Dynamische Clusteranalyse für DM-Verkaufsdaten

Diplomarbeit von Selma Mukhtar
Thesis of Selma Mukhtar
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Declaration

Hiermit erkläre ich, dass ich die vorliegende Diplomarbeit selbstständig verfasst und die vorgestellten Ergebnisse ohne die Hilfe Dritter erarbeitet habe. Ich habe auf keine anderen als die angegebenen Quellen und Hilfsmittel zurückgegriffen.

Selma Mukhtar
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Chapter 1

Introduction

1.1 Motivation

In the last decade large interbranch loyalty programs became a major trend among German companies and their customers. Being the biggest German loyalty program, PAYBACK started out in 2000 and by 2008 about 60% of all German private households owned a PAYBACK-card (Gmb08). Other German loyalty programs, like HappyDigits launched in 2001 or DeutschlandCard launched in 2008, show similar track records. Loyalty programs do not only try to commit customers to their companies by rewarding loyal buying patterns but they also collect a huge amount of data about their customers. When issuing the program’s card the customer is normally required to provide some personal and demographic data. Furthermore, every time the customer presents his loyalty card at a participating company’s cash register to receive some bonus, data about his purchase is stored. So receipts can be assigned to single customers and their buying behaviors can be tracked, which opens up new possibilities for highly effective and selective marketing concepts and for very close customer relationships.

This costly collection of customer data needs to be analyzed systematically to be of any value for the companies. The more information a company can gain about its customers and their purchasing behaviors the better it can respond to their needs and the closer to the market it actually is. A possible data analysis obviously suggests itself: The extraction of customer profiles. One can try many ways to accomplish this, but we chose graph clustering.

Our Contribution

The content of this work is a case study. We want to find out if graph clustering is a data mining technique that is suitable to extract meaningful customer profiles in PAYBACK-card data provided by the German retail chain dm-drogerie markt, in the following abbreviated as dm. In our approach, we model the data as a network of customers and
apply graph clustering methods to find groups of customers with similar buying behaviors. We begin by designing, implementing and analyzing different potential graph models that reflect similarity in shopping behavior. Having found the most appropriate graph model that yields reasonable clusterings, we try to identify stable customer profiles. Such profiles consist of customer clusters that verifiably occur in several graph clusterings of different points in time. We apply several techniques to identify and confirm the stability of those customer profiles, e.g., we require their clusters to have a similar customer base and similar buying patterns. Finally, we corroborate our results by trying to detect these stable customer profiles in the PAYBACK-card data of three totally different stores and by comparing those customer profiles on store-level. By verifiably identifying the same stable customer profiles in three different stores and by considering the period of an entire year, we can present very substantiated dm-customer profiles and a reliable and precise technique.

Previous and Related Work

Data mining is a huge and established field with many applications and techniques. But in this work we concentrate on graph clustering and so we refrain from discussing standard data mining techniques and refer the reader to (HK06) and (Fer03) and to references therein for an introduction to general data mining concepts and an overview of state-of-the-art methods.

Graph clustering techniques, similar to ours, were used for other purposes. Hopcroft et al. (HKKS04) try to extract natural communities in the citation graph of the NEC CiteSeer\textsuperscript{1} scientific literature database. In the citation graph, vertices represent papers in the CiteSeer database and a directed edge from paper A to paper B represents the citation of paper B in paper A. A natural community is defined as follows: Several graph clusterings of a NEC CiteSeer database snapshot are generated by randomly removing a small set of papers before each clustering run. Then the single clusters of each clustering are compared to the single clusters of the first generated clustering with the matching papers they contain. A cluster of the first generated clustering is called a natural community if this cluster has a sufficiently high (paper set)-\textit{match} value (see Section 3.3.2) to a sufficient amount of other clusters in other clusterings. Natural communities are supposed to represent ‘the true hidden structure of the data’. Because if such a cluster appears verifiably in a certain amount of these generated clusterings, it can not be a coincidence.

In (Gla08) a \textit{time-expanded} graph model is designed. Based on this model, graphs of the e-mail network of the computing faculty of the \textit{Universität Karlsruhe (TH)} are generated, clustered and evaluated. A \textit{time-expanded} graph connects vertices of graphs at different points in time via inter-time edges, if those vertices “resemble” each other. The \textit{time-expanded} graph is described in Section 3.3.1. The idea behind this is that in a clustered \textit{time-expanded} graph one can track the temporal evolution of single clusters. Furthermore, clusters can be smoothened over time and certain outliers can be diminished.

\textsuperscript{1}CiteSeer is a scientific literature digital library.
1.2 Data Source

We used the sales data of the German retail chain *dm* from mid 2004 to mid 2008. The data was gathered via the customer loyalty program *PAYBACK*. This data is based on a massive customer base and carefully collected, thus it is highly reliable; however, we should keep two flaws of the data in mind: only about 50 percent of *dm* customers have a *PAYBACK* card and it is possible to lend it or use it infrequently. Being aware of this, we can now base our study on *PAYBACK*. If a customer presents his *PAYBACK* card during the payment process at the cash register, customer ID, date, store ID and bought items are recorded. The database contains customer master data, article master data, store master data and receipt data. The customer master data includes information about the customers like age, gender, postal code and favorite store. In the article master data, each of the *dm* articles is classified into one of assortments\(^2\), into one of sub-assortments\(^1\) and into much more, but we will only operate on article- or sub-assortment-level. Additionally the articles are divided into different brands. The store master data contains postal code, location, assortment size and sales area of every store. In the receipt data each record describes when and where each customer bought particular items and how many of them. This is by far the largest set of data. Because the data amount of all 1012 German *dm* stores is huge, we made some temporal and local restrictions. That is we restricted the receipt data to single months or quarters of a year and to single stores. Just limiting the data to a single month of 2006 means that we have to deal with approximately receipts. In 2008 a single month even yielded over receipts. Further restricting the data to a single store (and a

\(^1\)Warenbereich (sub-assortment)
\(^2\)Warensortiment (assortment)
Introduction

<table>
<thead>
<tr>
<th>Store</th>
<th>Store Label</th>
<th>City</th>
<th>Postal Code</th>
<th>Location Label</th>
<th>Sales Area Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>S-SILLEN-BUCH</td>
<td>Stuttgart</td>
<td>70619</td>
<td></td>
<td>400 to 499 sqm</td>
</tr>
<tr>
<td>242</td>
<td>M-OEZ</td>
<td>München</td>
<td>80993</td>
<td></td>
<td>500 to 599 sqm</td>
</tr>
<tr>
<td>518</td>
<td>KA-KÄPPELE</td>
<td>Karlsruhe</td>
<td>76131</td>
<td></td>
<td>over 600 sqm</td>
</tr>
</tbody>
</table>

Table 1.1: The considered stores.

single month) leaves only up to receipts.
To remain representative, we selected three different stores in Karlsruhe, Stuttgart and Munich. As shown in Table 1.1, they all differ in location and sales area.
Chapter 2
Graph Modeling

2.1 Very Brief Introduction to Graph Theory

Throughout this thesis, we will use the notation of (BE05). We refer the reader to (Die00) for a more detailed introduction to graph theory.

Let $G = (V,E,\omega)$ be an undirected, connected, and simple graph with $n := |V|$ vertices and $m := |E|$ edges. The edge weight is defined as $\omega : E \rightarrow \mathbb{R}^+$. We denote the sum of all edge weights with $W$. For a vertex $v$, we define the vertex weight $\omega(v)$ as the sum of the weights of its incident edges. The degree $\text{deg}(v)$ of a vertex is the number of edges incident to the vertex. The adjacency matrix $A$ of graph $G$ is a symmetric $n \times n$ matrix where entry $a_{ij}$ is the edge weight from vertex $i$ to vertex $j$ or zero if $\{v_i,v_j\} \notin E$, and the diagonal entry $a_{ii}$ is zero.

Let $C = \{C_1, \ldots, C_k\}$ be a partition of $V$. We call $C$ a clustering of $G$ and the elements $C_i$ clusters. Let $E(C_i) := \{\{v,w\} \in E : v, w \in C_i\}$. Then $E(C) := \bigcup_{i=1}^k E(C_i)$ is the set of intra-cluster edges and $E \setminus E(C)$ the set of inter-cluster edges. $m(C)$ denotes the number of intra-cluster edges and $m(C)$ the number of inter-cluster edges.

Figure 2.1 depicts an example of a clustered graph $G_1$ with $n = 6$, $m = 7$ and $W = 23$. Vertex b has the vertex weight 8 and a degree of 3. The adjacency matrix of $G_1$ is shown in (2.1). The clustering $C = \{C_1, C_2\}$ of Figure 2.1 consists of two clusters $C_1$ and $C_2$ with $C_1 = \{a, b, c\}$ and $C_2 = \{d, e, f\}$. The number of intra-cluster edges $m(C_1)$ is 6 while the number of inter-cluster edges $m(C_2)$ is 1.

\[
\begin{pmatrix}
0 & 2 & 3 & 0 & 0 & 0 \\
2 & 0 & 5 & 1 & 0 & 0 \\
3 & 5 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 6 & 2 \\
0 & 0 & 0 & 6 & 0 & 4 \\
0 & 0 & 0 & 2 & 4 & 0
\end{pmatrix}
\] (2.1)
2.2 Similarity Coefficients

Similarity Coefficients are designed to quantify the likeness between two vectors or two sets of objects by specifying one numeric value. This value increases as the similarity of the vectors increases. We need similarity coefficients for the edge weights of our graphs. Below, we describe a basic representation of our data, some characteristics of similarity coefficients and five commonly used similarity coefficients. We assume that the single objects or vector components are elements of $N_0$.

2.2.1 The Basic Representation

The calculation of similarities between customers requires the purchases to be represented as collections of items, analog to (JF87). The frequency with which a customer has bought a certain item can be taken into account in the form of a weight. A matrix representation of the collection of purchases, as in Table 2.1, is appropriate. The items are associated with the rows and the purchases of the customers are associated with the columns of the matrix. Table 2.2 shows a concrete example. This example points out two important aspects about weights. First, if we compare the weights within a column to each other, we can see which items are important for the representation of the customers’ buying behavior. For example, Customer$_1$ buys mainly cat products and no baby products. Second, comparing the weights within a row might show some similarities between customers. Customer$_1$ and Customer$_3$ both buy mainly cat products and Customer$_2$ and Customer$_4$ are more into baby products. However, in some cases the weight of an item is not very meaningful. Customer$_5$ buys cat and baby products and almost every customer buys plastic bags. So, Customer$_5$ is not easy to describe and plastic bags are not very helpful to discriminate between customers. Finally, the last items are bought very infrequently compared to the cat food, but they are probably more interesting and distinguishing items than cat food. That is why we are more interested in whether or not a customer has bought a certain item than in how frequently he has bought it.

In this context, two geometric representations of our data are feasible. In Figure 2.2
2.2 Similarity Coefficients

<table>
<thead>
<tr>
<th>Items</th>
<th>Purchases / Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>$W_{11}$  $W_{12}$</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$W_{21}$  $W_{22}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$A_n$</td>
<td>$W_{nm}$</td>
</tr>
</tbody>
</table>

Table 2.1: A matrix representation of the purchases of the customers.

<table>
<thead>
<tr>
<th>Items</th>
<th>Purchases / Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>dm-BrandB1 KatzeSeelachs</td>
<td>3  0  1  0  1</td>
</tr>
<tr>
<td>BrandA1 Milchbrei</td>
<td>0  7  0  5  2</td>
</tr>
<tr>
<td>Plastiktüte</td>
<td>4  3  1  2  0</td>
</tr>
<tr>
<td>dm-BrandB1 KatzeKalb+Geflügel</td>
<td>10 0 7 0 1</td>
</tr>
<tr>
<td>BrandA1 Frühstück-Brei</td>
<td>0 1 0 1 0</td>
</tr>
<tr>
<td>BrandC1 Gardinenwaschmittel</td>
<td>0 1 1 0 1</td>
</tr>
<tr>
<td>BrandD Scheuermilch</td>
<td>0 1 1 0 1</td>
</tr>
</tbody>
</table>

Table 2.2: An example of a matrix representation.

Customers are points in space and items are represented by coordinates. For instance, the vector of Customer$_1$ lies on the axis of Item$_1$, at (3,0) in space. In other words, Customer$_1$ bought Item$_1$ three times and never bought Item$_2$. Another possible geometric representation would have customers as coordinates and items as points in space.

2.2.2 Characteristics of Similarity Coefficients

Jones, et al. (JF87), proposed some attributes, with which similarity coefficients can be compared to each other. They are illustrated in Figures 2.3 to 2.6. Let $\sim(\vec{A}, \vec{B})$ be the similarity value of the vectors $\vec{A}$ and $\vec{B}$:

**Angle monotonicity** - Let $\vec{B}$ and $\vec{C}$ be two vectors of the same length. If the angle between $\vec{A}$ and $\vec{B}$ is smaller than the angle between $\vec{A}$ and $\vec{C}$, than $\sim(\vec{A}, \vec{B})$ must be higher than $\sim(\vec{A}, \vec{C})$.

**Radial monotonicity** - Let $\vec{B}$ and $\vec{C}$ be two vectors of the same direction. If $\vec{B}$ is longer than $\vec{C}$, than $\sim(\vec{A}, \vec{B})$ must be higher than $\sim(\vec{A}, \vec{C})$.

**Component-wise monotonicity** - Let us increment any component of $\vec{B}$ and call it $\vec{B}_2$. $\sim(\vec{A}, \vec{B}_2)$ must be higher than $\sim(\vec{A}, \vec{B})$. 
Figure 2.2: A geometric representation.

Figure 2.3: An illustration of the *angle monotonicity* characteristic (JF87). It means that \( \text{sim}(\vec{A}, \vec{B}) > \text{sim}(\vec{A}, \vec{C}) \).

Figure 2.4: An illustration of the *radial monotonicity* characteristic (JF87). It means that \( \text{sim}(\vec{A}, \vec{B}) > \text{sim}(\vec{A}, \vec{C}) \).

Unbounded single-component influence - The increment of one component can result in an infinitely high similarity value.

Boundedness of similarity values - The similarity value has an upper limit, mostly 1.
2.2 Similarity Coefficients

2.2.3 Simple Matching Coefficient

The simple matching coefficient or inner product measure is the simplest of all similarity coefficients. Equation 2.2 shows the simple matching coefficient between the customers \( C_1 \) and \( C_2 \). In the boolean case, as shown in Equation 2.3 (vR79), the simple matching coefficient is composed of the cardinality of the intersection between the set of items bought by \( Customer_1 \) and the set of items bought by \( Customer_2 \).

\[
\sum_{i=1}^{n} W_{iC_1} \cdot W_{iC_2} \quad (2.2)
\]

\[
|X \cap Y| \quad (2.3)
\]

Figure 2.7 illustrates the contours of equal similarity for the reference vector \( \vec{R}(0.5, 1.0) \). For two different vectors \( \vec{A} \) and \( \vec{B} \) that point to the same contour, \( \text{sim}(\vec{R}, \vec{A}) \) is equal to \( \text{sim}(\vec{R}, \vec{B}) \). A disadvantage of this coefficient is, that its similarity values do not have an upper limit. The lack of a perfect similarity value makes ranking very difficult. Single-components should not have a dominating influence either. As mentioned in Section 2.2.1, frequently bought items like plastic bags are often less interesting than rarely bought ones. In our case, the more is not the better. Furthermore, our focus lies on the combination of items a customer has bought. So the angle between two vectors should have a much bigger influence on the similarity value than the length of a vector or the increment of a single component.

But despite its many disadvantages, the simple matching coefficient is (normalized) often part of other similarity coefficients.
2.2.4 Cosine Coefficient

The cosine coefficient, as shown in Equation 2.4, consists of the simple matching coefficient, which serves as the comparison operation, divided by the product of the Euclidean lengths of both vectors. Notice that the denominator of this formula normalizes both vectors to the Euclidean lengths of one. Because of this normalization, only the directions and not the lengths of both vectors have an impact on their similarity value. Thus, the cosine coefficient is angle monotone and not radially monotone.

An outline of the regions of equal similarity is given in Figure 2.8. In 2-space, those regions are wedge-shaped.

Another advantage of the cosine coefficient is the boundedness of similarity values. As illustrated by Figure 2.8, the maximal similarity value of one lies in the wedge of the contemplated vector.

$$\frac{\sum_{i=1}^{n} W_{iC_1} \cdot W_{iC_2}}{\sqrt{\sum_{k=1}^{n} (W_{kC_1})^2} \cdot \sqrt{\sum_{j=1}^{n} (W_{jC_2})^2}}$$  \hspace{1cm} (2.4)

$$\frac{|X \cap Y|}{\sqrt{|X| \times |Y|}}$$  \hspace{1cm} (2.5)

2.2.5 Overlap Coefficient

The formulas of the overlap coefficient are shown in Equations 2.6 and 2.7. The numerator of this coefficient is a different comparison operation. Unlike the other discussed similarity coefficients, it does not contain the simple matching coefficient. The denominator acts as a normalization operation.
2.2 Similarity Coefficients

![Diagram showing regions of approximately equal similarity of the cosine coefficient (JF87).](image)

Figure 2.8: Regions of approximately equal similarity of the cosine coefficient (JF87). (Of course cosine is continuous.)

\[
\sum_{i=1}^{n} \min(W_iC_1, W_iC_2) \\
\min(\sum_{k=1}^{n} W_kC_1, \sum_{j=1}^{n} W_jC_2)
\] (2.6)

\[
\frac{|X \cap Y|}{\min(|X|, |Y|)}
\] (2.7)

The overlap coefficient has a very unique behavior. Figure 2.9 illustrates the regions and contours of equal similarity. The two black boxes represent regions of maximal similarity. For every vector \( \vec{B} \), that falls into one of the black boxes, \( \text{sim}(\vec{A}, \vec{B}) \) is equal to one. So, if all components of Vector \( \vec{B} \) are smaller (/bigger) than all components of Vector \( \vec{A} \), then \( \text{sim}(\vec{A}, \vec{B}) \) is maximal.

Figure 2.10 demonstrates this major disadvantage of the overlap coefficient. Vectors \( \vec{B} \) and \( \vec{C} \) both fall into the upper black box of vector \( \vec{A} \). Their similarity values are equal, although the angle between \( \vec{A} \) and \( \vec{B} \) is much smaller than the angle between \( \vec{A} \) and \( \vec{C} \) and the first components of \( \vec{A} \) and \( \vec{C} \) differ a lot more than the first components of \( \vec{A} \) and \( \vec{B} \).

Table 2.3 summarize all characteristics of this coefficient.

2.2.6 Jaccard Coefficient

The formula of the jaccard coefficient for binary vectors is shown in Equation 2.8. It is composed of the cardinality of the intersection between the set of items bought by Customer\(_1\) and the set of items bought by Customer\(_2\) divided by the cardinality of the union of both sets. In (Fer03) the weighted version of the jaccard coefficient is defined like in Equation 2.9. The disadvantage of this version is that the denominator can become 0 even if all vector components are nonnegative. This can yield discontinuities in the similarity of vectors. In 2-space there are places where tiny changes of a vector can yield
Figure 2.9: Regions and contours of equal similarity of the overlap coefficient. (JF87)

Figure 2.10: Overlap coefficient example.
2.2 Similarity Coefficients

arbitrarily huge changes in the similarity to another vector. If \((a,b)\) is the reference vector, these discontinuities are given for all points on the following straight line:

\[
y = \frac{1 - a}{b - 1} x + \frac{a + b}{b - 1}.
\]

For instance, if the reference vector is \((4,2)\), this straight line is \(y = -3x + 6\). The vector \((0,6.2)\) has a similarity of \(-62\) to the reference vector, while the vector \((0,6.1)\) has a similarity of \(-122\) to the reference vector.

In (Tan57) Tanimoto introduces the *tanimoto coefficient*, which is shown in Equation 2.10. The formula differs from that of Equation 2.9 in that its denominator always remains positive by not taking the sums of vector components but the sums of squared vector components. This formula extends the *cosine coefficient*. For binary vectors it is equal to the *jaccard coefficient*, so it can be seen as a legitimate weighted version of the *jaccard coefficient*. The *tanimoto coefficient* is very popular in biological taxonomy and information retrieval (HK06). Its characteristics are similar to that of the *cosine coefficient* as can be seen in Table 2.3.

\[
\frac{|X \cap Y|}{|X \cup Y|} \quad \text{(Boolean Jaccard Coefficient)} \quad (2.8)
\]

\[
\frac{\sum_{i=1}^{n} W_{i}C_{1} \cdot W_{i}C_{2}}{\sum_{i=1}^{n} W_{i}C_{1} + \sum_{i=1}^{n} W_{i}C_{2} - \sum_{i=1}^{n} W_{i}C_{1} \cdot W_{i}C_{2}} \quad \text{(Weighted Jaccard Coefficient)} \quad (2.9)
\]

\[
\frac{\sum_{i=1}^{n} W_{i}^2C_{1} \cdot W_{i}^2C_{2}}{\sum_{i=1}^{n} W_{i}^2C_{1} + \sum_{i=1}^{n} W_{i}^2C_{2} - \sum_{i=1}^{n} W_{i}C_{1} \cdot W_{i}C_{2}} \quad \text{(Tanimoto Coefficient)} \quad (2.10)
\]

2.2.7 Summary

An overview of the similarity coefficient characteristics is shown in Table 2.3. We need similarity values to have an upper limit, because we want to rank similarity values. Further, we do not like to have a big influence of single-components, because we want to value frequently and infrequently bought items alike. The same argument speaks against radial monotonicity and component-wise monotonicity. This means that the *simple matching coefficient* is not very suitable for our purposes. But a similarity coefficient should be angle monotone, because this means that the smaller the angle between two vectors, the more similar is each component of one vector to the corresponding component of the other vector. The *overlap coefficient* is not angle monotone. Comparing the introduced characteristics of the *cosine coefficient* to that of Tanimoto’s
### Table 2.3: A comparison of similarity coefficient characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Simple</th>
<th>Cosine</th>
<th>Overlap</th>
<th>Jaccard/Tanimoto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle monotonicity</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>(regardless of vector length)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial monotonicity</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(radial-constant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component-wise monotonicity</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(only if angle changed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbounded single-component influence</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Boundedness of similarity values</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>([0,1])</td>
<td>([0,1])</td>
<td>([0,1])</td>
<td></td>
</tr>
</tbody>
</table>

version of the jaccard coefficient results in a tie. But an unwanted feature of the cosine coefficient is that in the area where two vectors have a very small angle (close to 0°) a change of the angle yields an extremely low change in the similarity value. But particularly in this area, changes are very interesting to observe. Thus, we decide to use Tanimoto’s version of the jaccard coefficient as our main similarity coefficient.

### 2.3 Thresholds

When generating a graph the user can adjust among others the three parameters minimum edge weight, absolute edge weight and single weight. The minimum edge weight is a threshold that allows only customers with a minimum purchasing similarity (edge weight) to at least one other customer to be represented as vertices in the graph. Thus, the lower the minimum edge weight the more vertices are in the graph, until all customers of the underlying data are represented in the graph (minimum edge weight=0). The purpose of this parameter is that we only want to take customers with a minimum purchasing similarity into consideration, because otherwise they can not help in defining any customer cluster. Analog to this, the absolute edge weight is an absolute threshold that allows only customers to be represented in the graph that bought a minimum number of items which at least one other customer bought. The following example illustrates the difference to the minimum edge weight: We set the minimum edge weight to 0.9, which is an extremely high value,
2.4 Graph Types

and we set the absolute edge weight to 2, which is an extremely low value. Two customers are described by the customer vectors\(^1\) (1,0,0,0,0,0) and (1,0,0,0,0,0). Their (Jaccard) edge weight is 1.0, because they have the exact same vectors. If we only consider the minimum edge weight of 0.9 during the graph generation, both customers are in the graph. But if we only consider the absolute edge weight of 2, both customers are not part of the graph, because they both bought just one item.

The single weight reflects the minimum amount of items a customer is required to have bought. The customer is only represented in the graph if he bought a certain amount of items. Applying a high single weight yields only major customers and excludes customers that only bought small amounts. To illustrate this, we use a second example. We set the single weight to 3, the absolute edge weight to 1 and the minimum edge weight to 0.01. Two customers are described by (1,0,1,0,1,0) and (0,1,0,1,0,1). If we just consider the single weight during graph generation, both customers are part of the graph, because they both bought 3 items. But if we just consider the absolute edge weight or the minimum edge weight, these customers are not in the graph.

In our tool, the user can adjust all three parameters. But we removed the single weight during our experiments, because it turned out to be irrelevant. Only high thresholds of single weight (≥ 10) had an impact, but we deem such values too restrictive in our model as we do not only want to consider heavy buyers. We fixed the absolute edge weight to 5, because it turned out to be dominated by the minimum edge weight. In our experiments the minimum edge weight ranged from about 0.2 to 0.03. In our view of the relevance of the data, it is the most interesting of the three parameters, because it does not expect absolute values of the customers.

2.4 Graph Types

A variety of questions can be posed to the given source data, introduced in Section 1.2. The appropriate model helps to find answers to these questions. In this work, we make use of the graph model. Remember that in the graph model entities are represented by vertices, relations are represented by edges, and natural communities or groups of similar entities are expressed by clusters.

So, for instance we might be interested in the customers’ main reasons for shopping at dm. In other words, we want to know which items are essential and should stay in the assortment to keep the customers. To reveal these essential items, we need to find groups of similar shopping carts. In this case, a graph model, whose vertices represent receipts and whose edges represent common items, would be appropriate. Clusters in this graph type are the sought-after groups of similar shopping carts.

Another example is a graph whose vertices stand for items and whose edges stand for customers (or just receipts). The clusters of this graph represent groups of similar items. This information is useful for the shop layout. It would make sense to place items that are

\(^1\)A summary of the customer’s receipts.
bought by a similar buyership in different areas of the shop to prolong the customers stay in the shop.

But what graph type suits best, if we want to reveal customer profiles and behaviors? We now introduce three different graph types that will be analyzed in this work. Note that those graph types were part of a long progress and that one graph type evolved from another graph type. But now we want to already provide the formalisms.

2.4.1 KAK-Graphs

As mentioned before, we intend to find customer profiles. That is, we want to discover groups of customers with similar buying patterns. So, an obvious graph model would consist of customers as vertices and common purchases as edges. The basic structure of this graph type is illustrated in Figure 2.11. We call this graph type KAK-Graph, because of the customer–item–customer (in German: Kunde–Artikel–Kunde) relation it represents. The similarity value of two customers, represented by the corresponding edge weight, is calculated using the Jaccard similarity coefficient. As described in Section 2.2.6, the Jaccard similarity of two customers is determined by dividing the number of the intersection of their bought items by the number of the union of their bought items.

The example of Table 2.2 and Figure 2.2 can easily be transformed into a KAK-Graph, as demonstrated by Figure 2.12. Note that we only want to take customers with a minimum purchasing similarity into consideration, because otherwise they can not belong to any customer cluster. So in this example, we determine a minimum edge weight of 0.1. This means that only customers with at least one similarity over 10 percent are kept. In Figure 2.12, only the solid edges and the vertices incident to those edges remain in the graph. A clustering algorithm splits a graph into dense groups of vertices that are sparsely connected (see Section 3.2). Such an algorithm would most likely group Customer $C_1$ and Customer $C_3$ in one cluster and Customers $C_2$, $C_4$ and $C_5$ in another cluster, as shown in Figure 2.13. As mentioned in Section 2.2.1, Customer $C_1$ and Customer $C_3$ mainly buy cat products and Customer $C_2$ and Customer $C_4$ mainly buy baby products. So in this case, transforming our source data into a KAK-Graph and applying a clustering algorithm reveals a Cat customer profile and a Baby customer profile.
2.4 Graph Types

Figure 2.12: Example of a KAK-Graph.

Figure 2.13: Example of a clustered KAK-Graph.
Table 2.4: Binary matrix representation.

<table>
<thead>
<tr>
<th>Marke/Warenbereich</th>
<th>Purchases / Customers</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>C₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>dm-BrandB1 Katze</td>
<td>1 0 1 0 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BrandA1 Babynahrung</td>
<td>0 1 0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>? Sontiges/Te</td>
<td>1 1 1 1 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BrandC1 WPR</td>
<td>0 1 1 0 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BrandD WPR</td>
<td>0 1 1 0 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4.2 **KMK-Graphs**

Another possibility to find customer profiles is provided by the so-called **KMK-Graph**. This graph type represents a customer–sub-assortment*brand–customer (in German: *Kunde–Warenbereich* *Marke–Kunde*) relation. The structure of the **KMK-Graph** is a little different to that of the **KAK-Graph**. Vertices still stand for customers. However, in this graph type edges stand for purchases in the same sub-assortment and of the same brand. So, all items in the same sub-assortment and of the same brand are merged. As mentioned in Section 2.2.1, one of our objectives is to valorize infrequently bought items. For this purpose, we now use binary customer vectors. In these vectors, ‘1’ means that the customer has bought at least one item in this sub-assortment and of this brand, and ‘0’ means the customer has not bought any item of this sub-assortment*brand combination. The geometric representation of a **KMK-Graph** is illustrated by Figure 2.14. Note that the article master data of *dm* contain sub-assortment*brand combinations and so the number of components of each customer vector is equal to this number.

The matrix representation of the example shown in Table 2.2 now shrinks to the matrix representation in Table 2.4. Customer C₁ bought thirteen items in the *Cat* sub-assortment and of the brand *dm-BrandB1*. In the new representation, these thirteen items just count as one. So, we see that frequently bought items are combined in one sub-assortment*brand combination while very infrequently bought items like *BrandC1 Gardinenwaschmittel* still count the same. This is due to the fact that in the Jaccard calculation (2.10) the high influence of many items inside the *Cat* cluster does no longer overshadow the infrequently bought items.

In the resulting **KMK-Graph** (2.15), Equation 2.8 is used to calculate the edge weights. If we determine a minimum edge weight of 0.3 and apply a clustering algorithm on our **KMK-Graph**, we again receive two clusters, as shown in Figure 2.16. But this time, customers C₂, C₃ and C₅ are grouped together. Unlike the other customers, those three have bought items in the sub-assortment *WPR*. In other words, we reveal a new WPR customer profile using the **KMK-Graph** type.

---

³This sub-assortment contains cleaning supplies.
Figure 2.14: Geometric representation of a *KMK*-Graph.

Figure 2.15: Example of a *KMK*-Graph.

Figure 2.16: Example of a clustered *KMK*-Graph.
In the KhK-Graph type, a customer is characterized by its most frequently bought brand of every sub-assortment. KhK stands for the customer–most-frequent-brand*sub-assortment–customer (in German: Kunde–häufigste-Marke*Warenbereich–Kunde) relation. So, the more favorite brands two customers have in common, the higher their similarity value.

In this case, two different matrix representations are feasible. The first one consists of string values. Every row of this matrix represents one sub-assortment. For every sub-assortment a customer gets the string value of his favorite brand assigned. Compared to the KMK-Graph, in this representation a customer vector consists of many fewer components. The second feasible representation has as many components as the representation of the KMK-Graph and again, we use binary values. But here, ’1’ stands for the customers’ favorite brand. This means that every customer has at most one ’1’ per sub-assortment.

The advantage of the second representation is that it enables the calculation of similarity values. Note that it is easy to switch between both representations. Depending on whether we require less dimensions or we need to calculate similarity values, we can pick the appropriate representation. To distinguish between the two binary representations of the KMK- and the KhK-Graph, we call the latter the categorical representation. Compared to the KMK-Graph, we lose the information about whether or not a customer has bought other (not favorite) brands, but on the other hand we gain the information about the favorite brands of the customer.

To demonstrate the features of the KhK-Graph, we use a second example. In Table 2.5, the items are already ordered by sub-assortments. Here, in the first sub-assortment Customer C2 bought the brand BrandE1 most frequently. So, in the string representation for the field of this sub-assortment the value ‘BrandE1’ is assigned to him, as shown in 2.11. The corresponding categorical vector of customer C2 is shown in 2.12. Table 2.6 shows the complete categorical matrix representation. The corresponding KhK-Graph is shown in Figure 2.17. If we once again determine a minimum edge weight of 0.3 and apply a clustering algorithm on this KhK-Graph, we receive two Cleaning Supplies clusters of different brands (BrandI1 and BrandJ1) (Figure 2.18).

Now, let us compare this clustering result with the result we would get using the KMK-Graph type. Table 2.7 contains the binary matrix representation of this example and Figures 2.19 and 2.20 show the corresponding (clustered) KMK-Graph. With the same minimum edge weight of 0.3, we receive two totally different and less informative clusters. The first one is a mixture of cat products, cleaning supplies and plastic bags and the customers of the second cluster just have plastic bags in common. In other words, in this example the resulting clusters and their expressiveness heavily depend on the choice of the graph type. This statement is even emphasized by the resulting clusters of the corresponding KAK-Graph (A.1). With the same edge weight we receive two plastic bag clusters (A.2) and with a lower edge weight, we get one Dog and one Cat cluster (A.3). But both clustering results are completely different to the clustering results of the KMK- and KhK-Graphs.
### Table 2.5: Matrix representation of the KhK-Example.

<table>
<thead>
<tr>
<th>Marke/Warenbereich</th>
<th>Purchases / Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>dm-BrandB1 KatzeLamm</td>
<td>5 0 2 0 5</td>
</tr>
<tr>
<td>BrandE1 Mit Kaninchen</td>
<td>4 4 0 0 0</td>
</tr>
<tr>
<td>BrandF1 Geflügelcocktail</td>
<td>0 3 4 0 0</td>
</tr>
<tr>
<td>dm-BrandB1 Katze Trockenfutter</td>
<td>1 0 1 0 1</td>
</tr>
<tr>
<td>BrandG1 Wunderknochen</td>
<td>0 2 0 1 0</td>
</tr>
<tr>
<td>BrandH1 Rind</td>
<td>0 0 0 4 3</td>
</tr>
<tr>
<td>BrandI1 Allzweck-Reiniger</td>
<td>2 1 0 0 1</td>
</tr>
<tr>
<td>BrandJ1 Aprilfrisch</td>
<td>1 0 1 1 0</td>
</tr>
<tr>
<td>Plastiktüte</td>
<td>2 3 4 2 4</td>
</tr>
</tbody>
</table>

### Table 2.6: Categorical matrix representation of the KhK-Example.

<table>
<thead>
<tr>
<th>Marke/Warenbereich</th>
<th>Purchases / Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>dm-BrandB1 Katze</td>
<td>1 0 0 0 1</td>
</tr>
<tr>
<td>BrandE1 Katze</td>
<td>0 1 0 0 0</td>
</tr>
<tr>
<td>BrandF1 Katze</td>
<td>0 0 1 0 0</td>
</tr>
<tr>
<td>BrandG1 Hund</td>
<td>0 1 0 0 0</td>
</tr>
<tr>
<td>BrandH1 Hund</td>
<td>0 0 0 1 1</td>
</tr>
<tr>
<td>BrandI1 WPR</td>
<td>1 1 0 0 1</td>
</tr>
<tr>
<td>BrandJ1 WPR</td>
<td>0 0 1 1 0</td>
</tr>
<tr>
<td>? Sontiges/Te</td>
<td>1 1 1 1 1</td>
</tr>
</tbody>
</table>

\[
\left( \begin{array}{c}
S_{A1} \\
S_{A2} \\
S_{A3} \\
S_{A4}
\end{array} \right) \begin{array}{c}
\text{'BrandE1'} \\
\text{'BrandG1'} \\
\text{'BrandI1'} \\
'?' \end{array} \quad (2.11) \\
\left( \begin{array}{c}
B_1^1 \\
B_2^1 \end{array} \right) \begin{array}{c}
S_{A1} \\
S_{A2}
\end{array} \begin{array}{c}
0 \\
1 \end{array} \quad (2.12)
\]
Figure 2.17: \( KhK\)-Graph of the \( KhK\)-Example.

Figure 2.18: Clustered \( KhK\)-Graph of the \( KhK\)-Example.

Table 2.7: Binary matrix representation of the \( KhK\)-Example.

<table>
<thead>
<tr>
<th>Marke/Warenbereich</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>( C_4 )</th>
<th>( C_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>dm-BrandB1 Katze</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>BrandE1 Katze</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BrandF1 Katze</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BrandG1 Hund</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>BrandH1 Hund</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BrandI1 WPR</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>BrandJ1 WPR</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>? Sontiges/Te</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2.19: \( KMK\)-Graph of the \( KhK\)-Example.

Figure 2.20: Clustered \( KMK\)-Graph of the \( KhK\)-Example.
Chapter 3

Graph Clustering

3.1 Quality Measurements for Clusterings

In a set of customers, we want to find customer groups that are as well-defined as possible. This means, we search for customer clusters, whose customers are a lot more similar to other customers of the same cluster than to customers of other clusters. In other words, we look for a customer clustering of high quality. To measure the quality of a clustering, we use structural indices, as described in (BGW03), (BGW07) and (GGW07).

3.1.1 Coverage

Coverage$(C)$ is a simple quality measurement for graph clusterings. It measures the quality of a clustering $C$ by comparing the number of intra-cluster edges to the total number of all edges (Equation 3.1). Equation 3.2 describes the weighted version of $\text{coverage}(C)$. The range of $\text{coverage}(C)$ is $[0,1]$. Basically, the higher the quality of a clustering $C$, the higher $\text{coverage}(C)$. Figure 3.1.1 illustrates this principle. 3.1(a) and 3.1(b) are two possible clusterings of one graph. Intuitively one would group the vertices like in 3.1(a). If every edge weight is equal to one, $\text{coverage}(C) = \frac{12}{13}$ and $\text{coverage}(C') = \frac{10}{13}$. So, clustering 3.1(a) is of higher quality.

But, note that $\text{coverage}(C)$ reaches its maximum, if $C$ consists of only one cluster containing all vertices of the graph. Therefore, additional constraints on the clustering like a minimum number of clusters or a maximum cluster size are necessary.

\[
\text{coverage}(C) := \frac{m(C)}{m} = \frac{m(C)}{m(C) + m(C')}
\] (3.1)

\[
\text{coverage}_\omega(C) := \frac{\omega(m(C))}{\omega(m)} = \frac{\omega(m(C))}{\omega(m(C)) + \omega(m(C'))}
\] (3.2)
3.1.2 Performance

The performance$(C)$ of a graph clustering $C$ is the fraction of 'correctly interpreted pairs of vertices' with respect to all possible pairs of vertices (Equation 3.3). A 'correctly interpreted pair of vertices' is either a pair of vertices connected by an intra-cluster edge or two vertices of two different clusters that are not connected by an inter-cluster edge. Performance$(C)$ reaches its maximum for graph clusterings, whose clusters are completely connected cliques without inter-cluster edges. Figure 3.2 depicts an example for such a clustering.

$$\text{performance}(C) := \frac{m(C) + \sum_{\{v,w\} \not\in E, v \in C_i, w \in C_j, i \neq j} 1}{\frac{1}{2} n(n - 1)}$$ (3.3)
3.1.3 Modularity

The modularity \( C \) of a clustering \( C \) is defined as \( \text{coverage}(C) \) minus the expected value of \( \text{coverage}(C) \). The expected value of \( \text{coverage}(C) \) is the coverage value of a graph clustering that results from a graph in which all expected vertex degrees remain the same but edges are placed at random. In (New04), modularity is described in detail. Equation 3.4 shows the formula of \( \text{modularity}(C) \). The weighted version of \( \text{modularity}(C) \) is shown in Equation 3.5. Remember from Section 2.1 that \( \omega(v) \) is defined as the vertex weight of a vertex \( v \). It is the sum of the weights of its incident edges. We denote the sum of all edge weights with \( W \). Weighted \( \text{modularity}_\omega(C) \) is a true generalization of \( \text{modularity}(C) \), because weighted \( \text{modularity}_\omega=1(C) \) with every weight \( \omega \) set to 1 yields \( \text{modularity}(C) \). Note the following trade-off: To maximize \( \text{coverage}(C) \), the number of intra-cluster edges of \( C \) should be high and the minimization of the expected value of \( \text{coverage}(C) \) is attained by having many clusters with small total degrees. The range of \( \text{modularity}(C) \) is \([-\frac{1}{2}, 1)\). If \( \text{coverage}(C) \) is higher than expected, \( \text{modularity}(C) \) is positive and otherwise negative. \( \text{Modularity}(C) \) reaches its maximum for clusterings consisting of many, equally sized cliques with no inter-cluster edges. The clustering of Figure 3.2 already has a relatively high \( \text{modularity}(C) \) of 0.44.

\[
\text{Modularity}(C) := \text{Coverage}(C) - \sum_{C \in C} \left( \frac{\sum_{v \in C} \deg(v)}{2m} \right)^2 \tag{3.4}
\]

\[
\text{modularity}_\omega(C) := \text{Coverage}_\omega(C) - \sum_{C \in C} \left( \frac{\sum_{v \in C} \omega(v)}{2W} \right)^2 \tag{3.5}
\]

3.2 Clustering Methods

In this section, we introduce the Greedy Modularity Clustering algorithm, described in (GGW07). Despite the large variety of graph clustering algorithms, we only use the Greedy Modularity Clustering algorithm, because it is a well-known and good algorithm that yields sufficiently reliable clustering results. Besides we already have many degrees of freedom, so we better limit ourselves to one well working algorithm.

3.2.1 Greedy Modularity Clustering (Newman)

The Greedy Modularity Clustering algorithm (Algorithm 1) yields clusterings with high \( \text{modularity}(C) \) values. Note that the detection of a clustering with maximum modularity is \( \mathcal{NP} \)-complete (BDG+08). Hence, the Greedy Modularity Clustering algorithm uses a greedy heuristic. Tests indicate that this algorithm yields results close to the optimum
It starts with the singleton clustering and merges in every step those two clusters whose merging increases the modularity value the most. The iteration stops, after all vertices are merged together into one big cluster. At the end, the intermediate clustering $C$ with the highest modularity is returned.

Using appropriate data-structures and an efficient implementation, Algorithm 1 runs in $O(n^2 \log n)$ (GGW07).

**Algorithmus 1 : Greedy Modularity Clustering**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$C \leftarrow$ singleton clustering of graph $G$;</td>
</tr>
<tr>
<td>2</td>
<td>dendrogram $\leftarrow$ store Tuple $(C, \text{mod}(C))$;</td>
</tr>
<tr>
<td>3</td>
<td>while $</td>
</tr>
<tr>
<td>4</td>
<td>maxvalue $= -\infty$;</td>
</tr>
<tr>
<td>5</td>
<td>forall $C_i, C_j \in C$ with $i \neq j$ do</td>
</tr>
<tr>
<td>6</td>
<td>$C' = (C \setminus {C_i, C_j}) \cup {C_i \cup C_j}$;</td>
</tr>
<tr>
<td>7</td>
<td>value $\leftarrow \text{mod}(C') - \text{mod}(C)$;</td>
</tr>
<tr>
<td>8</td>
<td>if value $&gt; \text{maxvalue}$ then</td>
</tr>
<tr>
<td>9</td>
<td>candidate$_1 \leftarrow C_i$;</td>
</tr>
<tr>
<td>10</td>
<td>candidate$_2 \leftarrow C_j$;</td>
</tr>
<tr>
<td>11</td>
<td>maxvalue $\leftarrow$ value;</td>
</tr>
<tr>
<td>12</td>
<td>$C \leftarrow (C \setminus {\text{candidate}_1, \text{candidate}_2}) \cup {\text{candidate}_1 \cup \text{candidate}_2}$;</td>
</tr>
<tr>
<td>13</td>
<td>dendrogram $\leftarrow$ store Tuple $(C, \text{mod}(C))$</td>
</tr>
<tr>
<td>14</td>
<td>Select clustering $C$ from dendrogram with maximum modularity $\text{mod}(C)$</td>
</tr>
</tbody>
</table>

### 3.3 Time-Dependent Clusterings

A dynamic graph evolves over time. It consists of a chronological sequence of single graph states. Time-dependent clustering tries to find groups within a given dynamic graph. Note that here all data is available at the beginning of our procedure. This is an offline problem and so the considered temporal evolution completely happened in the past.

In our case, time-dependent clustering might be useful to smoothen customer clusters over time and diminish outliers, to observe the temporal evolution of customer groups, and to identify stable customer clusters. A stable cluster is a single cluster that occurs identifiably in several graph states, and thus is no incidental result. A stable customer cluster is a substantiated and very solid customer profile.

In this work, we go into two different time-dependent clustering approaches. The first one connects the single graph states to create one time-expanded graph and then clusters this graph. And the second one tries to identify similar clusters in different single, clustered
3.3 Time-Dependent Clusterings

3.3.1 Time-Expanded Graph

The time-expanded Graph is described in (GGWW06). Let 
\[ G := \{(V,E,\omega) \mid E \subseteq \binom{V}{2}, \omega : E \to \mathbb{R}^+\} \]
be the set of all undirected weighted graphs and 
\[ T := (t_1,t_2,...,t_d) \]
be a sequence of discrete points in time. Given a graph sequence 
\[ s : T \to G \]
the Time-Expanded graph 
\[ G = (V,E,\tilde{\omega}) \]
The vertex set \( V \) is a union of all vertex sets \( V \) of the single graphs in \( s \) (graph states). The edge set \( E \) is a union of the intra-graph edge set \( E_{\text{graph}} \) and the inter-time edge set \( E_{\text{time}} \). \( E_{\text{graph}} \) is defined as the set of all edges of the single graph states. This means that an intra-graph edge is incident to two different vertices of the same graph state. \( E_{\text{time}} \) is defined as the set of all edges that are incident to the same vertices at two different graph states. As mentioned in (Gla08), there are several possibilities to determine the number \( k < d \) of neighboring graph states that can be connected via inter-time edges. We only use time-expanded graphs, in which just vertices of directly neighboring graph states are connected \((k = 1)\). The weight of an intra-graph edge \( \{(v,t),(w,t)\} \in E_{\text{graph}} \) is the weight of the edge incident to \( v \) and \( w \) in the corresponding single graph state. There are again several methods to calculate the weight of the inter-time edges. We implemented three of them:

**Alpha** - All inter-time edge weights are equal to the same fix value \( \alpha \).

**Simple Jaccard** - The inter-time edge weights are calculated using the boolean Jaccard Similarity Coefficient of Equation 2.8. The weight of the inter-time edge \( \{(v,t),(v,t')\} \in E_{\text{time}} \) is the cardinality of the intersection between the set of neighbors of \((v,t)\) and the set of neighbors of \((v,t')\) divided by the cardinality of the union of both sets.

**Complex Jaccard** - Let \( v_t \) be the column vector of \((v,t)\) in the adjacency matrix \( A(t) \) and \( v_{t'} \) be the column vector of \((v,t')\) in the adjacency matrix \( A(t') \). The weight of edge \( \{(v,t),(v,t')\} \in E_{\text{time}} \) is calculated, using the Jaccard Similarity Coefficient of Equation 2.10 on the vectors \( v_t \) and \( v_{t'} \).

Figure 3.3 shows an example of a sequence of three single graph states with \( T = (t_1,t_2,t_3) \). The corresponding time-expanded graph with \( k=1 \) and simple jaccard inter-time edge weights is shown in Figure 3.4. Applying a clustering algorithm on this Time-Expanded graph yields three stable customer clusters, as illustrated by Figure 3.5. The analog (clustered) time-expanded graph with alpha inter-time edge weights can be seen in Figure B.1 (B.2). We see that in every point in time certain customers come and go and certain edges change, but the number of clusters remains the same. Furthermore, the clustered time-expanded graph illustrates how the single clusters evolve over time.
Figure 3.3: A graph sequence.

Figure 3.4: *Time-expanded* graph from Figure 3.3 with simple jaccard.
3.3.2 Comparison Measurements for Clusters

Comparison measurements for clusters try to identify similar clusters in different graph clusterings. So first, every single state of a graph sequence is clustered separately. Then, we try to find similar clusters in the resulting clusterings using a comparison measurement. In our case, detecting similar customer clusters in different clustered graph states, for example in clustered graphs of different quarters, directly leads us to stable customer clusters, and so, to potential customer profiles. In this section, we present the two comparison measurements \textit{bestmatch} and \textit{bestCD} and a quality characteristic to further compare detected similar clusters.

\textit{Bestmatch}

The \textit{bestmatch} comparison measurement for clusters is proposed in (HKKS04). In this work, the authors use \textit{bestmatch} to track evolving communities in the NEC CiteSeer database. For a given cluster $C_i$ in one clustering $\mathcal{C}$, \textit{bestmatch} determines the cluster $C_j$ in another clustering $\mathcal{C}'$ that contains most of the vertices of cluster $C_i$. In our case, vertices are customers. So, two clusters match, if they contain similar customers. To determine the \textit{bestmatch} cluster of a given cluster $C_i$, we first have to calculate the \textit{match} values between cluster $C_i$ and every cluster $C_j$ of clustering $\mathcal{C}'$. Therefore, the
number of equal vertices in both clusters is divided by the total number of vertices in the bigger cluster, as shown in Equation 3.6. \( \text{bestmatch} \) then calculates the cluster with the maximum match value to cluster \( C_i \) (3.7).

Figure 3.6 illustrates this for the example of Section 3.3.1. The \( \text{bestmatch} \) clusters are determined from left to right, because this direction corresponds to the temporal evolution\(^1\). Each big edge connects a cluster with its \( \text{bestmatch} \) cluster. The edge weights of the big edges, are the corresponding match values. Note that we receive exactly the same three stable clusters as we received clustering the time-expanded graph in the previous section.

\[
\text{match}(C_i, C_j) = \min\left( \frac{|C_i \cap C_j|}{|C_i|}, \frac{|C_i \cap C_j|}{|C_j|} \right) \quad (3.6)
\]

\[
\text{bestmatch}(C_i, C') = \max_{C_j \in C'} \left( \text{match} (C_i, C_j) \right) \quad (3.7)
\]

**Centroids and BestCD**

In our context, a centroid is the average customer vector of a certain cluster. Let us go back to our \( KhK \)-example of Section 2.4.3 and have a look at Table 2.6 and Figure 2.18. The WPR BrandI1 cluster consists of the customers \( C_3 \) and \( C_4 \). So, the centroid vector of this cluster is \((0,0,\frac{1}{2},0,\frac{1}{2},0,1,1)\). According to this, the centroid vector of the WPR BrandJ1 cluster with the customers \( C_1, C_2 \) and \( C_5 \) is \((\frac{2}{3},0,\frac{1}{3},\frac{1}{3},1,0,1)\). The seventh component of the WPR BrandJ1 centroid vector is 1. This means that 100% of the WPR BrandJ1 cluster’s customers bought at least one item of this sub-assortment*brand combination and BrandJ1 is their favorite WPR brand. Analog to this, the sixth component of the WPR BrandI1 centroid vector means that this sub-assortment*brand combination is beside the Sonstiges/Te \(^2\) combination the most popular combination of this cluster’s customers.

The centroid distance between two centroid vectors \( \vec{c} \) and \( \vec{z} \) is calculated using the Euclidean distance between both vectors, shown in Equation 3.8. In our example, the centroid distance of the WPR BrandI1 and the WPR BrandJ1 cluster is 1.55. Note that, due to binary customer vectors, the range of centroid vector components of \( KMK \)- and \( KhK \)-graphs is \([0,1]\). Let \( d \) be the number of centroid vector components\(^3\). The range of the centroid distance between centroids of \( KMK \)- or \( KhK \)-graphs is \([0,\sqrt{d}]\). The maximum centroid distance of \( \sqrt{d} \) is reached, if both centroids have a maximum difference of 1 in every component. A centroid distance below 1 is considered to be good, because then there can be no maximum difference in any component. And even if there is no difference of 0 in any component, the difference in each component must be below \( \frac{1}{\sqrt{d}} \).

Like the \( \text{bestmatch} \) comparison measurement, we use the \( \text{bestCD} \) comparison measurement.

\(^1\)We want to know: What happens to customers of one graph state in the next graph state? We are less interested in: Where do customers of one graph state come from?

\(^2\)This sub-assortment*brand combination contains uninteresting items like plastic bags.

\(^3\)In \( KhK \)-graphs \( d \) is equal to the number of sub-assortment*brand combinations, which is \( \square \).
3.3 Time-Dependent Clusterings

Figure 3.6: Best Match Clusters.
to compare a certain cluster of one clustering to the clusters of another clustering. More precisely, $\text{bestCD}$ determines the cluster $C_j$ of a clustering $C'$ with the minimum centroid distance to cluster $C_i$ (of another clustering $C$). Let $\vec{c}$ and $\vec{z}$ be the centroid vectors of clusters $C_i$ and $C_j$ with $C_j \in C'$. Equation 3.9 shows, how the $\text{bestCD}$ cluster $C_j$ of cluster $C_i$ is determined.

$$\text{cd}(\vec{c}, \vec{z}) = \|\vec{c} - \vec{z}\|_2 = \sqrt{\sum_{i=1}^{n} (c_i^2 - z_i^2)^2} \quad (3.8)$$

$$\text{bestCD}(C_i, C') = \min_{C_j \in C'} (\text{cd}(\vec{c}, \vec{z})) \quad (3.9)$$

**Avgdist**

Avgdist measures the average distance of a cluster’s customer vectors to their centroid vector. In Equation 3.10 the formula of avgdist is expressed without a square root, because we want to uprate outliers. Even without the root the formula remains monotone. Avgdist indicates the similarity and closeness of the customer vectors to their centroid vector. If two clusters are considered similar regarding their low cd value, avgdist can be an additional instrument to further confirm or reject their similarity. The similarity is weak, if the avgdist value of one cluster $C_i$ is much bigger than the avgdist value of another cluster $C_j$. Because then the customer vectors of cluster $C_j$ are on average much closer to their centroid value than the customer vectors of cluster $C_i$ to their centroid vector. So, the centroid vectors are just incidentally similar, but the actual customer vectors of both clusters are not. Note that avgdist is no sufficient comparison measurements for clusters. The avgdist values of two clusters can be equal or quite similar although the clusters are not similar.

$$\text{avgdist}(C) = \frac{\sum_{j=1}^{n} \left( \sum_{i=1}^{m} \left( \vec{k}_{i,j} - \vec{c}_i \right)^2 \right)}{n} \quad (3.10)$$
Chapter 4

Experiments

The main focus of this work is on the detection of meaningful customer profiles. We try to find groups of customers that are characterized by a certain, easily recognizable purchase behavior. Therefore, we successively analyze the three different graph types introduced in Section 2.4. We want to find appropriate parameters yielding customer groups that are consistent with experts' opinions. Note that those graph types are part of a long progress and that one graph type evolves from the insights gained from another graph type.

Our basic procedure is illustrated in Figure 4.1. It consists of two parts. In the first part, we try to find a promising graph model and promising settings. In the second part, we try to filter out stable clusters\(^1\), that can then be imported into the data mining component of ToolA\(^2\) via PMML (Chapter 5). Part one is divided into a design phase, an implementation phase and an experiment phase. The selection of a graph model happens in the design phase. Note that we commit ourselves to the Jaccard similarity coefficient and the Greedy Modularity Clustering algorithm, described and justified in Sections 2.2.6 and 3.2.1. The next phase consists of implementing these concepts. The implementation is done in Java. Based on the particular graph model, selected in the design phase, we implement and adjust a framework that provides the possibility to generate and cluster series of graphs, each with different settings. The experiment phase can be repeated several times for the same graph type. During each repetition, the settings are modified or techniques like sampling or elimination are applied.

If the experiments do not give satisfying results, we identify the reasons for this, return to the design phase and choose a different graph model. In case we find a promising graph type and promising settings, we continue with part two of our procedure. In this part, based on the clusterings constructed in part one, we try to identify stable customer clusters using Bestmatch and BestCD calculations (3.3.2). If these calculations do not return good enough values and we find out why, we return to the experiment phase of part one, modify certain parameters and again calculate the match and cd values.

---

\(^1\)Bigger clusters that are no incidental result, but occur in several graph states. For further explanation have a look at Section 3.3.

\(^2\)A business intelligence, enterprise reporting, and OLAP software suite employed by dm.
Eventually, we back up our results. To this end, we try to extract the detected stable clusters from the data of two other stores using the same means. The final stable clusters are then transformed into PMML and later imported into the data mining component of ToolA.

The huge amount of dm source data (1.2) forces us to considerable reductions during the algorithm engineering process. When the process is established, we can work with larger mounds of data.

First, we restrict our data to store 242. This store is located in a shopping center in downtown Munich and is, due to a sales area of 586 sqm, one of the bigger dm stores. We choose to start with this store, because it has one of the highest sales of all German dm stores.

Figure 4.1: The basic procedure of our experiments.
4.1 KAK-Graphs – [Item-Level]

First, we analyze the KAK-graph model, introduced in Section 2.4.1. Remember that our main objective is to find customer groups that reflect the different purchase behaviors of the \( dm \) customer base. So we start with the model that contains the most detailed information about the purchases. In the KAK-graph model, similarities are calculated using the purchased items of the customers. The items are not merged like in the KMK- or KhK-graphs.

4.1.1 I. Attempt: Time-Expanded Graph

For our first experiment, we implemented the time-expanded graph. Figure 4.2 shows our tool for generating graphs developed by us and reveals that we allowed several degrees of freedom concerning the graph generation, like the graph model or the minimum edge weight. Two of them regard the time-expanded graph generation: We can adjust the number of graph states and we can select one out of three methods to calculate the weights of the inter-time edges. But we only allow directly sequenced graph states to be bridged by inter-time edges, i.e., no inter-time edge spans three or more states.

Our first generated KAK-graph is a time-expanded graph with four different graph states of the months November 2004, December 2004, January 2005 and February 2005. Simple Jaccard is used to calculate the weights of the inter-time edges and the minimum edge weight of the intra-graph edges is set to 0.1. Figure 4.3 shows this graph after the Greedy Modularity Clustering algorithm was applied. Note that the colors of the vertices represent the customers’ age ranges (Table 4.1). No color means that the customer’s age is not specified. As can be seen in Table 4.2, the clustering has a high quality.

To be able to identify the purchase behaviors of the single customer clusters, we determine for each cluster the most frequent sub-assortment and the most frequent brand of the collectively bought items. In the case of our clustered time-expanded KAK-graph, the dominant sub-assortments are Cat Food and Baby Food and the dominant brands are \( dm\)-BrandB1 and BrandL1. Dominant means that 23 out of the 41 clusters (56%) are Baby Food/BrandL1 \(^3\) and Cat Food/dm-BrandB1 clusters, including the five biggest clusters. Interestingly, a high brand loyalty among Cat Food and Baby Food customers becomes apparent. For instance, in the five biggest clusters the respective percentage of those brands that are most frequently bought by their customers ranges from 70% to 91%.

Figure 4.4 shows the 12 clusters that are connected via inter-time edges. Only two clusters span more than one graph state. This is partly due to the fact that only few vertices are connected via inter-time edges. This means that the customers of the connected clusters change a lot. Furthermore, many inter-time edge weights are zero. So, the neighborhood of customers that do appear in more than one graph state changes a lot, too. But, although

\(^3\)A cluster is called after the sub-assortment and the brand that contain items collectively bought by most of the cluster’s customers.
the clientele of the clusters changes over the months, we still have one big stable Cat Food cluster and one smaller stable Baby Food cluster that appear in all four graph states. Moreover, there exists one small Dog Food cluster that appears in only two graph states. In summary, this first attempt already yields two stable customer clusters and a high brand loyalty among Cat Food and Baby Food customers. Unfortunately, these two Cat Food and Baby Food clusters are extremely dominant. Potentially, they overshadow other interesting clusters.

Because the KAK-graph of this attempt consists of single months, customers that do not shop every month in the same dm store do not recur in every graph state. This might be a reason for the few inter-time edges and for the dominance of cat food and baby food buyers. For instance, a customer that just buys toothpaste every few months, would not have any influence on the graph's clusters. Therefore, in our next attempt we try to increase the influence of such customers by considering four quarters of a whole year instead of just single months.
Figure 4.3: Clustered time-expanded KAK-graph of the months November 2004, December 2004, January 2005 and February 2005.

<table>
<thead>
<tr>
<th>Vertex Color</th>
<th>Age Range [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue</td>
<td>16 - 19</td>
</tr>
<tr>
<td>turquoise</td>
<td>20 - 34</td>
</tr>
<tr>
<td>green</td>
<td>35 - 49</td>
</tr>
<tr>
<td>yellow</td>
<td>50 - 64</td>
</tr>
<tr>
<td>red</td>
<td>65 - 99</td>
</tr>
</tbody>
</table>

Table 4.1: The colors of the vertices represent the customers’ age ranges. No color means that the customer’s age is not specified.

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$cov_w$</th>
<th>$per$</th>
<th>$sig_{cov,sub}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.98</td>
<td>0.93</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Table 4.2: Quality measurements of clustered Time-Expanded KAK-graph of Figure 4.3.

Figure 4.4: Cluster evolution of the time-expanded KAK-graph of Figure 4.3.
4.1.2 II. Attempt: Quarters

The extremely dominant Cat Food and Baby Food clusters of the first experiment appeared most likely because of the high frequency in which these items are bought. Food is needed daily and mostly bought by the week. So, in the next attempt, we examined the four quarters of an entire year instead of just single months. Consequently, items that are bought every few months, like for example sanitary products, should carry more weight. We generated a time-expanded KAK-Graph consisting of the four quarters of 2005. Simple Jaccard is used for the inter-time edge weights and the minimum intra-graph edge weight is set to 0.175. The clustering of this graph has a high quality again (Table 4.3) and a very clear structure. Once again, the most common clusters are either Baby Food/BrandL1 or Cat Food/dm-BrandB1 clusters (47%). But this time, the Baby Food clusters are very small. Figure 4.5 shows the bigger clusters and clusters that are connected via inter-time edges. We see that there is just one big Cat Food/dm-BrandB1 cluster connected via inter-time edges in every graph state. We call this cluster stable, despite the small splitting-offs. Moreover, there is one mid-size Cat Food/BrandF1 cluster and one big Bath/BrandM1 cluster in the winter quarter. In other words, this attempt yields only one stable Cat Food cluster and many small Baby Food clusters. We assume that there exists more than two different customer groups in the dm customer base. Other customer clusters might exist in addition to or underneath the two Cat Food and Baby Food clusters. So it is likely that either more fine-grained clusters are hidden by the Cat Food and Baby Food clusters or that those two clusters extremely dominate other coexisting clusters.
4.1 *KAK*-Graphs – [Item-Level]

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$cov_w$</th>
<th>$per$</th>
<th>$sig_{cov,sub}$</th>
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<tbody>
<tr>
<td>Quarters</td>
<td>0.99</td>
<td>0.94</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 4.3: Quality measurements of clustered *time-expanded* *KAK*-graph of Figure 4.5.

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$cov_w$</th>
<th>$per$</th>
<th>$sig_{cov,sub}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminations</td>
<td>0.98</td>
<td>0.96</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 4.4: Quality measurements of clustered *time-expanded* *KAK*-graph with eliminations. See Figure 4.6.

### 4.1.3 III. Attempt: Eliminations

The first two experiments yielded a very dominant *Cat Food/dm-BrandB1* cluster that possibly overshadowed other interesting clusters. So the next attempt is the elimination of similarities based on items of this sub-assortment*brand combination. This means that the *Jaccard* similarity value of two customers is calculated using all their bought items, except the *Cat Food/dm-BrandB1* items.

We generated a *time-expanded* *KAK*-Graph of January, February and March 2005. Again, *Simple Jaccard* is used for the inter-time edge weights. The intra-graph edge weights are calculated without considering *Cat Food/dm-BrandB1* items and their minimum weight is set to 0.1. The clustering of this graph has a very high quality (Table 4.4). For instance, a *Coverage* value of 98% means that there are only 2% inter-cluster edges. The graph consists of quite strongly connected components. Note that the *Greedy Modularity Clustering* (3.2.1) algorithm tends to transform these components into clusters with only little regard to the actual edge weights. So more fine-grained clusters inside these components can easily be missed.

As shown in Figure 4.6, the resulting clusters are very small. But, we can still see the *Baby Food/BrandL1* amassment. 10 out of 24 clusters (42%) are *Baby Food/BrandL1* clusters and two *Baby Food/BrandL1* clusters appear in two different graph states. A *Cat Food/BrandF1* cluster and a *Dog Food/dm-BrandB1* cluster are the only two other clusters that are connected via inter-time edges and appear in more than one graph state. So, in this experiment, we received *Baby Food/BrandL1*, *Cat Food* and *dm-BrandB1* clusters. These are all clusters that we have already received in Attempt I and II.

### 4.1.4 Conclusion *KAK*-Graphs

In this section, we tried to find interesting customer clusters in *KAK*-Graphs. For that purpose, we examined three different *time-expanded* clustered *KAK*-Graphs. The first one consisting of four chronologically ordered single months, the second consisting of the four quarters of 2005 and the third one with elimination of *Cat Food/dm-BrandB1* items.
Figure 4.6: Clustered *time-expanded KAK*-graph with *Cat Food/dm-BrandB1* eliminations.
Basically, in all three cases we received stable and very persistent Baby Food and Pet Food clusters. This is due to the specific characteristics of such sub-assortments. Customers usually buy several flavors of the same product at once, because they like their babies or pets to have a variety in their daily food. And they also buy a big amount of these items, because these items are consumed daily. These specific characteristics explain the high edge weights between pet food buyers and between baby food buyers. After having eliminated Cat Food/dm-BrandB1 and Baby Food/BrandL1 items, we could continue with further eliminations. But we expect further eliminations to result in clusters of items that belong to sub-assortments with the above mentioned specific characteristics. An example for another sub-assortment with such specific characteristics is the Bath sub-assortment. Products like shower gel, liquid hand soap or bath salt are also needed daily and their buyers like to try different flavors of the same product.

Note that we are not just interested in frequently bought items, but in frequently and infrequently bought items alike. And, we are definitely not just interested in items of sub-assortments with some specific characteristics. So with the next graph model we try to achieve a more equal consideration of all items and sub-assortments.

4.2 \textit{KMK-Graphs – [Sub-assortment*Brand-Level]}

As a possible remedy to the issues found in the context of the \textit{KAK}-graph, we now evaluate the \textit{KMK}-graph model. As described in Section 2.4.2, the \textit{KMK}-graph model represents the customer–sub-assortment*brand–customer relation. Similarities between customers are no longer calculated using the items a customer bought. They are calculated using the sub-assortment*brand combinations of the items a customer bought. The advantage of using sub-assortment*brand combinations is that sub-assortments and brands do not change a lot over the years while single items have a high fluctuation. Oftentimes new items are included into the assortment or unpopular items are no longer carried.

The \textit{KAK}-graph favors frequently bought items. We hope to remove this disadvantage with the design of the \textit{KMK}-graph. In this graph type binary customer vectors are used and items in the same sub-assortment and of the same brand are merged. So, now frequently and infrequently bought items should have the same influence on the similarity calculation.

4.2.1 \textbf{I. Attempt: One Quarter}

To get a general idea of the clusters that result from this graph type, we first generate a simple (not \textit{time-expanded}) \textit{KMK}-graph consisting of three months. We use a minimum edge weight of 0.2. Figure 4.7 shows the resulting clustered graph. Many of the clusters
are characterized\footnote{A cluster is characterized by the sub-assortment that contains items collectively bought by most of the cluster’s customers.} by sub-assortments like Sonstiges/Te, Kosmetik-Pap, Hygienepapie or Haushaltspap. These sub-assortments contain items like plastic bags, toilet paper, cotton swabs, tissues et cetera. Furthermore, most clusters (62\%) are characterized by dm-owned brands like dm-BrandN1, dm-BrandO1 or dm-BrandK1. These items are bought by most of the dm customers. They are not very suitable to distinguish between certain customer groups.
4.2 KMK-Graphs – [Sub-assortment*Brand-Level]

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$\text{cov}_{w}$</th>
<th>$\text{perc}$</th>
<th>$\text{sig}_{\text{cov,sub}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Attempt</td>
<td>0.97</td>
<td>0.96</td>
<td>0.87</td>
</tr>
<tr>
<td>II. Attempt</td>
<td>0.99</td>
<td>0.95</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 4.5: Quality measurements of the clustered KMK-graphs of Figures 4.7 and 4.8.

<table>
<thead>
<tr>
<th>graph state</th>
<th>average age</th>
<th>female [%]</th>
<th>male [%]</th>
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<tbody>
<tr>
<td>$t_1$</td>
<td>37</td>
<td>87</td>
<td>12</td>
</tr>
<tr>
<td>$t_2$</td>
<td>38</td>
<td>89</td>
<td>10</td>
</tr>
<tr>
<td>$t_3$</td>
<td>37</td>
<td>87</td>
<td>12</td>
</tr>
<tr>
<td>$t_4$</td>
<td>38</td>
<td>86</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 4.6: Age and gender distribution of the colored stable cluster of the time-expanded KMK-graph of Figure 4.8.

4.2.2 II. Attempt: Time-Expanded Graph of Whole Year

Then, we generate a time-expanded KMK-graph consisting of the four quarters of 2005, similar to the time-expanded KAK-graph in Section 4.1.2. The high quality of the clustering of this graph can be seen from Table 4.5. This clustering consists of 754 clusters. Figure 4.8 shows the eight biggest clusters, that are connected via inter-time edges. Remember that the colors of the vertices represent the customers’ age ranges. No color means that the customer’s age is not specified. We can easily recognize two stable clusters that appear in each of the four graph states. All customers of the first stable cluster have specified their age, while the customers of the second stable cluster have not. Table 4.6 shows that the average ages and the percentages of the female and male customers of the first colored stable cluster are almost equal in every single graph state. This indicates the inner homogeneity of the two stable clusters. Seven of the eight shown clusters are characterized by the sub-assortment $\text{Sonstiges/Te}$ and the eighth one by the sub-assortment $\text{Haushaltspap}$. Four clusters feature the brand $\text{dm-BrandN1}$. As already mentioned, these sub-assortments contain items like tissues, plastic bags and toilet paper, that are bought by most of the $\text{dm}$ customers. Besides, the average age of all $\text{dm}$ customers in 2005 was 42 years. In this year, 86% of the $\text{dm}$ customers that specified their gender were female and 13% male. Comparing these facts with the age and gender distribution of the first colored stable cluster (Table 4.6) shows that they are very similar.

In summary, the two stable clusters are characterized by sub-assortments that contain items bought by most of all customers. And additionally, the age and gender distribution of the first colored stable cluster is quite close to the overall age and gender distribution of the $\text{dm}$ customer base. So this experiment yields two average customer profiles.
4.2.3 Conclusion $KMK$-Graphs

In this section, we analyzed two different clustered $KMK$-graphs. The first one consisting of three sequential months and the second, time-expanded one consisting of the four quarters of 2005. Both clusterings mostly contained clusters characterized by sub-assortments and brands that are not appropriate to discriminate between dm customers. Items of these sub-assortments and brands are needed by almost everybody. They are bought additionally to the individual needs and are usually no motive to go to a certain store or to go shopping at all. Furthermore, one of the two stable clusters of the time-expanded clustered $KMK$-graph had a female and male customer proportion similar to the general gender distribution of the dm customer base. The same applied to the average age of this stable clusters’ customers.

So, the $KMK$-graph just partly met our expectations by not favoring very frequently bought items. In exchange of the Baby and Pet Food customer groups resulting from clustered $KAK$-graphs, we received even less interesting average customer groups from clustered $KMK$-graphs.
4.3 *KhK*-Graphs – [Sub-assortment*FavoriteBrand-Level]

Finally, we analyze the *KhK*-graph type. Remember from Section 2.4.3 that the *KhK*-graph model represents customer–most-frequent-brand*sub-assortment–customer relations. A customer is characterized by his most frequently bought brand of each sub-assortment.

In the last two sections, we learned about the *KAK*-graph that it favors frequently bought items and about the *KMK*-graph that its clusters reflect the average *dm* customer. The resulting clusters of both graph types did not turn out to be acceptable and diverse *dm* customer profiles. So, by merging a customer’s bought items, similar to how it is done in the *KMK*-graph, frequently bought items should no longer dominate infrequently bought ones. And, by just considering the customers’ favorite brands, we hope to sharpen the expressiveness of the resulting customer groups by disregarding items that are bought by everybody.

Another advantage of the *KhK*-graph is the possibility of a compressed matrix representation by just memorizing the string value of the favorite brand for each sub-assortment. So, a customer vector just consists of as many dimensions as there are sub-assortments. In the case of the *KMK*-graph the number of dimensions is given by the number of brand*sub-assortment combinations and in the case of the *KAK*-graph it is given by the number of customers (or at least by the number of items). Currently, *dm* has about customers with *PAYBACK* cards, different items and brand*sub-assortment combinations, but only sub-assortments. We found out, that the number of dimensions is crucial for the successful *PMML*-import into the data mining component of *ToolA*.

4.3.1 I. Attempt: Sampling

First, we generate a *KhK*-graph containing the first quarter of 2005. The minimum edge weight is set to 0.2. Figure 4.9 shows the resulting clusters after applying the *Greedy Modularity Clustering* algorithm to this graph. There are three very big clusters with more than 420 customers, one big cluster containing 129 customers and 15 very small clusters with 2 to 10 customers. So, the clusters differ a lot in size. The black beams are edge bundles and stand for the many inter-cluster edges. This clustering has a *Coverage* value of 0.58 (Table 4.7), which means that 42% of all edges are inter-cluster edges. The inferior quality of this clustering is even confirmed by its low *Modularity* value.

One possible reason for this inferior clustering could be the high minimum edge weight of 0.2. The clustering contains 1581 customer vertices which account for only 4% of all customers in this quarter. These customers are selected, because they all have a minimum purchasing similarity value of 20% to at least one other customer, which is quite restrictive.

\footnote{Customer IDs in our data source.}
These selected customers are probably not very representative of the \textit{dm} customer base. A solution to this problem could be \textit{Sampling}. That is, we first sample the customer base and then reduce the minimum edge weight in a way, that the resulting clustering again contains a similar number of customers and a number which our methods in their present form can handle.

So, next we generate a customer sample by selecting those customers of the first quarter of 2008, whose IDs are divisible by 4. Then, we generate a \textit{KhK}-graph, that contains only sampled customers. With a reduced minimum edge weight of 0.05, we receive a clustering containing 1196 customer vertices. As we can see in Figure 4.10, the resulting clustering looks like the clustering without \textit{Sampling} (Figure 4.9). Unexpectedly, its quality is even worse.

The high amount of inter-cluster edges between the four biggest clusters in both clusterings indicates a certain similarity between those clusters and cluster centroids\textsuperscript{6} respectively. A closer examination of the cluster centroids reveals that most of the clusters are extremely dominated by some popular \textit{dm}-owned brands like \textit{dm-BrandK1}, \textit{dm-BrandN1}, \textit{dm-BrandP1}, \textit{dm-BrandQ1}, \textit{dm-BrandD} et cetera\textsuperscript{7}. In other words, these clusterings reflect more or less one big customer profile, namely the \textit{dm} customer. All \textit{dm} customers have the purchase of popular \textit{dm} items in common.

Consequently, we hope to reveal more interesting customer groups underneath this one big \textit{dm} customer group by eliminating the specific popular \textit{dm}-owned brands, considering them as non-discriminative.

\textsuperscript{6}Centroids are explained in Section 3.3.2.
\textsuperscript{7}Table E.1 contains these popular \textit{dm}-owned brands.
4.3 $KhK$-Graphs – [Sub-assortment*FavoriteBrand-Level]

Figure 4.10: Clustered $KhK$-graph containing the first quarter of 2008 with sampling.

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$cov_w$</th>
<th>$per$</th>
<th>$sig_{cov, sub}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>05Q1</td>
<td>0.58</td>
<td>0.73</td>
<td>0.26</td>
</tr>
<tr>
<td>08Q1 with Sampling</td>
<td>0.54</td>
<td>0.67</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 4.7: Quality measurements of clustered $KhK$-graphs of Figures 4.9 and 4.10.
4.3.2 II. Attempt: Eliminations

The last experiment resulted in one big *dm* customer group due to strong similarities between *dm* customers based on popular *dm*-owned brands, which almost everybody seems to buy regularly. So, next we eliminate similarities based on sub-assortment*brand combinations containing popular *dm*-owned brands. This means that a customers favorite brand of every sub-assortment is determined without considering popular *dm*-owned brands. Then the *Jaccard* similarity value of two customers is calculated using their favorite, not (popular) *dm*-owned brands of every sub-assortment.

Figure 4.11 depicts a clustered *KhK*-graph of the first quarter of 2006 with such eliminations. This clustering is a tremendous improvement compared to the clusterings of the first attempt. Table 4.8 highlights the high quality of this clustering. Furthermore, we received several midsize clusters instead of just three to four huge clusters.

So our assumption has been confirmed: The elimination of specific popular *dm*-owned brands yields better clustering results. The dominance of the *dm*-owned brands shows that they are certainly well received by the customer base, but they are also non-discriminatory and they obliterate possible customer profiles.

Since we have found a promising graph type and promising settings, the next step of our basic procedure (Figure 4.1) is to find stable clusters, which can serve as representative *dm* customer profiles.
4.3 KKK-Graphs – [Sub-assortment*FavoriteBrand-Level] 49

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>cov</th>
<th>per</th>
<th>sig_{cov,sub}</th>
</tr>
</thead>
<tbody>
<tr>
<td>06Q1 with Eliminations</td>
<td>0.95</td>
<td>0.97</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Table 4.8: Quality measurements of clustered KKK-graph of Figure 4.11.

4.3.3 Stable Clusters

Now we try to find stable clusters in KKK-graphs, in which popular dm-owned brands are eliminated. Therefore, we compare either the clusters of sequential quarters of the same year, or the clusters of the same quarter of sequential years to each other. We use the comparison measurements Bestmatch and BestCD, introduced in Section 3.3.2. A high match value of two clusters of different quarters means that those two clusters have a lot of customers in common and are therefore similar to each other. A low cd value of two clusters means that the centroids of those clusters are very similar and so the customers of both clusters have similar average buying patterns. To find one stable cluster, means that we have to find the Bestmatch and/or BestCD clusters for a certain cluster in some other quarters with corresponding high match and/or cd values.

First, we analyze the clusters of the fourth quarters of 2004 (04Q4) and 2005 (05Q4). For this purpose, we generate the two corresponding clustered KKK-graphs with a minimum edge weight of 0.05 each and extract those clusters containing more than 9 customers. This threshold is an arbitrary choice from us, but the clusters should not be too small because match and cd values need a certain cluster size to be meaningful. For instance, a match value of 50% of two clusters of the size 2 has a different relevance than the same match value of two clusters of the size 50. It could be a coincidence, if one customer appears in two different clusters. But it is no longer a coincidence if 25 customers appear in two different clusters. The clustered KKK-graph of 04Q4 contains 16 big clusters. Their match values to corresponding Bestmatch clusters range from 2.4% to 8.4% and their cd values to corresponding BestCD clusters range from 0.6 to 1.7. Table 4.9 reveals a correlation between Bestmatch and BestCD clusters for five of the 16 big 04Q4 clusters. The Bestmatch clusters of these five 04Q4 clusters are equal to their BestCD clusters, which strengthens our findings.

Note, that a maximum match value (to the Bestmatch clusters) of 8.4% is not very high, since it means that at most 8.4% of the customers belonging to a 04Q4 cluster are part of the corresponding 05Q4 Bestmatch cluster. But, how many customers of 04Q4 are still customers in 05Q4? The answer is 25%. Although this relativizes the 8.4%, it still means that only a maximum of one-third of all possible customers match. A possible explanation for these poor match values could be the big temporal gap between both clusterings. For this reason, we have a look at the match value of the clusters of two sequential quarters. In the case of the big 06Q3 and 06Q4 clusters, the maximum match values are even worse, scilicet 7.4%. So, the bad match values are not due to the temporal gap.

To get a general idea of these results, we calculate the Bestmatch and BestCD clusters of the four quarters of 2006 (06Q1–06Q4) and the Bestmatch and BestCD clusters of the
fourth quarters of 2004 to 2007 (04Q4–07Q4). To visualize this, we generate Bestmatch- and BestCD-graphs. The vertices of these graphs represent the clusters, the colors of the vertices represent the graph state (year and quarter) and the vertex size represents the size of the cluster. An edge connects a cluster with its Bestmatch (BestCD) cluster of a neighboring state and the edge weight stands for the match (cd) value of both clusters. The basic structure of the Bestmatch-graph is illustrated by Figure 4.12. Figure 4.13 shows the Bestmatch-graph of 06Q1–06Q4. Note that only the mentioned clusters of 06Q3 and 06Q4, illustrated by the yellow and grey clusters, have a maximum match value of 7.4%. The maximum match value of all 2006 quarters is 10.9 %. As can be seen in Figure D.1, the maximum match value of 04Q4–07Q4 is just 8.6%.

We wonder about these low match values. So next, we try to identify the reasons for this. To this end, we only consider customers that appear in all four graph states. Note that those customers are only the regulars and very loyal PAYBACK card users. But they are the only customers, we can make reliable statements about. Thus, we determine the customer intersection of 06Q1, 06Q2, 06Q3 and 06Q4. Then, we generate the corresponding KhK-graphs that contain only customers of the determined intersection. Their minimum edge weights are set to 0.05. Finally, we cluster the four graphs and generate the Bestmatch-graph (4.14). By just considering the regular customers, we achieve a maximum match value of 15.8%. This value is better than before, but still curiously low.

So, we still try to identify the reasons for these relatively low match values. Therefore, we reduce the minimum edge weights of the used KhK-graphs. Note that first we keep only those customers in the KhK-graphs that are contained in the determined customer intersection and then we remove the customers that do not have a minimum purchasing similarity to at least one other customer. So, the lower the minimum edge weight, the more customers of the customer intersection remain in the graphs. Think of a scenario in which a certain customer has irregular buying patterns. He might buy a lot in 06Q1 and 06Q3 and just a few items in 06Q2 and 06Q4. So he potentially has a higher similarity (edge weight) to other customers in 06Q1 and 06Q3 than he has to customers in 06Q2 and 06Q4. If in 06Q1 and 06Q3 his highest edge weight to at least one other customer is above the minimum edge weight and in 06Q2 and 06Q4 it is below it, then reducing the minimum edge weight would increase the match value by this customer. Figure 4.15 shows the Bestmatch-graph equal to the last Bestmatch-graph of Figure 4.14, except that the minimum edge weights of the corresponding KhK-graphs are set to 0.03. The maximum match value of this graph is 39.7% between cluster 12 of 02Q3 and cluster 35 of Q3. This means that almost 40% of the customers of cluster 12⁹ are contained in cluster 35, too.

It would be interesting to find out, if a further reduction of the minimum edge weight would further increase the match values and what the highest reachable match value is. But as already mentioned the reduction of the minimum edge weight yields much bigger improvement.

---

8Of course the match value only increases, if the customer does buy similar items in all four quarters and thus would belong to the same customer profile in all four quarters, which seems likely.

9Generally speaking, it is almost 40% of the customers of cluster 12 or cluster 35, depending on which cluster is the biggest. See Section 3.3.2.
4.3 $KhK$-Graphs – [Sub-assortment*FavoriteBrand-Level]

graphs and during the algorithm engineering process the amount of data we can work with is limited.

To be sure that the single clusterings of the used $KhK$-graphs are still of good quality, we have a look at the quality measurements of one of the clustered graphs. Table 4.10 compares the quality measurements of the clustered $KhK$-graphs of $06Q1$ with mentioned eliminations and customer intersection. The quality measurements of the clustered $KhK$-graph with minimum edge weight of 0.05 are excellent, while the quality measurements of the clustered $KhK$-graph with minimum edge weight of 0.03 are still satisfying. But note that quality measurements depend on the size of the graph. The graph with minimum edge weight of 0.03 contains 4151 vertices and the graph with minimum edge weight of 0.05 contains only 321 vertices. In other words, what we have here is a trade-off between the quality measurements, i.e., the clarity, of the single clusterings and the \textit{match} values of the \textit{Bestmatch} clusters. A low minimum edge weight yields high \textit{match} values, but also lower clustering qualities, as more data means more outliers and more garbage.

Now, that we have stable clusters with good \textit{match} values based on clusterings of satisfying quality, we continue with the analysis of these stable clusters. For that purpose we compare the \textit{Bestmatch}-graph of Figure 4.15 to its corresponding \textit{BestCD}-graph. The cut-out of this graph in Figure 4.16 shows only those stable clusters that are contained in the \textit{Bestmatch}-graph, too. The \textit{cd} values range from 0.22 to 0.67, which is very good. So, with the \textit{Bestmatch}- and the \textit{BestCD}-technique we have extracted four stable clusters. Table 4.11 summarizes the \textit{match} and \textit{cd} values of the found stable clusters. Apparently, the \textit{match} values anti-correlate with the \textit{cd} values in a way that high \textit{match} values come along with low \textit{cd} values.

Next, we analyze the age and gender distribution of our four stable clusters. Table 4.12 reveals that the stable clusters differ significantly in their average ages. The average customer ages of the first stable cluster range from 45.7 to 51.1, in the second stable cluster they range from 39.6 to 41.3, in the third one they range from 35.7 to 36.8 and in the last one they range from 42.7 to 46.5. Unfortunately, the gender distribution is less interesting, except for the fact, that the last two stable clusters have a little higher proportion of men than the first two stable clusters. But at large, the gender distribution is quite similar in all clusters.

Finally, we have a closer look at the purchase behaviors of the stable clusters’ customers. Therefore, we compare the highest and most interesting \textit{centroid} component values of the single clusters for each stable cluster. Remember from Section 3.3.2 that the \textit{centroid} component value of a certain sub-assortment*brand combination reflects the proportion of the cluster’s customers whose favorite brand belongs to this sub-assortment*brand combination. At least this proportion of customers must have bought at least one item in this sub-assortment*brand combination and in the case of the $KhK$-graph, the highest value of one sub-assortment reflects the cluster’s customers favorite brand of this sub-assortment. Tables 4.13, 4.14, 4.15 and 4.16 show the highest and most interesting \textit{centroid} component values for our four stable clusters. An underlined \textit{centroid} component value means that this value is the highest one of this cluster. Mind that regarding the \textit{centroid} component values, the single clusters of the stable clusters have partly the same first ranked sub-
Table 4.9: Clusters of 04Q4 and their corresponding bestmatch and bestCD clusters in 05Q4.

<table>
<thead>
<tr>
<th>Cluster ID</th>
<th>Bestmatch Cluster</th>
<th>match value</th>
<th>BestCD cluster</th>
<th>cd value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>0.083</td>
<td>1</td>
<td>0.603</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>0.035</td>
<td>13</td>
<td>0.934</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>0.084</td>
<td>11</td>
<td>0.908</td>
</tr>
<tr>
<td>16</td>
<td>23</td>
<td>0.076</td>
<td>23</td>
<td>0.818</td>
</tr>
<tr>
<td>17</td>
<td>21</td>
<td>0.044</td>
<td>21</td>
<td>1.188</td>
</tr>
</tbody>
</table>

Table 4.10: Quality measurements of clustered KhK-graphs of 06Q1 with eliminations and customer intersection.

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>covw</th>
<th>per</th>
<th>sig_{cov,sub}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Edge Weight of 0.05</td>
<td>0.95</td>
<td>0.96</td>
<td>0.89</td>
</tr>
<tr>
<td>Minimum Edge Weight of 0.03</td>
<td>0.67</td>
<td>0.86</td>
<td>0.46</td>
</tr>
</tbody>
</table>

assortment*brand combination\textsuperscript{10}, which is a strong and surprisingly positive observation. For instance, in the stable cluster of Table 4.13 three of four single clusters have the highest centroid component value for the sub-assortment*brand combination Kerzen/BrandR1. That applies to two of three single clusters of the stable cluster in Table 4.14 for the sub-assortment*brand combination Sonne/dm-BrandS1 and it applies to two of four single clusters of the customer profiles in Table 4.16 for the sub-assortment*brand combination Hand/dm-green-BrandT1, too. This is even more obvious for the stable cluster in Table 4.15. There, even the order of the top four sub-assortment*brand combinations is almost identical. We name this stable cluster the Baby/Young Families cluster due to the affinity to baby products. Almost 50% of the customers in this cluster buy diapers. The clusters’ relatively young average age of 36.5 is consistent to that. The stable cluster of Table 4.16 gets the label Green Concerns due to the affinity to natural products. In this stable cluster, green brands like dm-green-BrandT1 and green-BrandU1 appear more often. Due to the relatively high average age and the tendency to conservative products, we name the stable cluster of Table 4.13 the Traditional/Premium cluster. Because of its tendency to workaday products, the last stable cluster of Table 4.14 gets the label Mainstream.

In summary, by eliminating popular dm-owned brands, by considering only customers that appear in all four graph states and by reducing the minimum edge weight of the single KhK-graphs from 0.05 to 0.03, we receive, regarding Bestmatch and BestCD, four stable clusters that are based on clusterings of satisfying quality. We label them Traditional/Premium, Mainstream, Baby/Young Families and Green Concerns. Their stability is even confirmed by an interesting age distribution and by in each case individual buying behaviors.

\textsuperscript{10}This first ranked sub-assortment*brand combination of a cluster has the highest centroid component value of all sub-assortment*brand combinations. It is bought by most of the cluster’s customers.
Figure 4.12: Structure of bestmatch-graphs. A node represents a cluster. A cluster is connected with its bestmatch-cluster and an edge weight represents the match value of both clusters.

Figure 4.13: Bestmatch-graph of 2006 (Q1-Q4). The vertex colors represent the single quarters of 2006. Blue represents the quarter 06Q1, green represents the quarter 06Q2, yellow represents the quarter 06Q3 and grey represents the quarter 06Q4.
Figure 4.14: *Bestmatch*-graph of 2006 (Q1-Q4) with customer intersection and a minimum edge weight of 0.05.

Figure 4.15: *Bestmatch*-graph of 2006 (Q1-Q4) with customer intersection and a minimum edge weight of 0.03.
Figure 4.16: *BestCD*-graph of 2006 (Q1-Q4) with customer intersection and a minimum edge weight of 0.03. Only those clusters are included that are also in Figure 4.15.

**Table 4.11:** *Match* and *cd* values of stable clusters as in Figures 4.15 and 4.16.

<table>
<thead>
<tr>
<th>Cluster ID₁</th>
<th>Cluster ID₂</th>
<th><em>match</em> [%]</th>
<th><em>cd</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>39</td>
<td>21.9%</td>
<td>0.41</td>
</tr>
<tr>
<td>39</td>
<td>23</td>
<td>30.3%</td>
<td>0.23</td>
</tr>
<tr>
<td>23</td>
<td>7</td>
<td>22.9%</td>
<td>0.39</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>14.0%</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>24.1%</td>
<td>0.29</td>
</tr>
<tr>
<td>(0)</td>
<td>(7)</td>
<td>(17.9%)</td>
<td>(0.50)</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>36.7%</td>
<td>0.29</td>
</tr>
<tr>
<td>12</td>
<td>35</td>
<td>39.7%</td>
<td>0.23</td>
</tr>
<tr>
<td>35</td>
<td>14</td>
<td>33.7%</td>
<td>0.41</td>
</tr>
<tr>
<td>(13)</td>
<td>(11)</td>
<td>(3.1%)</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>7.0%</td>
<td>0.62</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>4.0%</td>
<td>0.67</td>
</tr>
<tr>
<td>ClusterID</td>
<td>Year/Quarter</td>
<td>avg(Age)</td>
<td>Women [%]</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>31</td>
<td>06Q1</td>
<td>47.4</td>
<td>87.3% (351)</td>
</tr>
<tr>
<td>39</td>
<td>06Q2</td>
<td>51.6</td>
<td>87.5% (448)</td>
</tr>
<tr>
<td>23</td>
<td>06Q3</td>
<td>51.1</td>
<td>89.1% (384)</td>
</tr>
<tr>
<td>7</td>
<td>06Q4</td>
<td>45.7</td>
<td>88.7% (713)</td>
</tr>
<tr>
<td>5</td>
<td>06Q1</td>
<td>40.9</td>
<td>88.9% (296)</td>
</tr>
<tr>
<td>30</td>
<td>06Q2</td>
<td>41.3</td>
<td>90.2% (468)</td>
</tr>
<tr>
<td>0</td>
<td>06Q3</td>
<td>39.6</td>
<td>87.7% (500)</td>
</tr>
<tr>
<td>7</td>
<td>06Q1</td>
<td>35.7</td>
<td>86.5% (244)</td>
</tr>
<tr>
<td>12</td>
<td>06Q2</td>
<td>36.7</td>
<td>82.6% (300)</td>
</tr>
<tr>
<td>35</td>
<td>06Q3</td>
<td>36.6</td>
<td>83.5% (289)</td>
</tr>
<tr>
<td>14</td>
<td>06Q4</td>
<td>36.8</td>
<td>82.8% (322)</td>
</tr>
<tr>
<td>(13)</td>
<td>(06Q1)</td>
<td>(50.7)</td>
<td>(71.4% (15)</td>
</tr>
<tr>
<td>11</td>
<td>06Q2</td>
<td>46.0</td>
<td>86.8% (59)</td>
</tr>
<tr>
<td>20</td>
<td>06Q3</td>
<td>46.5</td>
<td>80.0% (48)</td>
</tr>
<tr>
<td>18</td>
<td>06Q4</td>
<td>42.7</td>
<td>84.0% (121)</td>
</tr>
</tbody>
</table>

Table 4.12: Age and gender distribution of the customer profiles from Figures 4.15 and 4.16. The single customer profiles are separated by double lines. Note that the customer profiles differ significantly in their average ages, but the average ages of the single clusters of a customer profile vary just a little.
Table 4.13: Interesting centroid component values of the Traditional/Premium customer profile from Figures 4.15 and 4.16. An underlined centroid value is the highest one of its cluster.
<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>avgdist</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/06Q1</td>
<td>10.15</td>
<td>Bonbon (40)/BrandC2 (1772) Nassrasur (66)/dm-BrandD2 (218) Sonne (48)/dm-BrandS1 (210)</td>
<td>25.7% 13.4% 9.3%</td>
</tr>
<tr>
<td>30/06Q2</td>
<td>9.56</td>
<td>Bonbon (40)/BrandC2 (1772) Nassrasur (66)/dm-BrandD2 (218) Sonne (48)/dm-BrandS1 (210)</td>
<td>15.0% 14.8% 60.0%</td>
</tr>
<tr>
<td>0/06Q3</td>
<td>9.60</td>
<td>Bonbon (40)/BrandC2 (1772) Nassrasur (66)/dm-BrandD2 (218) Sonne (48)/dm-BrandS1 (210)</td>
<td>20.7% 16.0% 43.3%</td>
</tr>
</tbody>
</table>

Table 4.14: Interesting centroid component values of the Mainstream customer profile from Figures 4.15 and 4.16.

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>avgdist</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/06Q1</td>
<td>9.04</td>
<td>Windeln (27)/BrandE2 (899) Babynahrung (33)/BrandA1 (1846) Babyglasnahr (37)/BrandA1 (1846) Babyglasnahr (37)/BrandL1 (1847)</td>
<td>52.8% (1.) 34.3% (2.) 32.1% (3.) 25.2% (4.)</td>
</tr>
<tr>
<td>12/06Q2</td>
<td>9.57</td>
<td>Windeln (27)/BrandE2 (899) Babynahrung (33)/BrandA1 (1846) Babyglasnahr (37)/BrandA1 (1846) Babyglasnahr (37)/BrandL1 (1847)</td>
<td>49.4% (1.) 28.8% (2.) 28.6% (3.) 20.3% (4.)</td>
</tr>
<tr>
<td>35/06Q3</td>
<td>9.19</td>
<td>Windeln (27)/BrandE2 (899) Babynahrung (33)/BrandA1 (1846) Babyglasnahr (37)/BrandA1 (1846) Babyglasnahr (37)/BrandL1 (1847)</td>
<td>47.5% (1.) 29.5% (3.) 31.8% (2.) 22.0% (4.)</td>
</tr>
<tr>
<td>14/06Q4</td>
<td>9.63</td>
<td>Windeln (27)/BrandE2 (899) Babynahrung (33)/BrandA1 (1846) Babyglasnahr (37)/BrandA1 (1846) Babyglasnahr (37)/BrandL1 (1847)</td>
<td>34.6% (1.) 25.3% (2.) 23.5% (3.) 21.0% (4.)</td>
</tr>
</tbody>
</table>

Table 4.15: Interesting centroid component values of the Baby/Young Families customer profile from Figures 4.15 and 4.16.
Table 4.16: Interesting *centroid* component values of the *Green Concerns* customer profile from Figures 4.15 and 4.16.
4.3.4 Conclusion $KhK$-Graphs

In this section we tried to find meaningful customer profiles in clustered $KhK$-graphs. First, we generated and clustered a $KhK$-graph of 05Q1 with a minimum edge weight of 0.2. The resulting clustering of this graph was of inferior quality. We tried to find the reasons for this. So first we tried to improve the representativeness of the graphs’ customers. To this end, we generated a customer sample and reduced the minimum edge weight to 0.05. Unexpectedly, applying the sampling technique did not yield a higher quality of the resulting clustering. A closer examination of the centroids of the three to four biggest clusters revealed that they were all extremely dominated by popular dm-owned brands and thus represented one big dm customer profile. So, next we eliminated similarities based on sub-assortment*brand combinations containing popular dm-owned brands. The quality of the resulting clustering was excellent, so we continued to search for stable clusters in clustered $KhK$-graphs with such eliminations. Figure 4.17 summarizes the procedure of the extraction of stable clusters. The 06Q1–06Q4 $KhK$-graphs based on the customer intersection of 2006 with a minimum edge weight of 0.03 yielded four clusters that were stable with respect to Bestmatch and BestCD calculations. We labeled them Traditional/Premium, Mainstream, Baby/Young Families and Green Concerns based on the sub-assortment*brand combinations of their highest centroid component values. To some extent, their unique age distribution confirmed the stability of the clusters as well as their labels.

In the next sections, we try to confirm our results by extracting similar customer profiles out of analogous $KhK$-graphs based on the source data of two other dm stores.

4.4 Second Store

In this section, we analyze the source data of the dm store 518. This store differs from the previous store in location and sales area. While the previous store has a sales area of 586 sqm and is located in a Munich shopping center, this store has a much bigger sales area of 679 sqm and is located in Karlsruhe in a small industrial area close to a residential area. Nearby are several supermarkets, a home improvement store and a pet food store, all with big parking lots. So people drive to this area, to run several errands at once.

4.4.1 $KhK$-Graphs – [Sub-assortment*FavoriteBrand-Level]

First, we cluster the $KhK$-graph of 06Q1 (Figure 4.18). Analog to the corresponding $KhK$-graph of the previous store, we receive three huge clusters containing 1068, 783 and 238 customers and eleven small clusters containing 2 to 14 customers. Accordingly, the clustering’s quality is unsatisfying (Table 4.17). The table of Section F.1 shows the sub-assortment*brand combinations with the highest centroid component values of the three biggest clusters (4, 6 and 9). We see that the huge clusters of this $KhK$-graph are again
Figure 4.17: Stable cluster extraction.
dominated by specific popular \(dm\)-owned brands. So, we again eliminate those brands. The resulting clustered \(KhK\)-graph is shown in Figure 4.19. Instead of three huge clusters we now have several mid-sized clusters. The clustering is of much higher quality than before the elimination (Table 4.17). In other words, the elimination technique takes a positive effect on \(KhK\)-graphs of store 518, too.

### 4.4.2 Stable Clusters

Next, we generate the \(Bestmatch\)- and \(BestCD\)-graphs of \(KhK\)-graphs with \(dm\)-owned brand eliminations. As can be seen in Figures F.1 and F.2 the highest \(match\) value is 20.3% and the \(cd\) values range from 0.63 to 1.86. Remember that the corresponding highest \(match\) value of all 2006 quarters of the previous store was 10.9%. So, here we have double the highest \(match\) value. It is possible that a store inside a shopping center has a higher proportion of occasional customers than a store in the described industrial area. This could explain the difference between both highest \(match\) values.
Figure 4.19: Clustered $KhK$-graph of $06Q1$ with eliminations, store 518.
But 20.3% is still relatively low. Analog to the previous store, we determine the customer intersection of 06Q1, 06Q2, 06Q3 and 06Q4. This means that only regular customers remain in the \( KhK \)-graphs. We again set the minimum edge weights of these graphs to 0.05 and cluster them. Then we generate the Bestmatch-graph (Figure F.3). Now, the highest \( match \) value is 24.1%, which is just slightly better.

We again assume, that the reason for this is the too high minimum edge weight of 0.05. Remember that we first keep the customers of the customer intersection in the four \( KhK \)-graphs and then we remove those customers that do not have a minimum purchasing similarity to at least one other customer. So, we reduce the minimum edge weight to 0.03. The corresponding Bestmatch- and BestCD-graphs are shown in Figures 4.20 and 4.21. We see that now the highest \( match \) value is 48.4%. The \( cd \) values improve, too. They now range from 0.26 to 1.5. Table 4.18 shows, that in contrast to store 242 there is no longer an anti-correlation between the \( match \) values and the \( cd \) values\(^{11}\). Analog to the previous store there is a trade-off between higher \( match \) values and a high clustering quality. As can be seen in Table 4.19, reducing the minimum edge weight does not only yield better \( match \) values, but also a much bigger graph with a poorer clustering quality. Note that though the clustering quality is poorer, it is still sufficiently good.

Next, our expectations are satisfied, because we can confirm the results of store 242. Going over the highest \( centroid \) component values of big clusters that have high enough \( match \) and low enough \( cd \) values to big clusters of other quarters, we discover the same stable customer profiles as in the previous store. But here, only the Baby/Young Families profile spans all four quarters, while the Mainstream profile, the Traditional/Premium profile and the GreenConcerns profile span only two quarters. And the Traditional/Premium profile is, regarding its highest \( centroid \) component values, a mix of typical Traditional/Premium sub-assortment*brand combinations and typical Mainstream sub-assortment*brand combinations.

Some high and interesting \( centroid \) component values are listed in Tables 4.21, 4.22, 4.23 and 4.24. To facilitate comparisons with the customer profiles of the previous store, we list the exact same sub-assortment*brand combinations. The complete lists of the highest \( centroid \) component values of the single clusters can be seen in the appendix (Section F.3). Those complete lists show that our customer profiles definitely consist of profile-specific sub-assortment*brand combinations. For instance, the complete \( centroid \) component value lists of the Baby/Young Families clusters are shown in Sections F.3.3 (Cluster 11), F.3.3 (Cluster 13), F.3.3 (Cluster 24) and F.3.3 (Cluster 2). The sub-assortment*brand combination Baby-Push/BrandG\( G \) has the highest \( centroid \) component value in Clusters 13 and 24, and it has the second highest \( centroid \) component value in Clusters 11 and 2. So, these clusters clearly belong to the customer profile Baby/Young Families. Another observation is that the GreenConcerns customer profile is much clearer now (Table 4.24). For example, the sub-assortment*brand combination Hand/dm-green-BrandT\( 1 \) has the highest \( centroid \) component value of Cluster 7, that is 45.8%.

Table 4.20 contains the age distribution of the four stable clusters. Like in the previous

\(^{11}\)This table contains only the \( match \) and \( cd \) values of the stable clusters.
4.5 Third Store

The \textit{dm} store 22 is analyzed in this section. This store again differs from the two previous stores in location and sales area. It is located in a suburban residential estate of Stuttgart. Due to its sales area of 480 sqm, it is the smallest one of the three stores.
Figure 4.21: *BestCDs* of 2006 (Q1-Q4) with customer intersection and minimum edge weight of 0.03, store 518.

<table>
<thead>
<tr>
<th>Cluster ID&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Cluster ID&lt;sub&gt;2&lt;/sub&gt;</th>
<th>match [%]</th>
<th>cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>4</td>
<td>30.9%</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>37.4%</td>
<td>0.34</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
<td>21.4%</td>
<td>0.77</td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>6.1%</td>
<td>0.71</td>
</tr>
<tr>
<td>12</td>
<td>31</td>
<td>20.1%</td>
<td>0.35</td>
</tr>
<tr>
<td>31</td>
<td>21</td>
<td>20.3%</td>
<td>0.76</td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>38.4%</td>
<td>0.48</td>
</tr>
<tr>
<td>13</td>
<td>24</td>
<td>48.4%</td>
<td>0.26</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>36.5%</td>
<td>0.63</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>7.7%</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Table 4.18: *Match* and *cd* values of stable clusters, store 518

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>cov&lt;sub&gt;u&lt;/sub&gt;</th>
<th>per</th>
<th>sig&lt;sub&gt;cov,sub&lt;/sub&gt;</th>
<th># Cluster</th>
<th># Nodes</th>
<th># Edges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection 0.05</td>
<td>0.73</td>
<td>0.85</td>
<td>0.51</td>
<td>30</td>
<td>351</td>
<td>732</td>
</tr>
<tr>
<td>Intersection 0.03</td>
<td>0.69</td>
<td>0.77</td>
<td>0.34</td>
<td>60</td>
<td>1914</td>
<td>13761</td>
</tr>
</tbody>
</table>

Table 4.19: Quality measurements of clustered *KhK*-graphs of *06Q1* with eliminations, customer intersection and reduced minimum edge weight, store 518.
<table>
<thead>
<tr>
<th>ClusterID</th>
<th>Year/Quarter</th>
<th>avg(Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(41)</td>
<td>(06Q1)</td>
<td>(41.4)</td>
</tr>
<tr>
<td>4</td>
<td>06Q2</td>
<td>41.3</td>
</tr>
<tr>
<td>1</td>
<td>06Q3</td>
<td>40.9</td>
</tr>
<tr>
<td>(21)</td>
<td>(0604)</td>
<td>(41.4)</td>
</tr>
<tr>
<td>(35)</td>
<td>(06Q1)</td>
<td>(40.8)</td>
</tr>
<tr>
<td>12</td>
<td>06Q2</td>
<td>42.2</td>
</tr>
<tr>
<td>31</td>
<td>06Q3</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>06Q1</td>
<td>37.0</td>
</tr>
<tr>
<td>13</td>
<td>06Q2</td>
<td>37.0</td>
</tr>
<tr>
<td>24</td>
<td>06Q3</td>
<td>36.8</td>
</tr>
<tr>
<td>2</td>
<td>0604</td>
<td>36.5</td>
</tr>
<tr>
<td>7</td>
<td>06Q2</td>
<td>41.0</td>
</tr>
<tr>
<td>0</td>
<td>06Q3</td>
<td>41.4</td>
</tr>
</tbody>
</table>

Table 4.20: Age distribution of stable clusters, store 518. Note that the average ages of the single clusters inside each customer profile vary in less than 0.5 years.

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/06Q2</td>
<td>Kerzen (45)/BrandR1 (2075)</td>
<td>6.8%</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>8.2%</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>13.6%</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>12.4%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>12.2%</td>
</tr>
<tr>
<td>31/06Q3</td>
<td>Kerzen (45)/BrandR1 (2075)</td>
<td>28.4%</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>7.7%</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>13.8%</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>14.1%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>14.5%</td>
</tr>
<tr>
<td></td>
<td>Kosmetik-Pap (4)/BrandB2 (1241)</td>
<td>4.6%</td>
</tr>
</tbody>
</table>

Table 4.21: Interesting centroid component values of Traditional/Premium/Mainstream stable cluster, store 518.
<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/06Q2</td>
<td>Bonbon (40)/BrandC2 (1772)</td>
<td>14.8%</td>
</tr>
<tr>
<td></td>
<td>Nassrasur (66)/dm-BrandD2 (218)</td>
<td>17.2%</td>
</tr>
<tr>
<td></td>
<td>Sonne (48)/dm-BrandS1 (210)</td>
<td>39.9% (2.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/06Q3</td>
<td>Bonbon (40)/BrandC2 (1772)</td>
<td>14.7%</td>
</tr>
<tr>
<td></td>
<td>Nassrasur (66)/dm-BrandD2 (218)</td>
<td>19.9%</td>
</tr>
<tr>
<td></td>
<td>Sonne (48)/dm-BrandS1 (210)</td>
<td>28.1%</td>
</tr>
</tbody>
</table>

Table 4.22: Interesting centroid component values of Mainstream stable cluster, store 518.

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/06Q1</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>46.4% (1.)</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>20.3%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>27.4%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/06Q2</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>37.9%</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>17.5%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>21.8%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>17.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/06Q3</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>40.1% (2.)</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>17.1%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>24.8%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>13.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/06Q4</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>29.8%</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>16.3%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>20.8%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Table 4.23: Interesting centroid component values of Baby/Young Families stable cluster, store 518.
<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/06Q2</td>
<td>Bad (54)/dm-green-BrandT1 (201)</td>
<td>37.3% (2.)</td>
</tr>
<tr>
<td></td>
<td>Hand (39)/dm-green-BrandT1 (201)</td>
<td>45.8% (1.)</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/dm-green-BrandT1 (201)</td>
<td>25.4%</td>
</tr>
<tr>
<td></td>
<td>Bodylotion (61)/dm-green-BrandT1 (201)</td>
<td>16.9%</td>
</tr>
<tr>
<td></td>
<td>WPR (15)/BrandF2 (238)</td>
<td>28.8% (4.)</td>
</tr>
<tr>
<td>0/06Q3</td>
<td>Bad (54)/dm-green-BrandT1 (201)</td>
<td>29.5% (2.)</td>
</tr>
<tr>
<td></td>
<td>Hand (39)/dm-green-BrandT1 (201)</td>
<td>26.9% (4.)</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/dm-green-BrandT1 (201)</td>
<td>28.2% (3.)</td>
</tr>
<tr>
<td></td>
<td>Bodylotion (61)/dm-green-BrandT1 (201)</td>
<td>10.3%</td>
</tr>
<tr>
<td></td>
<td>WPR (15)/BrandF2 (238)</td>
<td>21.8%</td>
</tr>
</tbody>
</table>

Table 4.24: Interesting centroid component values of GreenConcerns stable cluster, store 518. The centroid component values are much higher and clearer as in the GreenConcerns profile of the previous store. See Table 4.16

<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>covw</th>
<th>per</th>
<th>sig_{cov,sub}</th>
<th># Cluster</th>
<th># Nodes</th>
<th># Edges</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Eliminations</td>
<td>0.65</td>
<td>0.66</td>
<td>0.24</td>
<td>9</td>
<td>1520</td>
<td>29356</td>
</tr>
<tr>
<td>Eliminations</td>
<td>0.73</td>
<td>0.93</td>
<td>0.61</td>
<td>29</td>
<td>442</td>
<td>823</td>
</tr>
</tbody>
</table>

Table 4.25: Quality measurements of clustered KhK-graphs of 06Q1 with and without eliminations, store 22.

### 4.5.1 KhK-Graphs

First, we have a look at unmodified KhK-graphs of store 22. The clustered KhK-graph of 06Q1 is shown in Figure 4.22. Its structure is reminiscent of the corresponding clustered KhK-graphs of the two previous stores. It consists of three huge clusters containing 633, 564 and 288 customers and six small clusters containing 2 to 9 customers. Table 4.25 shows the clustering’s poor quality. The table of Section G.1 shows that the huge clusters (1, 2 and 5) are again dominated by popular dm-owned brands. So, according to the previous stores we eliminate those brands. As expected the resulting clustered KhK-graph (4.23) has a much better structure and the clustering’s quality (4.25) is much higher. This means that in this store the elimination of specific dm-owned brands improves clusterings of KhK-graphs, too.

### 4.5.2 Stable Clusters

Now, we calculate the Bestmatch and BestCD clusters of KhK-graphs with dm-owned brand eliminations. Here, the highest match value is 11.0% and the cd values range from
1.27 to 1.58. These values are as unsatisfying as the corresponding values of store 242. To remain comparable to the last two stores we continue with the generation of the customer intersection of the four quarters of 2006. We again cluster the four \( KhK \)-graphs whose minimum edge weights are set to 0.05 and whose vertices are contained in the customer intersection. The corresponding \( \text{Bestmatch} \)-graph (Figure G.1) shows, that now the highest \( match \) value is 29.5%. This is a big improvement compared to the 11%. But we consider this highest \( match \) value to be an outlier, because the second highest \( match \) value already is 14%.

Because of the experience gained with the last two stores, we next reduce the minimum edge weight of the four \( KhK \)-graphs from 0.05 to 0.03 and cluster them. Figures 4.24 and 4.25 depict the corresponding \( \text{Bestmatch} \) and \( \text{BestCD} \)-graphs. Now, the highest \( match \) value is 52.7% and the \( cd \) values range from 0.3 to 1.3. So, the procedure of eliminating specific popular \( dm \)-owned brands, generating the customer intersection and reducing the minimum edge weight again yields stable customer clusters with relatively high \( match \) values and relatively low \( cd \) values. Table 4.26 illustrates the trade-off between higher \( match \) values and a high clustering quality. Reducing the minimum edge weight to 0.03 impairs the clustering’s quality, but just to a still acceptable extent.

Fortunately, we can again confirm the results of stores 242 and 518. Inspecting the highest \( centroid \) component values of those big single clusters that have high enough \( match \) and low enough \( cd \) values to other big single clusters, yields a Baby/Young Families customer
Figure 4.23: Clustered $KhK$-graph of $06Q1$ with eliminations, store 22.
profile, that spans three quarters, a Mainstream customer profile, that spans two quarters, and a Traditional/Premium customer profile, that even spans four quarters, see Figures 4.24 and 4.25. We can not assign the GreenConcerns customer profile.

For a better comparison to the previous stores, we list the centroid component values of the same sub-assortment*brand combinations in Tables 4.28, 4.29 and 4.30, except that for the Kerzen sub-assortment of the Traditional/Premium customer profile we list the brand BrandH2. In this store, the brand BrandH2 has 2 to 8 percentage points higher centroid component values than the brand BrandR1 (see Tables of Section G.3.3). In the previous stores, the brand BrandR1 is the most popular brand of the sub-assortment Kerzen in the Traditional/Premium customer profile. Analog to store 242, the combination Sonne/dm-BrandS1 has the highest centroid component value in both single clusters of the Mainstream customer profile. Another observation is that like in store 518 the Baby-Push/BrandG2 combination is among the top two centroid component values in the Baby/Young Families customer profile.

The age distribution of the three stable customer profiles is shown in Table 4.27. The age distribution of this store is similar to that of store 242, except that the average ages of this store are between 3 to 5 years higher. It seems plausible, that the customers’ average ages are higher in a suburban residential estate than in an industrial area or in a downtown shopping center. Once again\textsuperscript{12}, the Traditional/Premium customer profile has the highest average ages (49.7 – 56.6), the average ages of the Mainstream customer profile are in the middle (43.3 – 44.6) and the average ages of the Baby/Young Families customer profile are the lowest (39.6 – 40.0). Note that the average ages of the Baby/Young Families customer profile vary in less than 0.4 years. This further confirms the profile’s stability.

In other words, using the same procedure as in stores 242 and 518 we can confirm three of the four stable customer profiles. Although, all three stores have different sizes and locations.

### 4.6 Comparison on Store-Level

In the last three sections, we identified three to four stable customer profiles in three totally different stores. They were all stable due to their high match and low cd values and partially due to their age distribution. If we compare the customer profiles on store-

\textsuperscript{12}Like in store 242.
4.6 Comparison on Store-Level

Figure 4.24: Best matches of 2006 (Q1-Q4) with customer intersection and minimum edge weight of 0.03, store 22.

Figure 4.25: BestCDs of 2006 (Q1-Q4) with customer intersection and minimum edge weight of 0.03, store 22.
Table 4.27: Age distribution of stable clusters, store 22.

<table>
<thead>
<tr>
<th>ClusterID</th>
<th>Year/Quarter</th>
<th>avg(Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>06Q1</td>
<td>39.6</td>
</tr>
<tr>
<td>10</td>
<td>06Q2</td>
<td>40.0</td>
</tr>
<tr>
<td>23</td>
<td>06Q3</td>
<td>40.0</td>
</tr>
<tr>
<td>(15)</td>
<td>(06Q1)</td>
<td>(48.6)</td>
</tr>
<tr>
<td>6</td>
<td>06Q2</td>
<td>44.6</td>
</tr>
<tr>
<td>5</td>
<td>06Q3</td>
<td>43.3</td>
</tr>
<tr>
<td>12</td>
<td>06Q1</td>
<td>49.7</td>
</tr>
<tr>
<td>8</td>
<td>06Q2</td>
<td>54.4</td>
</tr>
<tr>
<td>2</td>
<td>06Q3</td>
<td>52.7</td>
</tr>
<tr>
<td>9</td>
<td>06Q4</td>
<td>56.6</td>
</tr>
</tbody>
</table>

level, we can see that their sub-assortment*brand combinations with the highest centroid component values mostly match and that partially their age distributions match, too. But we still wonder, if those profiles are really similar to each other. On store-level, calculating the Bestmatch clusters would not make any sense, because the stores have totally disjoint customer sets. However, calculating the BestCD clusters is practicable. Figure 4.26 shows the single clusters of the customer profiles Traditional/Premium, Mainstream and Baby/Young Families of store 242 and their corresponding BestCD clusters in store 22. Fortunately, in all four quarters each considered single cluster of store 242 and its BestCD cluster of store 22 both belong to the same customer profile. Furthermore, the cd values range from 0.35 to 0.79, which means that their centroid vectors are relatively similar, too. Note that the cd values of the Traditional/Premium clusters range from 0.37 to 0.44 and the cd values of the Mainstream clusters range from 0.35 to 0.42 while the cd values of the Baby/Young Families clusters range from 0.67 to 0.79. The higher cd values of the Baby/Young Families clusters can be explained by the slightly different assortments of stores 242 and 22. For instance, store 22 sells products of the sub-assortment*brand combination Baby-Push/BrandG2 and store 242 does not. In 06Q1 of store 22, this sub-assortment*brand combination even has the highest centroid component value of cluster 4 (48%). This huge difference of both centroids in the centroid component value of this sub-assortment*brand combination accounts for the higher cd value range of the Baby/Young Families clusters. So, if we compare customer profiles of different stores to each other, we should keep in mind that their assortments can be slightly different. It is better to compare either just stores with very similar assortments to each other or exclude the assortments’ differences from the comparison.

Analog to the comparison of stores 242 and 22, Figure 4.27 shows the clusters of customer profiles and their BestCD clusters for the stores 518 and 22. Here, each cluster and its BestCD cluster both belong to the same customer profile, too. Their cd values range from 0.57 to 0.9.
4.6 Comparison on Store-Level

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/06Q1</td>
<td>Kerzen (45)/BrandH2 (2076)</td>
<td>9.3%</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>16.9% (1.)</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>14.7%</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>13.9%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>8.5%</td>
</tr>
<tr>
<td></td>
<td>Kosmetik-Pap (4)/BrandB2 (1241)</td>
<td>14.8% (4.)</td>
</tr>
<tr>
<td>8/06Q2</td>
<td>Kerzen (45)/BrandH2 (2076)</td>
<td>5.7%</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>17.3% (4.)</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>19.3% (3.)</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>16.9%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>14.9%</td>
</tr>
<tr>
<td></td>
<td>Kosmetik-Pap (4)/BrandB2 (1241)</td>
<td>12.2%</td>
</tr>
<tr>
<td>2/06Q3</td>
<td>Kerzen (45)/BrandH2 (2076)</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>15.9%</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>18.0%</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>13.2%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>11.5%</td>
</tr>
<tr>
<td></td>
<td>Kosmetik-Pap (4)/BrandB2 (1241)</td>
<td>8.6%</td>
</tr>
<tr>
<td>9/06Q4</td>
<td>Kerzen (45)/BrandH2 (2076)</td>
<td>18.0% (3.)</td>
</tr>
<tr>
<td></td>
<td>Filter&amp;Folien (56)/BrandX1 (1243)</td>
<td>14.0% (4.)</td>
</tr>
<tr>
<td></td>
<td>Haushaltspap (6)/BrandY1 (1265)</td>
<td>11.4%</td>
</tr>
<tr>
<td></td>
<td>Haarpflege (5)/BrandZ1 (33)</td>
<td>7.8%</td>
</tr>
<tr>
<td></td>
<td>Damenhygiene (3)/BrandA2 (2191)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kosmetik-Pap (4)/BrandB2 (1241)</td>
<td>6.6%</td>
</tr>
</tbody>
</table>

Table 4.28: Interesting centroid component values of Traditional/Premium stable cluster, store 22.

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/06Q2</td>
<td>Bonbon (40)/BrandC2 (1772)</td>
<td>13.8%</td>
</tr>
<tr>
<td></td>
<td>Nassrassur (66)/dm-BrandD2 (218)</td>
<td>20.0%</td>
</tr>
<tr>
<td></td>
<td>Sonne (48)/dm-BrandS1 (210)</td>
<td>41.2% (1.)</td>
</tr>
<tr>
<td>5/06Q3</td>
<td>Bonbon (40)/BrandC2 (1772)</td>
<td>18.3%</td>
</tr>
<tr>
<td></td>
<td>Nassrassur (66)/dm-BrandD2 (218)</td>
<td>22.3% (4.)</td>
</tr>
<tr>
<td></td>
<td>Sonne (48)/dm-BrandS1 (210)</td>
<td>39.6% (1.)</td>
</tr>
</tbody>
</table>

Table 4.29: Interesting centroid component values of Mainstream stable cluster, store 22.
Table 4.30: Interesting centroid component values of Baby/Young Families stable cluster, store 22.

<table>
<thead>
<tr>
<th>ClusterID/YearQuarter</th>
<th>Sub-assortment/Brand</th>
<th>Centroid Value [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/06Q1</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>33.8% (3.)</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>18.1%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>20.0%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>16.1%</td>
</tr>
<tr>
<td>10/06Q2</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>37.3%</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>16.2%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>24.5% (3.)</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>14.8%</td>
</tr>
<tr>
<td>23/06Q3</td>
<td>Windeln (27)/BrandE2 (899)</td>
<td>32.3% (2.)</td>
</tr>
<tr>
<td></td>
<td>Babynahrung (33)/BrandA1 (1846)</td>
<td>14.6%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandA1 (1846)</td>
<td>17.1%</td>
</tr>
<tr>
<td></td>
<td>Babyglasnahr (37)/BrandL1 (1847)</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Again we find our results corroborated: All three customer profiles are not only stable due to Bestmatch and BestCD calculations and age distributions of different quarters in the same store, but also due to BestCD calculations of the same quarters in different stores. So the comparison of our extracted customer profiles on store-level further confirms the stabilities of those profiles.
Figure 4.27: Centroid distances of clusters from stores 518 and 22. The blue vertices represent single clusters of store 518 and the green vertices represent single clusters of store 22.
Chapter 5

PMML

The Predictive Model Markup Language (PMML) is an XML-based markup language. It is used to describe data mining models like for example clustering models. PMML is developed and maintained by the Data Mining Group (DMG) (Gro). It offers a vendor-independent way to interchange data mining models for applications. So a user can develop a data mining model with one vendor’s application, and use another vendor’s application to further work with the model without having to deal with compatibility issues.

We use PMML to import our graph clustering results into the data mining component of the ToolA \(^1\) software suite employed by \(dm\). With this tool \(dm\) experts can easily classify customers based on their purchasing history (customer vector) in one of our clustering model’s customer profiles.

A PMML document consists of three basic components. The header component contains document information like for example the model’s copyright. The data dictionary component defines all the attributes (data fields) that are used by the model. It contains information about the attributes’ data types, their value ranges and their optypes\(^2\). The model component defines the data mining model, which in our case is a clustering model.

```xml
<?xml version="1.0"?>
<PMML version="3.2" xmlns="http://www.dmg.org/PMML-3_2">

  <Header copyright="dmg.org"/>
  <DataDictionary> ... </DataDictionary>
  <ClusteringModel ..> ... </ClusteringModel>

</PMML>
```

A clustering model can either be center-based or distribution-based. It contains the following sub-components:

\(^1\)A business intelligence, enterprise reporting, and OLAP software.
\(^2\)Continuous, categorical, or ordinal.
mining schema which lists the attributes used in the model,

comparison measure which can either be a distance or a similarity measure,

clustering fields which are the centroid vector components and have to be consistent with the attribute names defined in the data dictionary,

center fields which contains normalizations of the centroid vector fields and

clusters which are the centroid vectors of the model’s clusters.

Note that the normalization of the centroid vector fields is mostly used to map categorical input fields to numeric values. Thus, categorical fields are split into multiple dummy fields.

The following PMML example contains a clustering model that classifies people due to their education and gender. It is part of an example presented at a data mining workshop (MG08) hosted by ToolA.

```xml
<?xml version="1.0"?>
<PMML version="3.2" xmlns="http://www.dmg.org/PMML-3_2">
  <Header copyright="Copyright (c) 2008 by Microstrategy, Inc."/>
  <DataDictionary numberOfFields="2">
    <DataField dataType="string" optype="categorical" name="Education">
      <Value value="Graduate"/>
      <Value value="High School"/>
      <Value value="Other"/>
      <Value value="Undergraduate"/>
    </DataField>
    <DataField dataType="string" optype="categorical" name="Gender">
      <Value value="Female"/>
      <Value value="Male"/>
    </DataField>
  </DataDictionary>
  <ClusteringModel numberOfClusters="2" modelClass="centerBased" modelName="CustomerProfiles">
    <MiningSchema>
      <MiningField name="Education"/>
      <MiningField name="Gender"/>
    </MiningSchema>
    <ComparisonMeasure kind="distance">
      <squaredEuclidean/>
    </ComparisonMeasure>
    <ClusteringField field="Education" compareFunction="absDiff"/>
    <ClusteringField field="Gender" compareFunction="absDiff"/>
    <CenterFields>
      <DerivedField dataType="double" optype="continuous" name="Education=Graduate">
        <NormDiscrete field="Education" value="Graduate"/>
      </DerivedField>
      <DerivedField dataType="double" optype="continuous" name="Education=High School">
        <NormDiscrete field="Education" value="High School"/>
      </DerivedField>
      <DerivedField dataType="double" optype="continuous" name="Education=Other">
        <NormDiscrete field="Education" value="Other"/>
      </DerivedField>
      <DerivedField dataType="double" optype="continuous" name="Education=Undergraduate">
        <NormDiscrete field="Education" value="Undergraduate"/>
      </DerivedField>
      <DerivedField dataType="double" optype="continuous" name="Gender=Female">
        <NormDiscrete field="Gender" value="Female"/>
      </DerivedField>
      <DerivedField dataType="double" optype="continuous" name="Gender=Male">
        <NormDiscrete field="Gender" value="Male"/>
      </DerivedField>
    </CenterFields>
    <Cluster name="Cluster 1">
      <Array n="6" type="real">0.219563 0.412071 0.086384 0.281998 0.44641 0.55359</Array>
    </Cluster>
  </ClusteringModel>
</PMML>
The data dictionary component describes the two categorical attributes education and gender. For instance, the categorical attribute gender has the data type string and can take the values Female or Male. This clustering model is center-based and uses all the attributes defined in the data dictionary. The comparison measure of this model is the Euclidean distance. Each person is described by a binary vector with six vector components. The cluster centroids are calculated by the component-wise average of the people vectors. Note that in this example everybody takes a value for every attribute. So the sum of all centroid vector components that belong to one attribute is 1.

Next, we describe the PMML document’s basic layout of our clustering results. As already mentioned, the data dictionary component of every PMML document defines the attributes used by the model. In the case of the clustered KhK-graph the attributes are the 121 sub-assortments and the attributes’ values are the brands of the sub-assortments. So, for instance the data field of the attribute Babynahrung has the following structure:

```xml
<DataDictionary numberOfFields="121">
  ....
  <DataField dataType="string" optype="categorical" name="Babynahrung">
    <Value value="?"/>
    <Value value="BrandA1"/>
    <Value value="BrandU1"/>
    <Value value="BrandV1"/>
    <Value value="BrandW1"/>
    <Value value="dm-BrandQ1"/>
    <Value value="BrandL1"/>
  ....
</DataField>
  ....
</DataDictionary>
```

The mining schema sub-component lists all sub-assortments:

```xml
<MiningSchema>
  ....
  <MiningField name="Baby-Pull"/>
  <MiningField name="Baby-Push"/>
  <MiningField name="Babyglasnahr"/>
  <MiningField name="Babynahrung"/>
  ....
</MiningSchema>
```
The clustering fields are the centroid vector components and contain the sub-assortments, too:

```
<ClusteringField field="Baby-Pull" compareFunction="absDiff"/>
<ClusteringField field="Baby-Push" compareFunction="absDiff"/>
<ClusteringField field="Babyglasnahr" compareFunction="absDiff"/>
<ClusteringField field="Babynahrung" compareFunction="absDiff"/>
```

Like in the previous example, our clustering model is center-based and the model’s comparison measure is the Euclidean distance. Due to the mapping of categorical input fields to numeric values, the categorical sub-assortment attributes are split into sub-assortments*brand combination fields. So, there are center fields like the following:

```
<CenterFields>
  ...
  <DerivedField dataType="double" optype="continuous" name="c82" >
    <NormDiscrete field="Babynahrung" value="?" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c84" >
    <NormDiscrete field="Babynahrung" value="BrandA1" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c86" >
    <NormDiscrete field="Babynahrung" value="BrandU1" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c89" >
    <NormDiscrete field="Babynahrung" value="BrandV1" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c90" >
    <NormDiscrete field="Babynahrung" value="BrandW1" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c91" >
    <NormDiscrete field="Babynahrung" value="dm-BrandQ1" />
  </DerivedField>
  <DerivedField dataType="double" optype="continuous" name="c95" >
    <NormDiscrete field="Babynahrung" value="BrandL1" />
  </DerivedField>
  ...
</CenterFields>
```

Analog to Section 3.3.2, the single customer vector is binary, consists of components and has at most one '1' per sub-assortment (that stands for the customer’s favorite brand). The centroid vector of a certain cluster is the average customer vector. Note that unlike in the previous example, the sum of all centroid vector components that belong to
one attribute does not have to be 1, because not every customer buys items of all sub-assortments. The sub-component clusters, that contains those centroid vectors has the following structure:

```xml
<Cluster name="Cluster 0">
  <Array n="# sub-assortment*brand combinations" type="real">0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.025641 0.0 0.025641 0.0 ... 0.0</Array>
</Cluster>
<Cluster name="Cluster 1">
  <Array n="# sub-assortment*brand combinations" type="real">0.0 0.0 0.0 0.0 0.033333 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 ... 0.0</Array>
</Cluster>
...
Chapter 6

Conclusion

The main purpose of this work was a case study of extracting substantiated customer profiles out of loyalty card data of dm customers by means of graph clustering techniques. Roughly speaking, we modeled the data as a network of customers and employed graph clustering methods to find groups of customers with similar purchasing behaviors. We first designed, implemented and analyzed different promising graph models that represent similar shopping behaviors with different strengths and weaknesses. We began with the KAK-graph model which represents the customer–item–customer relation (modeling the similarity on item-level). We analyzed three different time-expanded approaches of this model. We came to the conclusion that the KAK-graph model favors sub-assortments like Pet Food or Baby Food due to their special characteristics: Customers that buy Pet Food or Baby Food products, frequently buy several flavors of the same product at once, which exaggerates ties between such customers. So, we continued with the KMK-graph model, which is not prone to favoring sub-assortments with such characteristics. This model represents the customer–sub-assortment*brand–customer relation. In this graph model, items in the same sub-assortment and of the same brand are merged, and thus an increased edge weight due to several different flavors and many small packages is avoided. For that purpose, binary customer vectors are used. After analyzing different clustered KMK-graphs, we found out that their clusters reflect the average and rather general dm customer. So, compared to KAK-graphs KMK-graphs do not favor very frequently bought items, but on the other hand their clusters are characterized by sub-assortments and brands like those containing items such as plastic bags that are not appropriate to discriminate between dm customers. Thus, we carried on with the analysis of the KhK-graph which represents the customer–sub-assortment*favorite-brand–customer relation. It differs from the KMK-graph in that it just considers the customers’ favorite brands of each sub-assortment. In this way, we wanted to keep the KMK-graph’s advantage of not favoring frequently bought items while trying to sharpen the expressiveness of the resulting customer clusters by ignoring items that are bought by everybody. The first attempts of clustered KhK-graphs yielded four huge unsatisfying customer clusters of very low significance that were very similar to each other. But after examining these huge similar clusters, we found out that they were extremely dominated by specific popular dm-owned brands like e.g. dm-BrandK1
or \textit{dm-BrandN1}. So the four clusters represented one overall \textit{dm} customer profile. We found a solution by eliminating similarities based on sub-assortment*brand combinations containing these brands and received a clustering of high quality that consisted of several meaningful mid-sized clusters.

Having found a promising graph model that yields reasonable clusterings on one probabilistic quarter, we next tried to identify stable customer profiles, that is, customer clusters that verifiably occur at different points in time, using the data from subsequent quarters in a whole year. The similarity of a customer profile’s single clusters was verified by four different comparisons: The single clusters of a customer profile needed to have a similar customer base (high set-\textit{match} values), we required their customers’ buying patterns to be similar (low \textit{centroid} distance values), their customers’ favorite sub-assortment*brand combinations needed to be alike (similar highest \textit{centroid} vector components) and their customers’ age distribution needed to be revealing (small variance of average ages). After calculating the customer intersection of the four quarters of 2006 and reducing the minimum required edge weight (i.e., similarity) for a customer to participate, we finally received the four stable customer profiles \textit{Traditional/Premium}, \textit{Mainstream}, \textit{Baby/Young Families} and \textit{GreenConcerns}.

To this point our results were based on the data of a single store. We confirmed our findings with a final test which broadened the set of data we base our results on. We tried to extract the same customer profiles out of the data of two other, totally different stores and compared those customer profiles on store-level. We attained the same results with the same success by using the same techniques!

On our journey through different models and approaches, we attained a number of secondary results, e.g. the high brand loyalty among \textit{Cat Food} and \textit{Baby Food} customers in the \textit{KAK}-graphs or that some favorite sub-assortment*brand combinations might vary from store to store while still being very closely related, but nevertheless remain specific to a certain profile\textsuperscript{1}.

We developed several software tools during our process of extracting customer profiles, e.g. for the \textit{time-expanded} graph generation, for the generation of \textit{KMK}- and \textit{KhK}-graphs and for the analysis and comparison of single clusters.

Experts of \textit{dm} corroborated the value of this work. They examined our results and came, among others, to the following conclusion: The biggest benefit lies in the sophisticated and detailed characterization of the customers’ purchasing behaviors. Prior approaches just tried to divide customers into different stereotyped categories, which simplified their purchasing behaviors too much, but they did not consider that even a customer who clearly belongs to a certain category buys most likely small amounts of items that are not category-specific. E.g. a customer who has a baby is not only a parent and thus buys not only baby products. Currently, there is a \textit{dm}-internal project in operation that tries to identify \textit{dm} customer segments. Our results are a valuable contribution to this project.

\textsuperscript{1}Remember the \textit{Kerzen/BrandR1} versus the \textit{Kerzen/BrandH2} sub-assortment*brand combination in the \textit{Traditional/Premium} customer profile or the \textit{Baby-Push/BrandG2} combination of the \textit{Baby/Young Families} customer profile.
6.1 Outlook

The many insights into the buying patterns of dm customers provided by this work revealed some open questions that should be addressed in future work:

1. Are there sub-profiles inside our four stable customer profiles?

   One possible way would be to separately analyze the stable customer profiles by just considering the customer set of one customer profile.
   Another possibility would be to refine the sub-assortment*brand combination. Analyzing sub-sub-assortment* brand combinations might yield interesting sub-profiles.

2. Can further knowledge be gained about the customer profiles by evaluating the \textit{avgdist} comparison measurement for clusters, introduced in Section 3.3.2?

   \textit{Avgdist} measures the average distance of a cluster’s customer vectors to their \textit{centroid} vector. Because this comparison measurement is not sufficient and due to the limited time we did not compare the single clusters of our customer profiles with their \textit{avgdist} values.

3. Are there more systematic ways to determine the sub-assortment*brand combinations that have to be eliminated?

   We assume that those sub-assortment*brand combinations have to be determined manually by \textit{dm} experts who employ background knowledge (and a fair amount of common sense). Because the single sub-assortments differ a lot in size, it would probably make sense to partition the huge sub-assortments.
   An automated procedure to determine the sub-assortment*brand combinations that have to be eliminated is not necessary because the (popular) sub-assortment*brand combinations do not change a lot over the years. It is enough to determine those combinations once and for all.

4. Which customers did we catch and which did we miss?

   Remember that only about 50 percent of \textit{dm} customers have a \textit{PAYBACK} card. Furthermore, we apply several thresholds and some local and temporal restrictions to the data. In what way, if at all, does this bias our results?

6.2 A Brief Note on Two Promising Applications

Although this was no central point of this work, we suggest two different obvious applications for the identified stable customer profiles, and the methods and models developed by us:
1. A customer can be classified into one of the customer profiles. Then the differences of this customer to the profile’s average customers are determined, that is roughly speaking the items which he does not buy but the rest of the profile’s customers does. Then, these items are individually promoted for this customer. The rationale behind this is that the fact that many customers of this profile buy these items encourages the assumption that this customer might also have an inclination to buy these items, but for some reason did not do so, yet.

2. A product launch scenario:
   
   (a) Arrange a test run with some selected stores that sell this product on trial.
   
   (b) Gather all customers that bought this product, calculate their average customer vector and treat this average customer vector as the prototypical buyer of the new product.
   
   (c) When launching the full release in other stores, call the attention of those customers, whose customer vectors resemble the average customer vector, to the new product.
Appendix A

*KAK*-Graph of the *KhK*-Example

![Diagram](image)

Figure A.1: *KAK*-graph of the *KhK*-example.

![Diagram](image)

Figure A.2: Clustered *KAK*-graph of the *KhK*-example with minimum edge weight of 0.3.

![Diagram](image)

Figure A.3: Clustered *KAK*-graph of the *KhK*-example with minimum edge weight of 0.2.
Appendix B

*Time-Expanded* Graph

Figure B.1: *Time-expanded* graph with alpha. See Section 3.3.
Figure B.2: Clustered *time-expanded* graph, alpha. See Section 3.3.
Appendix C

KhK Graphs of Store 242

Figure C.1: Clustered KhK-graph of Q1 2006.
Figure C.2: Clustered $KhK$-graph of $04Q4$ with eliminations.

Figure C.3: Clustered $KhK$-graph of $05Q4$ with eliminations.
Figure C.4: Clustered $KhK$-graph of $06Q4$ with eliminations.

Figure C.5: Clustered $KhK$-graph of $06Q3$ with eliminations.
Figure C.6: Clustered $KhK$-graph of 07Q4 with eliminations.

Figure C.7: Clustered $KhK$-graph of 06Q2 with eliminations.
<table>
<thead>
<tr>
<th>Quality Measurement</th>
<th>$cov_w$</th>
<th>$per$</th>
<th>$stg_{cov,sub}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>06Q1</td>
<td>0.62</td>
<td>0.71</td>
<td>0.27</td>
</tr>
<tr>
<td>04Q4 with Eliminations</td>
<td>0.73</td>
<td>0.92</td>
<td>0.61</td>
</tr>
<tr>
<td>05Q4 with Eliminations</td>
<td>0.71</td>
<td>0.93</td>
<td>0.58</td>
</tr>
<tr>
<td>06Q4 with Eliminations</td>
<td>0.69</td>
<td>0.89</td>
<td>0.49</td>
</tr>
<tr>
<td>06Q3 with Eliminations</td>
<td>0.91</td>
<td>0.97</td>
<td>0.86</td>
</tr>
<tr>
<td>07Q4 with Eliminations</td>
<td>0.68</td>
<td>0.89</td>
<td>0.52</td>
</tr>
<tr>
<td>06Q2 with Eliminations</td>
<td>0.92</td>
<td>0.96</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table C.1: Quality measurements of $KhK$-graphs in store 242.
Appendix D

*Bestmatch*- and *BestCD*-Graphs of Store 242

Figure D.1: *Bestmatch*-graph of Q4 (2004-2007).
Figure D.2: *BestCD*-graph of 2006.
Figure D.3: *BestCD*-graph of Q4 (2004-2007).
Appendix E

Details to Stable Clusters, Store 242

E.1 Eliminated Items in *KhK*-Graphs

Popular *dm*-owned brands:

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\section*{E.2 Centroids of Stable Clusters}

All centroid values greater than 5%.

\subsection*{E.2.1 The Traditional/Premium Cluster}

\textit{06Q1}, Cluster 31

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Details to Stable Clusters, Store 242

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### E.2 Centroids of Stable Clusters

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| 7 | 06Q1 | 0.084639484326019 | 30 | Babypflege | 2067 |
| 7 | 06Q1 | 0.084639484326019 | 3 | Damenhygiene | 2191 | BrandA2 |
| 7 | 06Q1 | 0.0830721003134796 | 11 | Haarstyling | 65 |
| 7 | 06Q1 | 0.0768025078369906 | 40 | Bonbon | 1772 | BrandC2 |
| 7 | 06Q1 | 0.0736677115987461 | 6 | Haushaltspapier | 1265 | BrandY1 |
| 7 | 06Q1 | 0.0721003134796238 | 42 | Mund/Zahn | 32 |
| 7 | 06Q1 | 0.069655172413793 | 42 | Mund/Zahn | 58 |
| 7 | 06Q1 | 0.0673981191222571 | 5 | Haarpflege | 33 | BrandZ1 |
| 7 | 06Q1 | 0.0658307210031348 | 5 | Haarpflege | 257 |
| 7 | 06Q1 | 0.0626959247648903 | 15 | WPR | 238 | BrandF2 |
| 7 | 06Q1 | 0.06128526645768 | 54 | Bad | 257 |
| 7 | 06Q1 | 0.06128526645768 | 53 | Posten/Saiso | -1 | ? |
| 7 | 06Q1 | 0.06128526645768 | 127 | Ebelin Body | 200 |
| 7 | 06Q1 | 0.0579937304075235 | 54 | Bad | 86 |
| 7 | 06Q1 | 0.0579937304075235 | 60 | Gesicht | 176 |
| 7 | 06Q1 | 0.0564263322884013 | 119 | Augen Make up | 29 |
| 7 | 06Q1 | 0.054858934169279 | 18 | Haush.artik. | 1884 |
| 7 | 06Q1 | 0.054858934169279 | 60 | Gesicht | 174 |
| 7 | 06Q1 | 0.0532915360501567 | 51 | Fu | 207 | dm-BrandK1 |
| 7 | 06Q1 | 0.0532915360501567 | 40 | Bonbon | 381 |
| 7 | 06Q1 | 0.0517241379310345 | 15 | WPR | 270 |
| 7 | 06Q1 | 0.0501567398119122 | 57 | Deo | 5 |
| 7 | 06Q1 | 0.0501567398119122 | 40 | Bonbon | 1789 |
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| 7 | 06Q1 | 0.0470219435736677 | 58 | Erlebnis dm | 32 |
| 7 | 06Q1 | 0.0454545454545455 | 33 | Babynahrung | 1856 |
| 7 | 06Q1 | 0.0454545454545455 | 5 | Haarpflege | 66 |
| 7 | 06Q1 | 0.0438871473354232 | 15 | WPR | 221 |
| 7 | 06Q1 | 0.0423197492163009 | 30 | Babypflege | 899 | BrandE2 |
| 7 | 06Q1 | 0.0423197492163009 | 30 | Babypflege | 268 |
| 7 | 06Q1 | 0.0407523510971787 | 15 | WPR | 262 |
| 7 | 06Q1 | 0.0407523510971787 | 4 | Kosmetik-Papier | 1244 | BrandB2 |
| 7 | 06Q1 | 0.0407523510971787 | 48 | Sonne | 210 | dm-BrandS1 |
| 7 | 06Q1 | 0.0407523510971787 | 61 | Bodylotion | 257 |
| 7 | 06Q1 | 0.0407523510971787 | 75 | Reform | 1937 |
| 7 | 06Q1 | 0.0407523510971787 | 40 | Bonbon | 1794 |
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E.2.4 The GreenConcerns Cluster

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### E.2 Centroids of Stable Clusters

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Appendix F

Details to Stable Clusters, Store 518

F.1 \textit{Centroid} values of $KhK$ graph 06Q1

See Section 4.4.1.

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F.2 Bestmatch- and BestCD-graphs of Store 518, with Eliminations

See Section 4.4.2.

Figure F.1: Bestmatch-graph with eliminations, store 518.

F.3 Centroids of Stable Clusters

All centroid values greater than 5%.

F.3.1 The Mainstream Cluster

06Q2, Cluster 4

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F.3 Centroids of Stable Clusters

Figure F.2: BestCD-graph with eliminations, store 518.

Figure F.3: BestMatch-graph with eliminations and customer intersection, store 518.

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#### F.3.2 The Premium/Traditional Cluster

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## Appendix G

### Details to Stable Clusters, Store 22

#### G.1 Centroid values of KhK graph 06Q1

See Section 4.5.1.

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### G.2 Bestmatch- and Best CD-graphs of Store 22, with Eliminations

See Section 4.5.2.

![Graph](image)

Figure G.1: BestMatch-graph with eliminations and customer intersection, store 22.

### G.3 Centroids of Stable Clusters

All centroid values greater than 5%.

#### G.3.1 The Traditional/Premium Cluster

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which develops data mining standards, such as PMML.


