functionalities that can be exploited by recommendation approaches. The first characteristic is "context-awareness", i.e., the knowledge of user's current context can be more easily detected and fetched either explicitly or implicitly. Nowadays, mobile devices are equipped with multiple sensors. For example, motions sensors can measure acceleration forces and rotational forces along three axes; air temperature and pressure can be measured by environmental sensors like barometers; user's current outdoor location can be detected by GPS and even indoor locations can also be detected using, for example, iBeacon promoted by Apple [40]. The second characteristic is ubiquity [28], i.e., the ability to deliver the information and services to mobile users wherever they are, and whenever they need. This characteristic has put forward new challenges for mobile applications and services. Since users are interacting with the mobile applications more frequently and in more diverse set of contextual scenarios, the influence of the changes of the context conditions is also larger, hence the requirement of the level of personalization, efficiency and accuracy is also higher.

As it can be seen, the constant changing of context conditions is a challenge for mobile recommender systems. On the other hand, mobile RSs can also benefit a lot from user's current contextual information. Thus context-aware recommender system has become an important research field in recommender systems, especially for mobile RSs.

2.1.6. Baseline System

In paper [20], an offline shopping recommender system was developed on mobile platform utilizing conversation-based Active Learning strategy. Based on this system, a context-aware mobile recommendation system using active learning strategies was

built in this thesis with the purpose of evaluating whether integrating of context-aware recommendation technique can help to improve the recommendation. So before discussing the application developed in this thesis, the baseline system will be introduced in this section.

This system is a conversation-based recommender system that actively selects training points for user critiques so as to further adapt the recommendations according to the learned user preference from user's critiques until a satisfactory item is found. The user can positively or negatively critique on the item features and the system will decide whether to find more items similar to the current critiqued item or to refocus and select more diverse set of items. It was argued that especially in an exploratory scenario such as going shopping without having a specific item in mind, the user doesn't need to give a search query at the beginning of the recommendation. Thus a case-based recommendation approach using critiquing as feedback is adopted in the system.

Results showed that the conversation-based Active Learning strategy is suitable for mobile situation and diversity-based information retrieval is preferred to only similarity-based retrieval method regarding prediction accuracy, user effort and the intention to return to the system.

Standard AL methods try to obtain ratings of representative training points from users so as to improve the predictive accuracy of the underlying recommender systems which are usually based on model-based approaches. Conversation-based AL methods, on the other hand, can quickly adapt to user's current need by starting from a general set of recommendations and updating and narrowing down the scope of interest iteratively according to user's feedback in each conversation cycle. It is especially suitable for users who do not have a clear preference at the beginning. Especially, regarding the clothes shopping scenario, it is unlikely that the user always wants to buy the same kind of items. Fashion changes, user's taste also changes. At some point, the user will look for trousers, the next time for shirts. When the user is on a tight budget, she/he will prefer cheaper clothes, but some other day she/he may have more spendable cash available. Conversation-based system can quickly learn and adapt to those changes compared to a static model.

Since the system is used on a mobile platform, users are usually less patient than PC users because of the limited interface space, the continuously moving state and the fact that they can not be fully focus on the application because they also need to interact with real world objects around, case-based critiquing is used as a feedback in the conversational system, because in this case users don't have to specify the exact preference at start which requires a lot of input and cognitive effort. Furthermore, the system does not rely on ratings from other users to infer recommendations as is done in collaborative filtering systems because data collection is time and resource consuming and also has privacy concerns. Case-base critiquing method is also suitable in this

situation because it does not require any large-amount of pre-existing ratings.

Concerning all the factors above, an algorithm that can be used in conversation-based Active Learning systems using case-base critique as feedback was adopted by extending an existing algorithm called Adaptive Selection in paper [23].

Adaptive Selection (AS) is a conversation-based recommendation algorithm that uses user's critiques as feedback between cycles. It differentiates itself from traditional similarity-based retrieval method by introducing a new diversity-enhancing technique so that a more diverse set of recommendations can be retrieved when the system detects that it is not homing in on the target region. If the system is heading in the right direction, the items most similar to the current query will be retrieved using similarity-based retrieval method.

AS detects whether the new recommendations are satisfying or not through, what McGinty and Smyth call, carrying the preference. In each cycle, the last critiqued item will be included in the new recommendations. It is argued that if the user keeps critiquing on the carried item, it is indicated that the new recommendations are not satisfying and the system should refocus and show more diverse set of items in the next cycle. Otherwise, the system should refine and show more similar items.

Algorithm 1 The bounded greedy selection of the Adaptive Selection algorithm by McGinty and Smyth.

```

1: function BOUNDEDGREEDYSELECTION( $q, CB, K, B$ )
2:    $CB' \leftarrow bk$  items in  $CB$  that are most similar to  $q$ 
3:    $R \leftarrow \{\}$ 
4:   for  $j = 1$  to  $k$  do Sort  $CB'$  by  $Quality(q, i, R)$  for each case  $i \in CB'$ 
5:      $R \leftarrow R + First(CB')$ 
6:      $CB' \leftarrow CB' - First(CB')$ 
7:   end for
8: end function
9:  $\alpha = 0.5$ 
10:  $Quality(q, i, R) = \alpha Sim(q, I) + (1 - \alpha) RelDiv(i, R)$ 
11:  $RelDiv(i, R) = \sum_{j=1...m} (1 - Sim(1, r_j)) / m$  if  $R! = \{\}$ ;  $= 1$  otherwise

```

The refocus function is relied on a quality measure which uses the bounded greedy selection algorithm (see Algorithm 1) that ranks items according to their similarity to the query and their dissimilarity to already selected items. A further refinement is done on the quality measurement by introducing a weighting factor . This factor allows to bias the quality metric in favor of either similarity to the target query or diversity

among selected cases as can be seen in Equation 2.4.

$$Quality(t, c, R) = \alpha * Similarity(t, c) + (1 - \alpha) * RelDiversity(c, R) \quad (2.4)$$

Paper [20] adopted the algorithm AS and modified it for ease of use reasons by using a two-step critiquing process as the feedback method. Instead of determining whether to refocus or refine the recommendations based on whether or not the last critiqued item is critiqued again, in the new algorithm, the user is asked to determine and tell the system whether she/he likes or dislikes an item before specifying what exactly those critiqued features are. For a detail explanation of the system please refer to paper [20] .

2.1.7. Methodology for Developing CARS

There are four main issues that influence the successful design of CARSs [4]. The first issue is to find out the contextual information worth considering while generating recommendations. As was discussed in section 2.1.4, not all contextual information is relevant or useful for recommendation purpose. After the context factors are selected, they can be integrated into the recommendation process either through context-driven querying and search or through contextual preference elicitation and estimation approach as was discussed in section 2.1.4. For both approaches, user's in-context preferences knowledge need to be collected for either building knowledge bases or training predictive model. However this is a time and resource consuming process. Thus the second issue is to find an effective way for the collection of training data. After the recommendation approach is built, a complete recommendation system can be generated. Thus the third problem is to develop an efficient recommendation system using the given recommendation approach. The fourth problem is the interface design and visualization problem, including useful item description and explanation for the recommendation.

Paper [4] developed a methodology for solving these four issues and to support the development cycle for CARS. This methodology comprises four steps: determining which context factors are interesting to study; acquiring user ratings in different contextual scenarios; predicting ratings given a specific context; context-aware recommendation visualization and updating. This methodology was adapted and applied to the system development in this thesis.

3. Build the System

In the next chapter, a detail description of the process of the system development following the methodology introduced before and how the methodology was adapted and implemented are presented.

3.1. Acquiring Context Relevance

The first step of the methodology is to discover the relevance of the contextual factors to the current implementation domain (i.e. clothes shopping).

To adapt the recommendations to the user's current contextual situation requires an understanding of the relationship between user preferences and contextual conditions. Thus it is proposed that explicit user ratings or any form of preferences should be given under several different contextual conditions. For instance, the user must rate a given clothes item when the temperature is hot, warm and cold. It is quite time and resource consuming because the user needs to only give ratings after they have experienced the context. Therefore, to reduce the risk of collecting data for unimportant context factors, an experiment needs to be first set up to determine which context factors are interesting to study [5].

The experiment should be able to investigate how the influence of each contextual factors changes on user's purchasing decision for different clothes types and to provide quantitative measurements so that they can be used as weight in the similarity measurement in the following retrieving algorithm. Considering all above reasons, the methodology developed in paper [5] was adopted to assess the context relevance.

This methodology is based on a web tool for acquiring context relevance judgements and a statistical data analysis method to quantitatively measure the influence of each contextual conditions on different clothes types. Following this methodology, a web survey was designed and developed in this thesis. First, an initial set of contextual factors and conditions (values for the factors) were selected referring to some existing literatures about context-aware applications [4, 33, 25]. The selected contextual factors and conditions are listed in Table 3.1. Then, the clothes items were retrieved from Zalando ¹. Especially, clothes of these brands are collected: Marc O'Polo, Tom Tailor,

¹<http://www.zalando.co.uk/>

3. Build the System

Esprit, S.Oliver, Benetton. Because these five brands are in the middle price category and are well known and generally acceptable by most people. Moreover, the types and number of clothes offered by these brands are similar to each other and are rich enough to cover most common clothes types. After the clothes were retrieved, they were aggregated into a relatively small list of categories so that the problem of data sparseness can be avoided. Totally, 14 categories were defined: tops, dresses, underwear, cardigans, trousers, coats, blouses, jackets, skirts, jeans, socks, swimwear, suits and shirts.

Table 3.1.: Context factors used in the Web survey

| Context Factor | Conditions | Context Factor | Conditions |
|-----------------|-------------------------|-------------------|-----------------------|
| budget | budget buyer | purchasing intent | work |
| | high spender | | daily wear |
| | price-for-quality buyer | | party |
| time of the day | morning time | | sports |
| | afternoon | | no special |
| | night time | companion | with girl-/boy-friend |
| day of the week | weekend | | with family |
| | working day | | with children |
| crowdedness | shop is crowded | | alone |
| | shop is not crowded | | with friends |
| | shop is empty | weather | snowing |
| mood | shopaholic | | clear sky |
| | outdoorsy | | sunny |
| | like a party animal | | raining |
| | normal | | cloudy |
| season | spring | transport | walking |
| | summer | | public transport |
| | autumn | | bicycle |
| | winter | | car |
| temperature | warm | time available | half day |
| | cold | | one day |
| | hot | | |

After the data was prepared, a simple web application was developed for acquiring the relevance of the selected contextual factors for different clothes categories (see Figure 3.1). In the web application, users are randomly given a clothes category and

are asked to imagine themselves being under a randomly chosen contextual condition and then choose the influence of the selected contextual condition on their intentions to buy the selected type of clothes. As an example of the questions posed to the user consider the situation depicted in Figure 3.1. Here we first requested the user to imagine a typical shopping scenario: "Imagine that you are in Munich and you are doing offline shopping for clothes. You are thinking about buying Skirts." Then the user was asked to select the influence (i.e., positive, no effect, negative) of the three randomly chosen contextual conditions on their decision to buy the clothes. As an example of a contextual condition: "Imagine that the weather is cloudy." Every user was requested to interact with at least 10 of these pages (as in Figure 3.1).

Imagine that you are in Munich and you are doing offline shopping for clothes.
You are thinking about buying **Skirts**. Please mark the conditions that would **positively** or **negatively** influence the decision to buy it, or would have **no effect**.

Imagine that the weather is cloudy.
☒ Positive ☐ No Effect ☐ Negative

Imagine that you are feeling like a party animal.
☒ Positive ☐ No Effect ☐ Negative

Imagine that you have never bought a similar clothes before.
☒ Positive ☐ No Effect ☐ Negative

Next 1 out of 10

Figure 3.1.: Web based survey tool to acquire context relevance.

38 participants took part in this web survey. Overall 1190 responses were given to one of the questions shown in Figure 3.1. Because no pre-knowledge was known whether certain context conditions are more likely to influence user's decision, we sampled the value of clothes categories and contextual conditions using uniform distribution so that all possible values can be reached with equal opportunities.

3.1.1. Analysis of Context Relevance

The goal of this web survey in this thesis is to find out quantitatively how the context factors influence user decisions on whether or not to buy clothes from different categories.

The web survey delivered samples for the distribution $P(I|C_i, T)$ where I (Influence) is the response variable taking one of the three values: positive, negative, or no effect, T is a clothes category (e.g., tops, skirts), and C_1, \dots, C_N are the context factors that may or may not influence the user decision. This distribution models the influence of the context factors on the user's purchasing decision considering different clothes categories.

The spread of a categorical variable $X = x_1, \dots, x_n$ can be measured by looking at the entropy of the random variable [21]. If $P(X = x_i) = \pi_i$, the entropy of X is:

$$E(X) = - \sum_{1 \leq i \leq n} \pi_i \cdot \log \pi_i$$

This measurement of the spread can be used to estimate the association between variable X_1 : user's intention to buy a certain item (i.e., positive, negative or no effect) and variable X_2 : one of the current context factor (e.g., current budget). Informally, if the influence of the context factor is strong, then the spread of variable X_1 will be reduced if X_2 is known, and it is weak if the spread of X_1 remains unchanged even if X_2 is known and this association can be formally defined as [5]:

$$U = \frac{E(X_1) - \mathcal{E}(E(X_1|X_2))}{E(X_1)}$$

where $E(X_1) - \mathcal{E}(E(X_1|X_2))$ is the difference between the spread of X_1 and the expected spread of X_2 which measures the influence of the context factor to user's decision. $\mathcal{E}(X)$ denotes the expected value of the random variable X . U is 1 if the spread of $(X_1|X_2)$ is zero. U is zero, however, if X_2 does not have any influence of X_1 . U can be seen as the mutual information of X_1 and X_2 normalized to the interval $[0,1]$.

With the definition, U can be used to measure how good I - the influence of context on the user's purchasing decision - can be predicted if C_i - one of the relevant context factors - is known [5]. In this thesis, the computed U of each context factors for all clothes types was computed and used as weight factor for similarity assessment. The ordered context factors in descending order of U for each clothes category can be seen in Appendix A of this paper.

3.2. The Proposed Approach

This section describes the recommendation approach that was built. The goal of this approach is to integrate the contextual information into the recommendation process and recommend items that might be of interest to users under a specific context situation.

To integrate the contextual information into the recommender system, context-driven querying and search approach was adopted. As was introduced in Section 2.1.4, this approach uses contextual information and/or user's specified interest to query or search a repository of resources and presents the most appropriate ones to the user. The repository usually contains resources that are tagged with contextual information while collecting them. Corresponding to this approach, case-based recommendation technique was used to realize it. As was discussed in Section 2.1.1, case-based recommendation technique is a branch of knowledge-based recommendation. Compared to collaborative filtering and content-based techniques, case-based recommendation has no cold-start problem because it can rely on the case base (or knowledge base) for the initial recommendation. This case base can be set up quickly using expert experience and does not require pre-training like what was done in paper [4] for model-based approach.

Each case in the case base is composed of an item and the contextual situation under which the item is bought. Here a contextual situation is a combination of several context factors and their corresponding values. For example, the user may ask for recommendation of clothes for work (condition one) when the weather is warm (condition two). For the recommendation, the user first submits the contextual information as a query. Then the system searches in the case base and selects the cases with the most similar context situation and then recommends the items or items similar to the items contained in the retrieved cases to the user.

On the other hand, knowledge-based recommender system has the disadvantage of static suggestion ability because the knowledge-base is usually preset by domain experts and barely changes. Also usually the domain experts and the knowledge engineers are not the same person, the communication cost requires an efficient way for knowledge engineering. Based on those considerations, in this thesis the case-based recommendation approach was extended by integrating collaborative filtering approach for case base (knowledge base) setup so that all the application users can play the expert role and their purchased items together with the contextual information can be added to the case base as a new case for future recommendation. Although the collaborative filtering approach was used, the correlation between users was performed at the session level (i.e., each submitted case is independent of itself and will not be related to the user who submits the case). Thus no user identification is required and a considerable amount of example data is not needed for each single user in order to deliver effective recommendations [29].

3.3. Towards Case-Based Recommender System

As was introduced in section 2.1.1, case-based recommender systems apply case-based reasoning (CBR) methodology to solve recommendation problems by re-using or adapting past recommendation solutions stored in past similar cases. In the CBRs framework introduced in paper [22], a typical recommendation process is composed of six steps: retrieval, reuse, revise, review, retain and iterate. This framework was used to build the context-aware case-based recommender system in this thesis and will be explained step by step below.

Input: To get a list of recommendations, the user first submits a query of current contextual information. A query is composed of a logical query with fixed context constraints and a feature value vector of context factors and their corresponding value that the user wishes to be considered in the recommendation. For example, if a user is a budget buyer and wants to buy clothes for sports purpose when the temperature is hot and the user wants to find clothes items sold in stores that will be still open in the next 30 minutes within 2000 meters, the query will be structured as follows:

$$\begin{aligned} query = \{ & ((distance \leq 2000m) \wedge (timeopen = now + 30min)), \\ & (budget(budget\ buyer), intent(sports), temperature(hot)) \} \end{aligned} \quad (3.1)$$

Retrieval: After the user submits a contextual query, contextual factors such as budget and intent will be used to find and rank cases with similar context. The definition of similarity and the similarity assessment algorithm will be introduced in section 3.5.

Reuse: In the final recommendation, nine items in the cases are recommended to the user. However those items are not only ranked according to the level of similarity to the current context. As for initial recommendation of conversational recommendation system in an exploratory mobile scenario, diversity is an important consideration to ensure the coverage of the current scope of candidate items. Thus the bounded greedy selection algorithm was extended to select the cases with the most diverse set of items among the retrieved most similar cases.

Revise: Before the items are recommended to the user, logical constraints such as distance (e.g. find clothes within 2000 meters) or open time (e.g., shops still open in the next 30 minutes) will be used to check the availability of those items. If for example a recommended item is too far away, then other similar items will be recommended instead.

Review & Iterate: After the initial recommendations are presented, the user can update the recommendations iteratively through critiquing directly on item features. This is also called conversation-based active learning strategy and has been explained in detail in section [?].

Retain: Finally, when the user selects and purchases an item, the time together with the current context situation will be stored as a new case in the case base.

3.4. Case Model

The case base consists of two components: the item bought (I) and the context situation (C):

$$CB = I \times C \quad (3.2)$$

Each case $c = (i, e) \in CB$ in the case base is composed of two sub-elements i, e which are instances of the spaces I, C respectively. As was introduced before, the cases are not correlated with the user who submits it, thus the user model is not contained in the case in this system. A case is built during a human/machine interaction [29]. In this system, a case is created when the user purchases the item. According to Peak-end Rule introduced in Section 2.1.4, how a user feels about an experience is highly influenced by the end of the experience. It was assumed here that users give high rates to the items they buy. Since the case is created when the user purchase an item, the evaluation model in the case base was also removed in this system. In the following, these two components will be explained in more detail.

C is the data structure that defines the context situation under which the item is bought. It is composed of a feature value vector of context factors and their corresponding values that the user wishes to be considered in the recommendation and a feature value vector of context factors and their corresponding factor importance weight. The factor importance weight reflects the level of influence of the context factors to the recommendation of the clothes item contained in the same case. They are determined by the type of the clothes and has been calculated in the experiment introduced in Section 3.1. For a full list of the factor importance weights for different clothes type please see Appendix A. The main context factors are: distance, day of the week, temperature, time available, transport, weather, time of the day, crowdedness, intent of purchasing, companion, season and budget. For a detail list of the context factors and their values, please refer to Table 3.1. For a typical example, if a user is a budget buyer and is looking for clothes for sports when the temperature is hot, the context situation can be structured as follows:

$$context_{attributes} = \{(budget(budget\ buyer), intent(sports), temperature(hot)), \\ ((w_{budget}(0.7), w_{intent}(0.6), w_{temperature}(0.9)))\} \quad (3.3)$$

I is the data structure that describes the clothes item bought by the user. It is represented as a feature value weight vector [20] and was borrowed directly from the baseline system introduced in Section 2.1.6.

With this case model, knowledge of what kind of items users buy in a certain context situation can be obtained. To provide recommendations, cases with context situation similar to the current user's context can be retrieved and the items contained in those cases can be used directly for the recommendation. They can also be used as reference items to find other similar items to recommend. Thus the next section will show how the similarity between the current context and retrieved cases and similarity between items are calculated.

3.5. Similarity Assessment

To get the similarity between the current context and retrieved cases, the Euclidean Overlap Metric (HEOM) was borrowed [29, 41]:

$$heom(x, y) = \frac{1}{\sqrt{\sum_{i=1}^n w_i}} \sqrt{\sum_{i=1}^n w_i d_i(x_i, y_i)^2} \quad (3.4)$$

where:

$$d_i(x_i, y_i) = \begin{cases} 1 & \text{if } x_i \text{ or } y_i \text{ are unknown} \\ overlap(x_i, y_i) & \text{if the } i\text{-th feature is symbolic} \\ \frac{|x_i - y_i|}{range_i} & \text{if the } i\text{-th feature is finite integer or real} \end{cases} \quad (3.5)$$

Here $range_i$ is the difference between the maximum and minimum value of a numeric feature, and $overlap(x_i, y_i) = 1$ if $x_i \neq y_i$ and 0 otherwise. This metric measures the distance between two vectors. Thus the further away two vectors, the more similar they are. In this thesis this metric was modified so that it can be applied to the system.

By using the previously discussed case model and query structure, the feature value vectors of context factors describing the context situation in both structures can be fed into the similarity metric. The context factor set contained in user's submitted query is called current context. The context factor set contained in the case is called target context. First, the similarity between current context and target context is calculated for each case. In some cases, the target context may not contain some context factors in the current context specified by the user (e.g., the user enables the context factor shopping intent and budget in current context, but the target context only contains budget). In some other cases, the current context may not contain some context factors contained in the target context. So when computing similarities, user specified context factors are used as base and only the context factors specified by the user in current context are used for similarity assessment. The context factors contained in the target context but not in the current context are ignored, because the user chooses to ignore those factors.

If the target context does not contain the context factors specified in current context, the similarity will be added by $1 * w_i$. (w_i here corresponds to the feature factor weight).

The simplified similarity metric is displayed as follows:

Algorithm 2 The simplified similarity metric

```

function GETSIMILARITY(query, case)
    targetContext  $\leftarrow$  getCaseContext(case)
    currentContext  $\leftarrow$  getQueryContext(query)
    for all contextFactors defined in targetContext do
        if the targetContext contains the current context factor in currentContext then
            sim  $\leftarrow$  sim + factorSimilarity( $\pi_f$ (targetContext),  $\pi_f$ (currentContext))
            weight  $\leftarrow$  weight + getWeight(case,  $\pi_f$ (targetContext))
        else
            sim  $\leftarrow$  sim + 1 * getWeight(case,  $\pi_f$ (targetContext))
            weight  $\leftarrow$  weight + getWeight(case,  $\pi_f$ (targetContext))
        end if
    end for
end function

```

After the similarities between the submitted query and the cases retrieved are calculated, the cases will be first ranked according to the calculated similarity, the most similar the first. Then the bounded greedy selection algorithm is used to select and rank the cases based on the diversity of items contained in those cases.

3.6. Explanation Generation

The learned factor importance weights contained in each case are used for generating explanations for the recommendation. Analyzing the learned importance weights one can generate explanations based on the values of these parameters. More specifically, given a case that includes an item i and a context situation c in which a set of context factors (c_1, \dots, c_k) as well as the corresponding factor weights (w_1, \dots, w_k) are specified, firstly, the set of context factors (c'_1, \dots, c'_j) that overlaps with the context factors specified in the user's query as well as the corresponding factor weights (w'_1, \dots, w'_j) are picked out. Then a fixed number of the context factors f, g, h with the highest importance weights w'_f, w'_g, w'_h are identified from those overlapped context factors (in this system, at most three context factors are identified). If the number of overlapped context factors is smaller than the fixed number, then the whole set of overlapped context factors will be used. After those identified context factors are ranked in

descending order based on their corresponding weights, they will be used to generate a positive explanation for recommending item i . For example, if item i (e.g., a dress) is recommended in the contextual situation "the shopping purpose is for party, the user is a budget buyer and the temperature is hot" and the overlapped contextual conditions are "the shopping purpose is for party" and "the user is a budget buyer", it is observed that the factor "budget" has a higher importance weight than "shopping purpose", then the generated explanation will be "This dress is recommended because other users bought similar clothes when they are budget buyers and the shopping purpose is for party."

3.7. Interaction and Interface Design

In this section the main features of Shopper, a mobile context-aware recommender system is illustrated. Shopper is an Android application built based on a personalized recommender system using conversion-based active learning strategy developed in paper [20]. Shopper integrates contextual information using case-based recommendation approach into this system so that users can obtain recommendations adapted to the recommendation context. The detail of the case-based recommendation approach has been discussed before. To get an initial set of recommendations, the user makes a recommendation request specifying the current contextual conditions and then a list of clothing items (including pictures and descriptions) will be returned. Those recommendations are obtained through searching for items bought by other users under similar items. Then the user can critique and update the recommendations iteratively to get the most satisfying one. In this section a typical interaction of the system will be illustrated.

In the initial step of the interaction with Shopper the user normally sets the current shopping context. Figure 3.2a shows the GUI for enabling and setting the values of the selected contextual factors. It was built using Android's Preference APIs so that the settings interface can be consistent with the user experience in other Android apps (including the system setting). Here we can see the user can switch on/off some of these factors, e.g., "Time of the day" or "Weather" using the checkbox. When these factors are switched on the recommender system will take into account their current values (conditions) through querying a third party service. For example, to get the current weather and temperature, the system will query the Yahoo weather API ² and parse the returned XML file for the target information. For some other context factors, e.g., "Budget" or "Intent", the user can switch them off by selecting the "Off" option in a pop up dialog. When those factors are switched on, the user need to provide the

²<https://developer.yahoo.com/weather/>

value manually by selecting among the options in a pop up dialog as in Figure 3.2b. After the user closes the dialog, the selected value will be shown as subtitle under the corresponding item line so that the user can easily get a clear view of what are enabled and selected. The full set of contextual factors is the same as in the web application described earlier. The contextual conditions: distance, day of the week, temperature, weather, time of the day, crowdedness and season are automatically obtained from third party services. The remaining contextual conditions, if the user enables them, must be entered manually by the user.

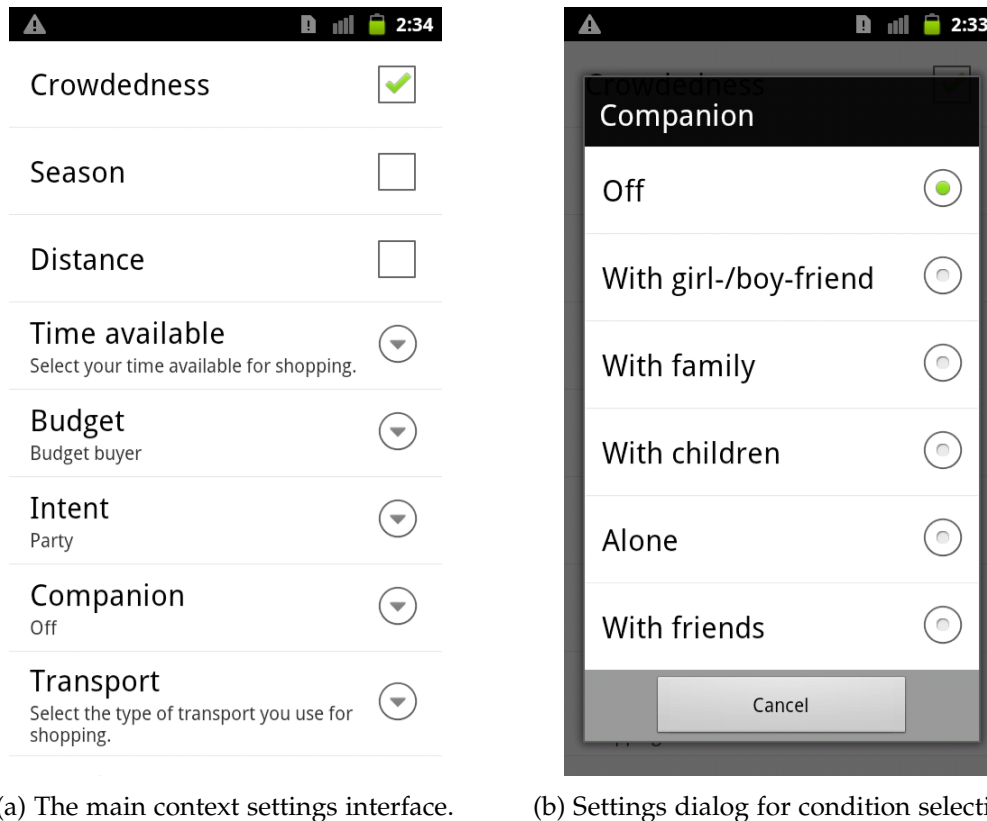
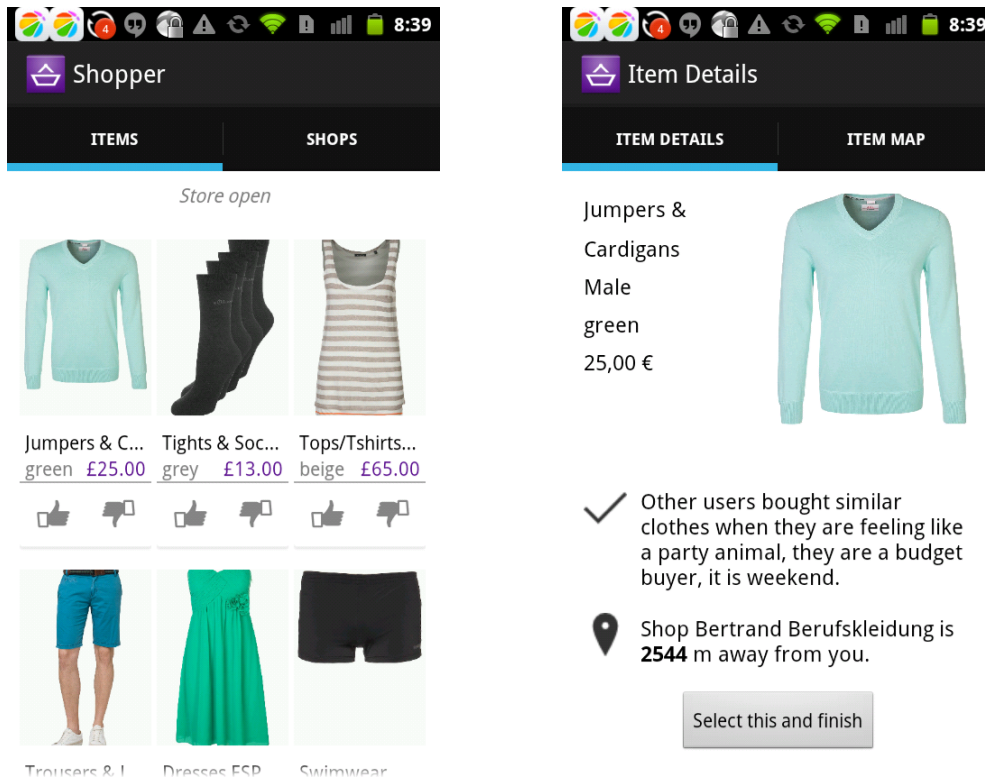


Figure 3.2.: The final design of the context settings interface.

After the user enables some contextual factors and provides the values for them, the system can be requested for recommendations. A short number of recommendations (nine in this thesis) will be presented to the user as depicted in Figure 3.3a. If the user is interested in any of the item, she/he can click on the picture and see the detail page of the item as depicted in Figure 3.3b. In the detail view, the user can see an explanation of the reason why this item is recommended to the user. It was believed

3. Build the System

that explanation can boost the transparency and user's trust in the system. A typical explanation can be "Other user bought similar clothes when they are feeling like a party animal, they are a budget buyer, it is weekend." Those are the contextual conditions that are most influential for the recommendation of the current clothes item (as was explained in previous section).



(a) The grid view of the recommendations in each cycle. (b) The detail view of each recommended item with contextual explanations.

Figure 3.3.: The final design of the recommendation interface.

The initial consideration was to put the explanations in the main view so that they can be more directly observed by the user. However, it can be seen that there are already critiques explanations in the main view. Considering the limited space of mobile devices, the user experience will be reduced if too much text is displayed together. Moreover, each item has a different reason for being recommended. For example, if a user requests for recommendation of clothing item for context situation "budget buyer, for work and for cold temperature". One case satisfying contextual condition "budget buyer" and another case satisfying contextual condition "for work

and for cold temperature" can all be recommended to the user. Thus it is better to put the explanations in the detail page of each item separately.

In the detail view, the user can also see an explanation of the location of the clothes as well as a map view of the location of the clothes relative to user's current location as depicted in Figure 3.4. For users who only want to find clothes nearby, it is an important factor for making the purchasing decision. If the user is not satisfied with the recommended clothes, she/he can critique on the item features to iteratively update the recommendations. This step corresponds to the review and iterate step in case-based recommendation as was discussed in Section 3.3. It relies on the main functions of the system built in paper [20].

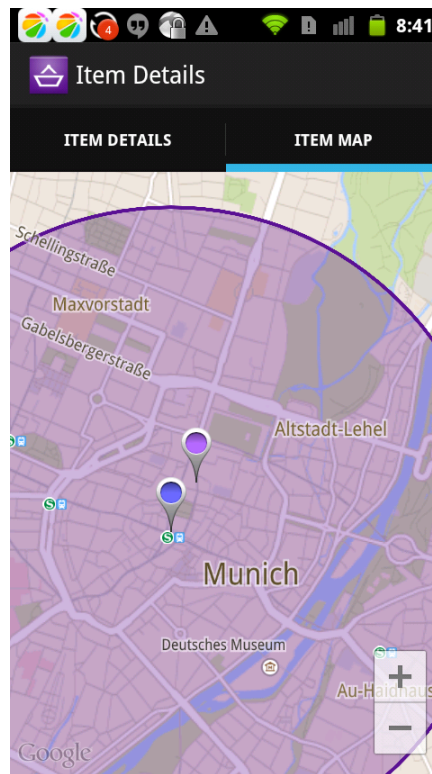


Figure 3.4.: The map view in the detail view of each recommended item.

If the user finds the ideal item, she/he can enter the detail view and click on the button "select and finish" (Figure 3.3b). Then the selected item together with the current contextual situation are recorded as a new case in the system case base.

4. Evaluation

After illustrating the system designed and developed, this chapter evaluates this system in real user study and shows and discusses the the results.

4.1. Motivation and Goals

Initially, recommender systems are usually evaluated based on their prediction accuracy - how accurately they can predict the items that the users are most interested in. However, it is now widely agreed that accuracy is an important but not unique measurement for the quality of recommender systems, because the user is not always looking for the best predictions of their tastes. Especially in cases where the user does not have specific preferences in mind and is still in the exploration stage, users may value more the diversity and novelty of the recommendation. Moreover, if the recommender system is built on a mobile system, the user is usually less patient when using the system. Decision effort that is needed in finishing a task is also an influential factor for the quality of the recommender system. Thus, besides the evaluation of prediction accuracy, user's decision effort and user's general satisfaction of the system should also be measured. Especially concerning the context-aware feature, whether the user is well aware of the benefits of context and the corresponding context-aware explanations should also be measured.

There are three different types of evaluation experiments: offline, user studies and online experiments [36]. Usually performing offline experiments is the easiest way because no user is involved. Through using existing data sets and a protocol that models user behavior, recommender system performances such as prediction accuracy can be easily measured at low cost. However, because the narrow set of properties it can measure, and the fact that it is difficult to create a reliable simulation of user interactions with the system [36], this approach is not appropriate for the system in this thesis. A more expensive option is the user study, where a small number of users are asked to perform a set of tasks using the system. A set of raw metrics are measured during the task for future statistical analysis and users usually need to answer a set of questions about their feelings of the system. This type of experiment provides a controllable experiment environment so that it can be adapted and used to measure different properties. It is suitable for recommendation approaches that rely on the

interaction of users with the system. Finally, for realistic recommender systems, online evaluation can be used where the performances of real users are evaluated when they are using the system and are not aware of the ongoing experiment. However this approach can not be adapted easily to specific evaluation requirements. Based on all the discussions above, the user study experiment was adopted for the evaluation of the system in this thesis.

Two variants of the system were tested. The baseline system is presented in Section 2.1.6. To test all candidates within subjects method was used, where each subject tests a set of candidates on different tasks [18] so that the two system variants can be more reasonably compared to each other. However, the same people testing both variants can introduce biases due to for example learning effect (e.g., the user may spend less time on the second tested variant because she/he become more familiar with the interface after using the first variant.). To avoid such bias, the order of variants to be tested by the user should be randomized and enough time should be left to let the user get familiar with the system before the task. Moreover, the case base (knowledge base) is kept fixed in the evaluation so that the recommendations are all based on the same foundation.

When drawing conclusions from the experiments, it was hoped that the conclusions can be applied to general cases rather only to the context of the experiments. To increase the probability of generalization of the results, firstly, the experiment participants should represent as closely as possible the true population of users of the real system. In this evaluation, people of various ages (from 21 to 56) and occupations (e.g., freelance, student, teacher and software engineer) are invited to participate in the user study so that the test results can be as much generalized as possible. It was aimed to look for around 30 participants so that the number of sample data can be big enough to be evaluated using a paired t-test. To not overwhelm and exhaust the candidates, the experiment will be controlled in 10 to 15 minutes.

4.2. Data Set

4.2.1. Data Set for Clothes Items

In this evaluation, data set retrieved in section 3.1 will be used as the sample data. The extracted data is from online store Zalando as was introduced before. Those clothes items may not be actually available offline here in Germany. However for the evaluation purpose, they will be randomly assigned to a list of offline stores available in Germany.

After the raw data was retrieved, it was preprocessed to get rid of irrelevant categories such as "Home" and "Child". The depth of the initial category tree was five and in this thesis only the category information up to depth two was kept and some of the

categories that are similar to each other but have different names were merged to avoid sparsity problem. For example, "Lingeire & Nightwear" in women's clothes category was merged with "Underwear" in men's category. So finally, 14 categories were defined: tops, dresses, underwear, cardigans, trousers, coats, blouses, jackets, skirts, jeans, socks, swimwear, suits and shirts. Then for each clothing item, irrelevant information was removed and the following information was kept:

- a numeric identifier (id),
- the clothes name,
- the price (in Euro, stored unit-less),
- one of 34 colors,
- one of 12 brands (including the sub brands such as "QS by s.Oliver"),
- the sex,
- one of 14 types of clothes,
- the link to an image of the item

The result set contains 3920 items in total with 2238 clothes items for female sex and 1682 clothes items for male sex. For each clothing type there are between ???

4.2.2. Data Set for Context Case Base

As was mentioned in previous section, the case-based context-aware recommender system developed in this thesis recommends based on a case base which can be built up through collaborative as well as expert-driven approach. For the evaluation in this thesis, expert-driven approach was used to first set up a starting case base. Since the users were asked to make purchasing decisions while imagining themselves being in a certain context scenario, the starting case base should be as various as possible for the corresponding scenarios. Take buying clothes for sports purpose for example, user's potential choice may vary from sports trousers, sports shirts to swimming suits and yoga pants. Apparently, it can be difficult to find enough people with choices vary enough for the case base in a short period of time, it was believed to be easier and more efficient to use expert-driven knowledge acquisition approach.

Clothes selection was done for each of the five predefined context scenarios that were used in the evaluation task, for which both common sense and the Zalando website were used as the main resources. For example, according to the common sense, thick clothes such as jacket, sweater, long trousers, coat will be selected for cold weather and

clothes such as dresses will be selected for party purpose. On the other hand, in the Find your style page¹ in Zalando website, different styles such as going out, romantic, casual, business are defined and they were also used as references for the selection of clothes for the case base. In total, ten cases were added for each context scenario with five cases for men and five cases for women.

4.3. Test Setup

In the baseline system, the system recommends without initial preferences from the user. To optimize the initial recommendation quality, a set of items are selected using a diversity-enhanced technique to ensure the coverage of the presented items. Compared to that, the system developed in this thesis tries to improve the the initial recommendation through integrating complex contextual information into the recommendation algorithm. So the baseline system is a simplified version of the developed variant. It does not consider contextual information during recommendation and does not contain the context setting UI in Figure 3.2a. However for both systems, the user can critique on items features and iteratively update the recommendations according to their personal interests.

The test hardware is a 3.7 inch 480 x 854 resolution Android smartphone (Motorola DEFY) running the Android operating system of version 2.3.7.

4.3.1. Testing Framework

In this evaluation, the testing framework follows the one presented in paper [4] and the recommendation quality was mainly qualitatively measured with a standard questionnaire. Quantitative information was also collected to better interpret the result [36, 11]. The measured data was divided into four areas: prediction accuracy, decision effort, explanation benefits and context benefits.

Prediction Accuracy

Prediction accuracy is by far the most discussed and the most important property for recommender system evaluation. It is based on a basic assumption that a system that provides more accurate predictions will be preferred by the user [36]. It measures the ability a system can help users find the items they like. In this thesis, this property was measured qualitatively by asking the user which system suggests more appropriate clothes. The appropriateness here reflects the accuracy of the recommendations.

¹<http://www.zalando.co.uk/styles/>

Decision Effort

People usually want a recommender system with high prediction accuracy and low decision effort. However, strategies yielding more accurate choices are often more effortful, but simple strategies can lead to lower levels of accuracy [12]. Especially in mobile exploratory scenario, a recommender system that is accurate but takes longer time or a lot of cognitive effort to reach the goal is also not useful. Thus in this evaluation, the decision effort was measured using both qualitative and quantitative methods.

Quantitative Measurements The decision effort can be quantitatively measured by the task time and the interaction effort. Task time is the time a user needs to find and select an ideal item after she/he is presented with the initial recommendations. Interaction effort here can be represented by the number of critiquing cycles. One critiquing cycle is counted when the user issues a critique on the item features, triggering the selection of new recommendations.

Qualitative Measurements The decision effort is also measured quantitatively by asking the user to rate the easiness of finding the information she/he needs using the system and asking the user the effectiveness of the system in helping her/him to complete the scenario. The scenario here means giving a context scenario, finding an ideal item to buy.

Context Benefits

In spite of the goal of improving the quality of the recommendation, the integration of contextual information into the system also provides a new way for the user to personalize their recommendations. To study whether or not the user is interfered by the extra step of context setting and whether or not the user is aware of the benefits of context-aware recommendation, the user was asked does she/he understand the benefits of using contextual conditions.

Explanation Benefits

From the user's perspective, explanation is an important experience because it helps the user understand how the recommender system work. Explanation is supposed to have many benefits including improving the transparency of the system, increasing the trust of the user to the system, persuading the user to try or buy the recommended item, etc. So in this evaluation, users were also studied to see whether they were aware of the explanation benefits through asking them whether they think the contextual explanations are useful. The clearness of the contextual explanations was measured

qualitatively by asking the user whether she/he is satisfied with the provided contextual explanations and whether the contextual explanations provided by the system are clear.

4.3.2. Testing Procedure

The actual testing procedure used in the evaluation was structured as follows:

1. Introduce the application to the user.

Because the users were of different knowledge backgrounds, not all of them were familiar with terms like "recommender system" or "context". Since most of them had online shopping experiences before, to let the user quickly learn the concept of recommender system and the core functions of this application, websites like Amazon were used as real life examples to help the user gain a quick feeling of what the application does.

After the user understood the basic idea of the application, she/he was explained how to use it. Nowadays, mobile applications usually show a quick graphic instruction to tell the user how to use the system when they are first launched. Here a manual instruction was given with the same purpose.

2. The user was asked to play around with the application.

Before starting the evaluation task, the user was asked to play around with both variants of the system and ask questions whenever they were confused. They were asked to finish a simple task (i.e., select an ideal item using the current system). Usually, more questions would come out when they were trying to finish this simple task. In this way, it could be made sure that during the formal study, the user could focus on the task itself but not figuring out how to use the system.

3. Explain the task setting to the user.

There were two variants of the system as was introduced before. When testing with both variants, the user was asked to select an item she/he was most satisfied with while imagining her/himself being in a context scenario that was randomly selected by the system from a set of five pre-created context scenarios. A typical context description could be:

"Imagine that you want to buy clothes for daily wear, you are a budget buyer and the temperature is cold. You don't care the exact location of the clothes."

For each context, usually four factors were included. To see the full list of those scenarios, please refer to Appendix B. The user was first explained to the concept of context and then shown to the descriptions of the context scenarios that would

be randomly selected during the user study. In this way, the user could get a full view of the study, feel more in control of the study and feel more confident in her/his actions.

The amount of advantages or disadvantages of context-aware recommender system compared to non context-aware recommender system might vary among different pre-created context scenarios. To avoid this bias, for each user study, the two system variants were tested using the same randomly chosen context scenario so that they could be compared under the same controlled situation.

One thing that needs to be pointed out is that because in the formal study, when users were using the context-aware variant developed in this thesis, they didn't need to configure the context settings by themselves and the system would be automatically configured to be in the chosen context scenario. Because for pre-defined context scenarios, the context conditions such as the weather or the temperature could be different from the current one, thus must be programmatically set and could not be automatically retrieved from third party services. In some cases, the user might forget the existence of the context setting step. To avoid this situation, users were especially asked to use the context setting function and see the reaction of the system (updating of the item list) according to the change of their context settings. With this extra step, it could be made sure that they understand how the context-aware system works. They were also explained carefully the reason why they didn't need to configure the context in real user studies.

4. Conduct the task.

Once the user understood the task mentioned above, a variant of the application was set up and handed back to the user. After the user selected one item, she/he was given to another variant and asked to do the task again. To reduce the effect of learning curve, the order of the first variants to give was randomly selected. The user was also encouraged to give oral feedbacks during the task.

At first the testing procedure was designed to ask the user to test each variant of the system twice, each time with a different context scenario, so that the user could be aware of the different reactions of these two variants when context changed. However, considering that this procedure design was too time consuming, with the goal of not overwhelming the user, this design was given up and the current procedure design was adopted.

5. Finish the survey.

After the user tested on both variants, she/he was asked to fill out a survey.

The survey was created online using google form so that the user could fill it out privately. In this way, the influence of the interviewer could be reduced the most. These questions were extracted and adapted to our evaluation from the IBM Computer System Usability Questionnaire [37] and included the following statements:

- Q1: It was easy to find the information I needed.
- Q2: The system is effective in helping me to complete the scenario.
- Q3: I like using this system.
- Q4: I understood the benefit of using the contextual conditions.
- Q5: I am satisfied with the provided contextual explanations.
- Q6: I believe that the contextual explanations are useful.
- Q7: The contextual explanations provided by this system are clear.
- Q8: Which system do you prefer?
- Q9: Which system suggest more appropriate clothes?

Statements 4-7 were provided only for the context-aware version. Statements 4-7 were asked for both variants. At the end of the survey, the user was asked which system she/he preferred (Q8) and which system suggested more appropriate points of interest (Q9). The user could express a level of agreement to the statement ranging from 1 (strongly disagree) to 5 (strongly agree).

4.4. Results

This section analyzes the data collected in the user study for each property measurement.

4.4.1. Participants

For the study, participants of various age, religion, nationality, knowledge background and current profession were looked for. Overall a number of 23 people participated the user study, among which 17 people were students as well as employees in academia in fields including Computer Science, Electronic Engineering, Finance, Economics, and other 6 people were employees and freelancers from outside of the university. The average age was 27, with a maximum of 56 and a minimum of 21.

4.4.2. Overview

The measurements for decision effort and system preference for both two systems (CW denoting the variant using context-aware recommendation, NCW the one recommending without contextual information) are shown in Table 4.1. Next to the mean is the standard deviation and the last column denoting the p-value of a one-tail paired t-test with 22 degrees of freedom (23 participants - 1).

In the following sections, a detailed discussion of the measurements of the four properties (prediction accuracy, decision effort, explanation benefits and context benefits), the general system preference as well as the informal feedback will be given.

Table 4.1.: Overview of the result.

| | | CW | | NCW | | p value |
|-------------------|---|--------|-------|--------|-------|---------|
| | | mean | stdev | mean | stdev | |
| Decision Effort | It was easy to find the information I needed. | 3.74 | 0.92 | 3.61 | 1.16 | 0.3 |
| Decision Effort | The system is effective in helping me to complete the scenario. | 4.09 | 0.79 | 3.74 | 0.92 | 0.029 |
| Decision Effort | Critiquing cycle | 2.83 | 2.46 | 3.43 | 2.35 | 0.171 |
| Decision Effort | Completion time | 122.91 | 77.67 | 117.52 | 73 | 0.405 |
| System Preference | I like using this system | 4.04 | 0.77 | 3.39 | 0.94 | 0.004 |

4.4.3. Prediction Accuracy

After the users tried both systems, they were asked which system provided more appropriate clothes (Q9). The majority (87%, 20 people) selected the context-aware variant (CW). Among the three people who selected non context-aware variant, two of them still preferred the context-aware variant when they were asked to select the preferred system.

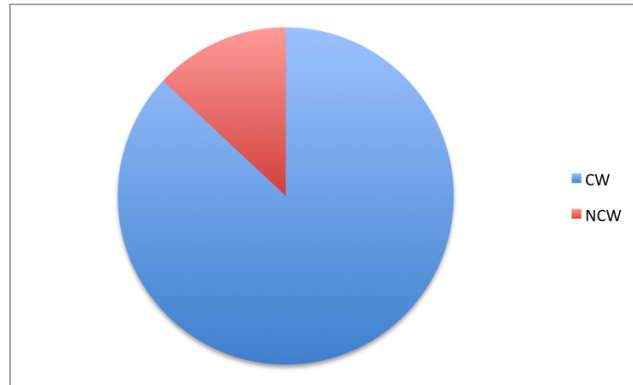


Figure 4.1.: Prediction accuracy in terms of which variant provided more appropriate clothes.

4.4.4. Decision Efficiency

The quantitative measurements for decision effort were broken down into the number of critiquing cycles and the time it took to complete a recommendation session.

Critiquing Cycles

Figure 4.2 shows the box plot of critiquing cycles for CW and NCW. It can be observed that the box of CW is obviously lower than the box of NCW, which suggests a difference between CW and NCW in critiquing cycles with cycles of CW being generally smaller than the ones of NCW. The mean of critiquing cycles for CW (2.83 cycles) is also smaller than the one for NCW (3.43 cycles) in Table 4.1 but the difference is not significant ($p=0.171$). It can also be found that the box of NCW is comparatively shorter than the box of CW which suggests that some of the critiquing cycles of CW varies more than the ones of NCW. This can also be reflected from the standard deviations of critiquing cycles of these two variants in Table 4.1 (2.46 for CW compared to 2.35 for NCW).

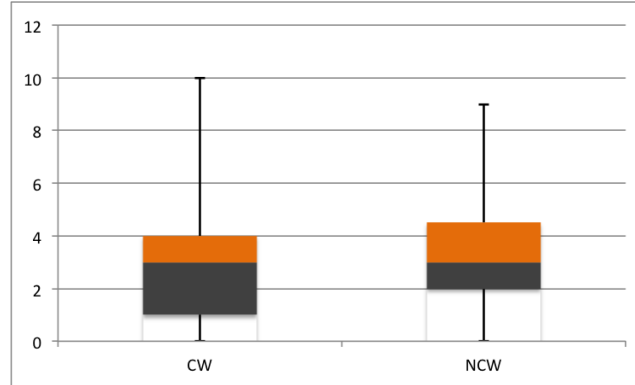


Figure 4.2.: Decision efficiency in terms of critiquing cycles.

Critiquing Time

Figure 4.3 shows the box plot of critiquing time for CW and NCW. It can be observed that the medium of CW (109 seconds) is larger than the one of NCW (81 seconds), but the the box length of CW is comparatively shorter than the one of NCW, which suggests that the majority of the critiquing time of CW is more stable and is neither too long nor too short. For both two variants, the maximum (302 seconds for CW and 297 seconds for NCW) and minimum (26 seconds for CW and 18 seconds for NCW) critiquing time are almost the same. From Table 4.1, it can be seen that from a general view, the critiquing time of CW varies more than that of NCW. NCW slightly beats CW in critiquing time when looking at the average time in Table 4.1, however, NCW is not significantly better.

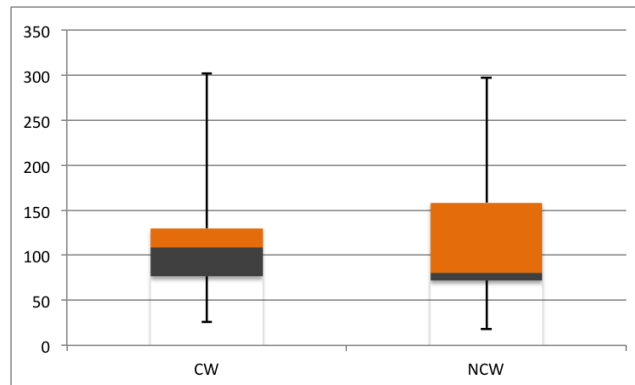


Figure 4.3.: Decision efficiency in terms of critiquing time.

The qualitative measurements of decision efficiency were broken down into the rate for the ease of use of the system and the rate for the effectiveness of the system from the users.

Ease of Use

To measure the ease of use of the system, the user was asked was it easy to find the information she/he needed (Q1). Whether or not useful information can be easily found depends on both the design of the recommendation approach and the design of the interface. When looking at the mean of the rate of this question in Table 4.1, CW slightly beats NCW (3.74 against 3.61). However the difference is not significant enough ($p=0.3$). The standard deviation of CW (0.92) is smaller than the one of NCW (1.16), which suggests that users have a higher level of agreement on the mean rate of CW.

When looking at Figure 4.4. It can be seen that more users gave score five for NCW than for CW (seven people for NCW and six people for CW). However, four people also gave negative rates for NCW (value 2), which did not appear to CW. Quite a number of people (9 people) hold a neutral view towards NCW compared to CW (6 people).

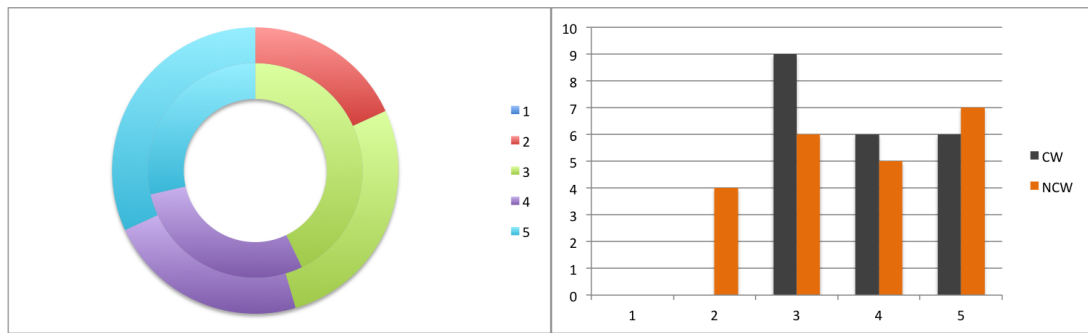


Figure 4.4.: Decision efficiency in terms of distribution of ratings for ease of use on a 5 point Likert scale (1, worst to 5, best). a) CW inner, NCW outer b) CW left, NCW right

Effectiveness

To measure the effectiveness of the system, the user was asked the question was the system effective in helping her/him to complete the scenario (Q2). In the evaluation, the user was given a context scenario and was asked to imagine her/himself being in the context scenario while using the system. With this context-aware scenario, CW was rated significantly better than NCW ($p=0.029 < 0.1$). Some users mentioned that they found the context settings quite useful during the test. The average rate of CW (4.09) is

also higher than that of NCW (3.74). On the other hand, the standard deviation of CW (0.79) is smaller than that of NCW which suggests that users had a higher degree of agreement towards the rating of CW than NCW.

If we look at Figure 4.5, CW collected twice the number of positive (value 4 on the Likert scale) ratings and three quarters of the number of neutral ratings (value 3) compared to NCW. Also NCW received a negative ratings (value 2), while CW obtained a shared positive view.

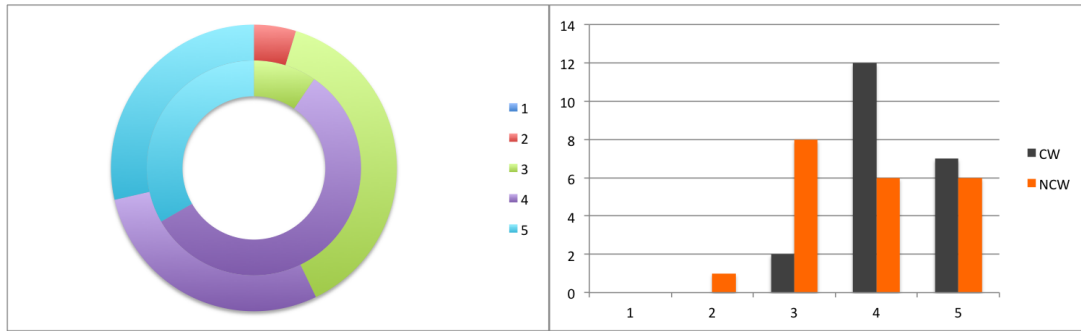


Figure 4.5.: Decision efficiency in terms of distribution of ratings for effectiveness on a 5 point Likert scale (1, worst to 5, best). a) CW inner, NCW outer b) CW left, NCW right

4.4.5. Context Benefits

To investigate whether users intuitively understood the benefits of using contextual information for recommendation but not seeing it as an obstruction, users were asked whether they understood the benefits of using the contextual conditions (Q4). In Figure 4.6, it can be seen that a majority of users (91%, 21 people) gave positive ratings to this question and no negative ratings (value 1-2) were given.

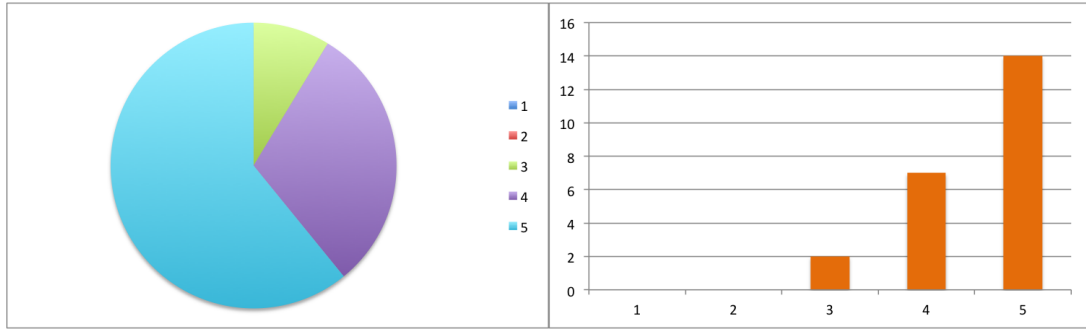


Figure 4.6.: Distribution of ratings for understanding of using contextual information on a 5 point Likert scale (1, worst to 5, best).

4.4.6. Explanation Benefits

Explanations for critiquing exist in both variants of the system. For the context-aware recommender system built in this thesis, another explanation was added in the detail page for each item to explain why an item was recommended using the contextual information. In this evaluation, it was investigated in particular the satisfaction, usefulness and clearness of this newly added explanation for the context-aware variant.

Satisfaction

To test the general satisfaction of the contextual explanation, users were asked to rate how much were they satisfied with the provided contextual explanations (Q5). The average rating of satisfaction is 4.1. In Figure 4.7, it can be seen that a majority of people (83%, 19 people) gave positive ratings (value 4-5) and no negative ratings (value 1-2) were given. However, among the positive ratings, more users (13 people) gave a more conservative rating (value 4) rather than the most positive rating (value 5).

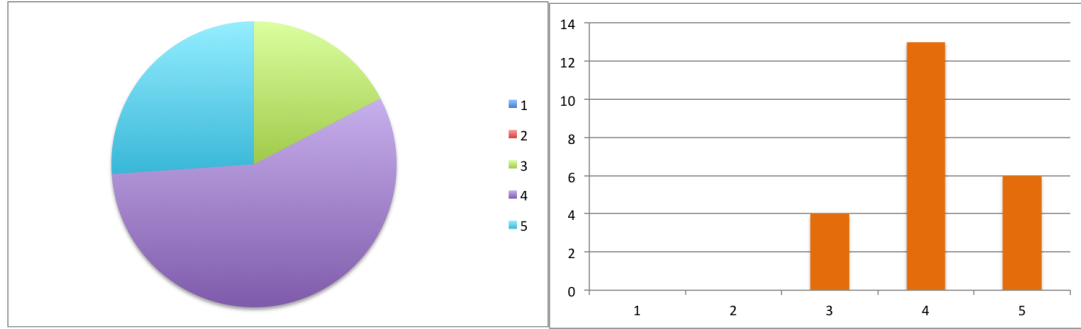


Figure 4.7.: Explanation benefits in terms of distribution of ratings for satisfaction on a 5 point Likert scale (1, worst to 5, best).

Usefulness

To test the usefulness of the provided contextual explanations, users were asked to rate how much did they believe that the contextual explanations were useful (Q6). The average rating of usefulness is 4.3, which is larger than the average rating of satisfaction. In Figure 4.8, it can be seen that a majority of people (83%, 19 people) gave positive ratings (value 4-5) and no negative ratings (value 1-2) were given. Among the positive ratings, more people gave the most positive rating (value 5).

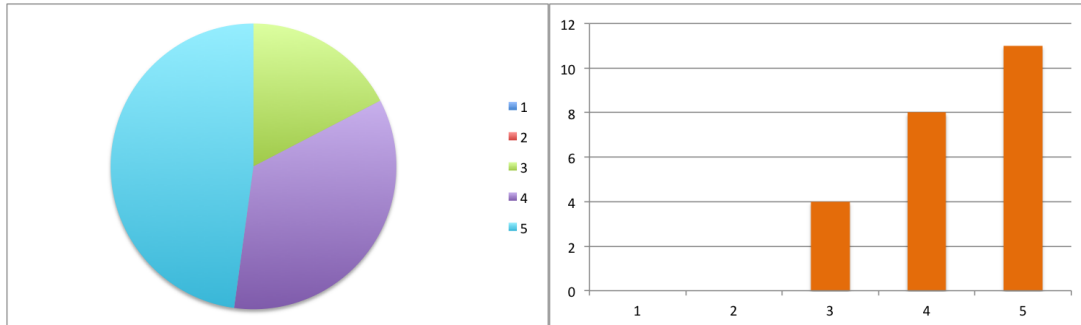


Figure 4.8.: Explanation benefits in terms of distribution of ratings for usefulness on a 5 point Likert scale (1, worst to 5, best).

Clearness

To measure the clearness of the contextual explanation, users were asked to rate how clear were the contextual explanations provided by the system (Q7). The average rating of the clearness is 4.4. In Figure 4.9, it can be seen that a majority of people (78%) gave

positive ratings (value 5). Among the positive ratings, 77% of the people gave the most positive ratings. Also no negative ratings (value 1-2) were given.

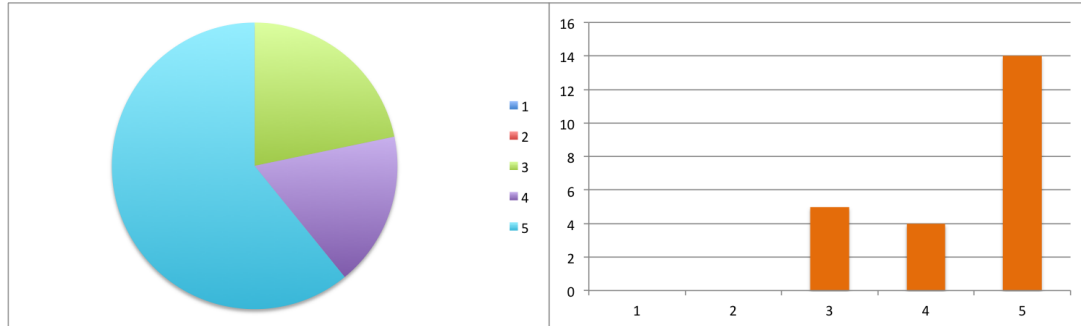


Figure 4.9.: Explanation benefits in terms of distribution of ratings for clearness on a 5 point Likert scale (1, worst to 5, best).

4.4.7. System Preference

General Preference

To investigate the system preferences, users were asked to choose which system they preferred more (Q8). In Figure 4.10, it can be seen that 91% people (21 people) preferred CW to NCW. Among the two people who selected NCW, one of them still preferred CW when they were asked to choose which system provided more appropriate clothes.

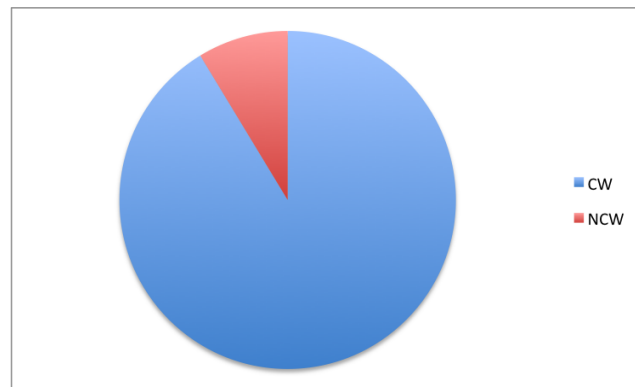


Figure 4.10.: System preference in terms of distribution of general preference.

Satisfaction

Users were also asked to give a specific rating of how much did they like using these two systems to provide a more detailed view (Q3). In Table 4.1, it can be seen that the mean rate of CW is higher than the one of NCW by about 0.65 and the difference is significant (with $p = 0.004 > 0.1$). Also the standard deviation of CW is smaller than NCW, which suggests that the users agreed more to the ratings of CW variant.

In Figure 4.11, it can be seen that users shared a positive view towards CW and no negative ratings were given to CW, while two negative ratings were given to NCW. When looking at the distribution of the positive ratings, CW collected twice the number of very positive ratings (value 5) and twice the number of positive ratings (value 4) compared to NCW variant.

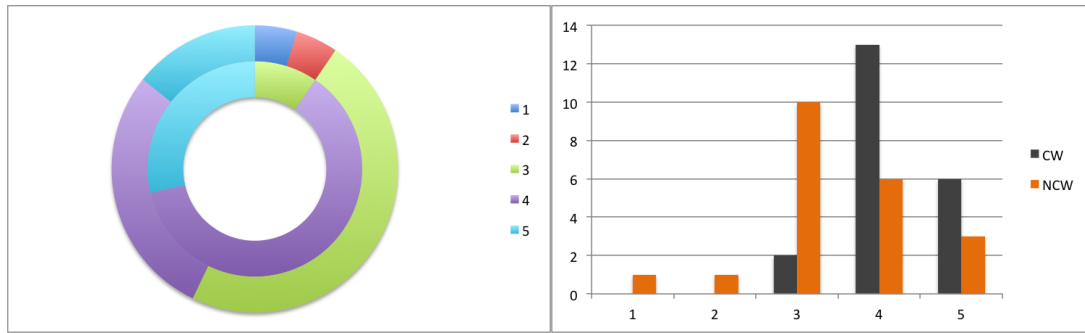


Figure 4.11.: System preference in terms of distribution of ratings for system satisfaction on a 5 point Likert scale (1, worst to 5, best). a) CW inner, NCW outer b) CW left, NCW right

4.4.8. Informal Feedback

During the test, users were encourage to give informal feedback, because it is user's most direct feelings of the system and can be used as guidance for further improvements of the system. Here summarizes the most relevant and most interest views here.

Allow manual input of the values for all available context factors. Two participants mentioned that they might not always want to buy clothes under the current context. It was also possible that they wanted to buy for future context. Thus the system should not automatically retrieve values for context factors such as weather, temperature, but let the user enter the value by her/himself. The system can also be designed to allow the user to choose whether to let the system automatically detect the context value or let the user enter the value by her/himself.

Improve the explanation through using icons and color. From previous analysis, it

can be seen that users value the usefulness of contextual explanations. There was a user who mentioned that instead of using only text, icons and different colors could also be used for displaying explanations because images and colors were quicker than words and they could especially help to improve the user experience in mobile scenario.

Put location information in more conspicuous place. One user suggested that location, as a special context information, should be placed at a more conspicuous place (e.g., in the grid view where the user sees the list of all recommendations), because he thought that users were usually sensitive to location information.

Add a refresh button. The system was built to display nice items for each cycle of recommendation. A few participants pointed out that a refresh button could be added. Instead of critiquing, they might want the system to show more items recommended based on the contextual information. It can be seen from here that the users valued the benefits of context and would like to rely more on it for recommendations.

4.4.9. Correlation Analysis

To understand the relationship between different measurements instead of only interpreting single ones, a correlation analysis was performed on the measured data using the Pearson correlation coefficient. The correlation coefficient, denoted as r , measures the linear relationship between two variables and varies numerically between -1.00 and 1.00. The closer the value of r to 0, the weaker the relationship between the two variables is, with value 0 indicating an absence of relationship. The closer the value of r to 1 or -1, the stronger the relationship between the two variables is, with 1 indicating a perfect positive linear relationship and -1 indicating a perfect negative linear relationship. The values for all calculated r can be seen in Table 4.2.

It can be seen that larger critiquing cycles is correlated with longer completion time ($r=0.78$). However, critiquing cycles and completion time are not correlated with the ease of use ($r=0.04$ for critiquing cycle, $r=-0.11$ for critiquing time), effectiveness ($r=-0.08$ for critiquing cycle, $r=0.02$ for critiquing time) and system satisfaction ($r=-0.08$ for critiquing cycle, $r=-0.06$ for critiquing time). Higher rating for system effectiveness is correlated with higher satisfaction of the system ($r=0.5$).

When looking at the context benefits, it can be seen that the perceived benefits of using contextual conditions is not related to the general satisfaction of the current system ($r=0.04$). It is also not related to the clearness and the general satisfaction of the current system's explanation ($r=0.08$ for explanation satisfaction, $r=0.18$ for explanation clearness). So it can be suggested that user's preference of using contextual conditions is stable.

Table 4.2.: The correlation analysis.

| | EoU | E | SS | CB | ES | EU | EQ | CC | CT |
|--------------------------|-----|------|------|------|------|------|------|-------|-------|
| Ease of Use | 1 | 0.56 | 0.25 | 0.08 | 0.11 | 0.05 | 0.08 | 0.04 | -0.11 |
| Effectiveness | | 1 | 0.5 | 0.08 | -0.1 | 0.03 | 0.36 | -0.08 | 0.02 |
| System Satisfaction | | | 1 | 0.04 | 0.08 | 0.05 | 0.18 | -0.08 | -0.06 |
| Context Benefits | | | | 1 | 0.3 | 0.48 | 0.27 | -0.08 | -0.27 |
| Explanation Satisfaction | | | | | 1 | 0.48 | 0.42 | 0.01 | -0.03 |
| Explanation Usefulness | | | | | | 1 | 0.59 | 0.1 | 0 |
| Explanation Clearness | | | | | | | 1 | 0.06 | 0.19 |
| Critiquing Cycle | | | | | | | | 1 | 0.78 |
| Completion Time | | | | | | | | | 1 |

4.5. Discussion

Regarding prediction accuracy, the majority of people thought that context-aware variant CW showed more appropriate clothes than non context-aware variant. According to some informal feedbacks, clothes presented in CW looked better than those presented in NCW for the users. It might be because CW was recommending based on user's contextual information as initial preferences and could filter out clothes that were not satisfying. Also the clothes in the case base of CW were carefully selected manually according to expert knowledge, clothes with good design and cheaper cost could be discovered using collaborative effort which helped with raising the recommendation accuracy.

Regarding ease of use, CW slightly beats NCW by 0.13, but the difference is not significant ($p=0.3$). However, users shared a positive view towards CW but gave 4 negative ratings (value 2) to NCW. It might be because users were given a way to express their contextual requirements and thus found the CW variant to be more multifunctional and powerful. But it should also be noted that a too complicated user interface or unclear recommendation logic will also make the users be confused and rate the system low.

Regarding system effectiveness, CW significantly beats NCW by 0.35 ($p=0.029$). Since the users were asked to imagine a contextual scenario, users were more aware of the contextual requirement and thus valued the context-aware recommendation more. There was one time, when the user was shown the context setting interface, the user commented that it was the exact thing he was looking for. On the other hand, more users gave positive ratings (value 4) than most positive ratings (value 5). It might be caused by their dissatisfaction of the missing of some other recommendation approaches that can always be seen in the online recommendation systems like Amazon. Some users commented that the system should allow the user to select the clothes category and gender first. Some other users would like to have a refresh button so that they can update the recommendations using the current context settings without critiquing.

Regarding context benefits, it is interesting to notice that the users all shared a positive view towards using context for recommendation and users gave twice the number of most positive ratings (value 5) compared to positive ratings (value 4). Thus it can be suggested that users are not against to using contextual information. In the correlation analysis, it is shown that user's preference of using contextual information was not related to the clearness and satisfaction of the current system's explanation. Thus it was not the special design of the system that highlighted the importance of context and it can be suggested that users are expecting recommender systems that can recommend based on their current context.

Regarding the contextual explanations, it is shown that users shared a positive view towards the provided contextual explanations. The usefulness of the contextual explanation was scored high (average = 4.30), but the satisfaction of the explanation was scored a little bit lower (average = 4.09). It can be suggested that the importance of contextual explanations is valued high and users are quite sensitive to the quality of the explanations. The quality of the explanation can not be measured only by clearness, which can be indicated from the high score obtained by clearness (average = 4.39).

Finally, regarding system preference, more participants preferred using CW over NCW and significantly more participants were generally more satisfied with CW than NCW. Also a close relation was detected between system satisfaction and system effectiveness. It might be because for mobile application, users are more sensitive to the effectiveness of the system and the system effectiveness thus influences the general satisfaction of the system more than usual. Overall, the developed context-aware recommender system was proved to have successfully integrated contextual information into the conversation-based Active Learning system using case-based recommendation approach.

5. Conclusions and Future Work

In this thesis, a context-aware recommender system that integrates contextual information into existing Active Learning recommender system using case-based recommendation approach was developed and evaluated.

Following the methodology developed for developing context-aware recommender systems [4], relevance of contextual factors was first acquired using a web tool developed to ask users to rate the influence of different context factors on their purchasing decisions by imagining themselves being in a selected contextual condition. After the relevance was obtained, a case-based recommendation approach was proposed to integrate contextual information into the recommender system by recommending clothes items bought by other users under similar contextual conditions to the current user. A case base was set up as the knowledge base for the recommendation using expert-driven approach. To solve the static suggestion ability problem of knowledge recommender system, collaborative filtering approach was used for long-term knowledge engineering. However, no privacy issue needs to be worried about because the correlation between users is performed at the session level and no user identification is required. To compute the similarity between retrieved case and user's submitted query, the Euclidean Overlap Metric (HEOM) was borrowed. Using the learned context factor relevance before, contextual explanation for each recommended item can be easily generated through finding out the most influential factors for the current type of the recommended clothes.

An Android mobile application Shopper using the developed recommender system was developed and evaluated and was shown to have a better evaluation regarding prediction accuracy, decision effort and general satisfaction compared to the baseline system that is not context-aware. Also users were shown to be well aware of the benefits of contextual information and expressed a strong demand for context-aware recommendation in the evaluation.

TODO ... More about evaluation ...

Several things can be done for future improvement. From the application design perspective, users can be allowed to control and specify values for as many context factors as possible. In the system developed in this thesis, values of part of the context factors such as weather or temperature are automatically detected if the users enabled them in the context setting interface. However, during the evaluation, some users were

complaining that the system was too intelligent by detecting the contextual information automatically and thus requirements for buying for future contextual scenarios can not be fulfilled.

For the proposed recommendation approach, clothes items are recommended as individual items to the user. In the future, recommendation of clothes set can be realized through extending the current case structure by including more than one clothes item in each case. For example, a user who bought a coat in cold temperature may also buy a scarf that can match with the coat. Then this scarf can be included in the same case with the coat and be recommended as a set to another user.

The recommendation quality can also be improved through extending the case model by including an evaluation model. Right now, a case is stored in the case base if the user buys an item and the bought item is automatically evaluated as an ideal item for the corresponding context. In the future, more approaches can be adopted for the evaluation of the idealness of an item. The item viewed by the user, the item positively critiqued by the user, the stores most often visited by the user can also be used as hints for the evaluation.

Regarding the commercialization of the application, real data set instead of the simulating one should be obtained from real offline stores, including the realtime stock information for each clothes item, the crowdedness of the store, etc. However, this can be difficult because retailers are usually quite sensitive to the exposition of such data. This then becomes a business model problem. Furthermore, currently for evaluation purpose, the recommendation calculation is done on the mobile device and the database is also stored locally. In the future, they should all be migrated to a remote server to reduce the burden of the client app and increase the system efficiency.

A. User Preferences for Categories of Clothest

Table A.1.: Table of the measured relevance of all contextual factors for each clothes category

| Tops | | Dresses | | Underwear | | Cardigans | |
|----------------------|------|----------------------|------|----------------------|------|----------------------|------|
| day of the week | 0.85 | time of the day | 1 | time available | 0.92 | day of the week | 1 |
| temperature | 0.84 | day of the week | 1 | day of the week | 0.9 | weather | 0.92 |
| time available | 0.84 | weather | 1 | time of the day | 0.9 | temperature | 0.92 |
| transport | 0.81 | time available | 1 | crowdedness | 0.88 | time available | 0.87 |
| weather | 0.8 | budget | 0.93 | season | 0.83 | mood | 0.87 |
| time of the day | 0.8 | companion | 0.91 | budget | 0.81 | crowdedness | 0.82 |
| crowdedness | 0.78 | temperature | 0.91 | transport | 0.81 | companion | 0.82 |
| intent of purchasing | 0.78 | season | 0.88 | temperature | 0.81 | intent of purchasing | 0.82 |
| companion | 0.76 | transport | 0.78 | weather | 0.79 | budget | 0.81 |
| season | 0.76 | intent of purchasing | 0.76 | companion | 0.78 | time of the day | 0.79 |
| budget | 0.76 | crowdedness | 0.74 | mood | 0.75 | season | 0.73 |
| mood | 0.71 | mood | 0.74 | intent of purchasing | 0.69 | transport | 0.73 |
| Trousers | | Coats | | Blouses | | Jackets | |
| intent of purchasing | 1 | temperature | 1 | time of the day | 1 | budget | 0.92 |
| weather | 1 | time available | 0.91 | day of the week | 1 | companion | 0.9 |
| day of the week | 0.89 | transport | 0.89 | transport | 1 | day of the week | 0.89 |
| time available | 0.87 | budget | 0.87 | time available | 0.9 | transport | 0.89 |
| transport | 0.84 | day of the week | 0.86 | intent of purchasing | 0.89 | temperature | 0.88 |
| mood | 0.83 | mood | 0.85 | mood | 0.89 | time available | 0.87 |
| companion | 0.82 | crowdedness | 0.82 | weather | 0.85 | intent of purchasing | 0.81 |
| budget | 0.81 | season | 0.81 | temperature | 0.82 | crowdedness | 0.8 |
| temperature | 0.8 | intent of purchasing | 0.8 | budget | 0.82 | time of the day | 0.79 |
| crowdedness | 0.8 | time of the day | 0.76 | crowdedness | 0.8 | season | 0.77 |
| season | 0.74 | weather | 0.75 | companion | 0.75 | mood | 0.77 |
| time of the day | 0.74 | companion | 0.68 | season | 0.74 | weather | 0.74 |

Continued on next page

A. User Preferences for Categories of Clothest

Table A.1 – Continued from previous page

| Skirts | | Jeans | | Socks | | Swimwear | |
|----------------------|------|----------------------|------|----------------------|------|----------------------|------|
| time available | 1 | time available | 1 | mood | 1 | budget | 1 |
| budget | 1 | companion | 0.91 | season | 1 | temperature | 0.92 |
| day of the week | 1 | temperature | 0.9 | crowdedness | 0.92 | day of the week | 0.9 |
| crowdedness | 1 | day of the week | 0.87 | time available | 0.89 | time available | 0.88 |
| companion | 1 | time of the day | 0.86 | intent of purchasing | 0.88 | crowdedness | 0.84 |
| intent of purchasing | 0.88 | crowdedness | 0.83 | day of the week | 0.86 | weather | 0.82 |
| temperature | 0.88 | transport | 0.82 | budget | 0.84 | intent of purchasing | 0.8 |
| weather | 0.87 | budget | 0.81 | temperature | 0.8 | mood | 0.8 |
| mood | 0.86 | season | 0.81 | companion | 0.79 | season | 0.8 |
| season | 0.85 | mood | 0.77 | time of the day | 0.77 | transport | 0.79 |
| time of the day | 0.77 | weather | 0.74 | weather | 0.73 | companion | 0.76 |
| transport | 0.74 | intent of purchasing | 0.72 | transport | 0.68 | time of the day | 0.75 |
| Suits | | Shirts | | | | | |
| budget | 1 | budget | 1 | | | | |
| intent of purchasing | 1 | time of the day | 1 | | | | |
| companion | 1 | day of the week | 1 | | | | |
| season | 1 | intent of purchasing | 1 | | | | |
| time of the day | 1 | weather | 1 | | | | |
| time available | 1 | season | 1 | | | | |
| weather | 0.92 | temperature | 1 | | | | |
| temperature | 0.89 | time available | 1 | | | | |
| crowdedness | 0.84 | companion | 0.9 | | | | |
| mood | 0.83 | crowdedness | 0.87 | | | | |
| day of the week | 0.82 | mood | 0.85 | | | | |
| transport | 0.72 | transport | 0.85 | | | | |

B. Context Scenarios

- Imagine that you want to buy clothes for daily wear, you are a budget buyer and the temperature is cold. You don't care the exact location of the clothes."
- Imagine that you want to buy clothes for daily wear, you are a budget buyer and the temperature is hot. You want to find only clothes that are near you (within 2km).
- Imagine that you are feeling like a party animal, it is weekend and you are a budget buyer. You don't care the exact location of the clothes.
- Imagine that you want to buy clothes for working purpose, you are a high spender and the temperature is warm. You only want to find clothes that are near you (within 2km).
- Imagine that you want to buy clothes for sports purpose, you are feeling outdoorsy and the temperature is hot. You only want to find clothes that are near you (within 2km).

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