FAKULTÄT FÜR !NFORMATIK
Faculty of Informatics

Interaktive Visualisierung von Medikationsverläufen

Ein Prototyp für die Patientenbehandlung

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieur

im Rahmen des Studiums

Medizinische Informatik

eingereicht von

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Wien, 13. Februar 2018

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FAKULTÄT FÜR !NFORMATIK
Faculty of Informatics

Interactive Visualization of Medication Histories

A prototype for physicians in direct patient care

DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Medical informatics

by

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Vienna, 13th February, 2018

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Fabian Filip

Danksagung

Ich möchte mich bei all jenen bedanken, die mich direkt und indirekt bei der Fertigstellung dieser Masterarbeit unterstützt haben. Besonders hervorheben möchte ich neben meiner Betreuerin Frau Univ.Prof. Mag. Dr. Silvia Miksch hierbei alle Ärzte, die sich Zeit für ausführliche Beratung, Interviews und Feedback genommen haben.
Unbezahlbar war die Unterstützung durch meine Freundin Babsi sowie meine Familie, auf welche ich mich durchgehend verlassen konnte.

Kurzfassung

Immer mehr Krankenhäuser steigen von papierbasierten auf elektronische Patientenakten um, wodurch sich neue Herausforderungen für das Krankenhauspersonal ergeben. Die gewaltige Menge an unterschiedlichen Daten, die Patientenakten enthalten können, kann ÄrztInnen gerade in dem stressigen Arbeitsumfeld eines Krankenhauses schnell überfordern. Dies kann in weiterer Folge dazu führen, dass wichtige Informationen übersehen oder auch falsch interpretiert werden. Medikationsdaten bergen hierbei besondere Gefahren, da Medikationsfehler der Gesundheit der PatientInnen direkt schaden können. Informationsvisualisierung besitzt das Potential, diese Probleme durch kognitive Unterstützung der BenutzerInnen und die Förderung von Einsicht in die Patientenakten bzw. Verständnis der Daten zu lösen.

Die Ziele dieser Diplomarbeit sind, eine entsprechende Visualisierung von patientenbezogenen Medikationsgeschichten für typische Behandlungsszenarien zu entwerfen und einen interaktiven Prototyp zu implementieren. Zu diesem Zweck wurden sowohl Projekte in der Literatur, die sich mit der Visualisierung von Medikationsdaten beschäftigen, als auch der derzeitige Stand der Medikationsdokumentation in österreichischen Krankenhäusern untersucht. Des Weiteren wurden die derzeitigen Anforderungen an die Medikationsdokumentation von Seiten österreichischer ÄrztInnen im Rahmen von qualitativen Interviews erfasst. Dabei konnten wir Potential für Verbesserungen sowohl für die in der Literatur gefundenen Projekte als auch für den derzeitigen Stand in Krankenhäusern aufzeigen.

Basierend auf den gesammelten Informationen wurde eine Liste an Medikationsbezogenen Eigenschaften sowie eine Sammlung von Szenarien und Fragestellungen, die sich im Krankenhausalltag mit Medikationsdaten befassen, erstellt. Weiters, haben wir eine Baumdatenstruktur für Verschreibungs-Listen entworfen, welche eine verdichtende Darstellung von großen Mengen an Verschreibungsdaten ermöglicht, während die detaillierten originalen Daten verfügbar bleiben. Diese Struktur wurde in unserem Visualisierungs-Prototypen, der in Javascript implementiert wurde, umgesetzt. Unserer Evaluierung konnte die Nützlichkeit dieses Prototypen speziell für den niedergelassenen Bereich bestätigen. Abschließend werden in dieser Diplomarbeit weitere Punkte für zukünftige Erweiterungen bzw. Verbesserungen vorgestellt.

Abstract

More and more hospitals have been switching from paper-based patient records to electronic health records within the last years, which introduced new challenges for healthcare professionals. Each electronic record can hold a vast amount of diverse data, which can easily overwhelm a clinician in the stressful environment of a hospital. Consequently, important information can easily be missed or misinterpreted. These effects are especially critical for medication data, as medication errors can harm the treated patient directly. Proper information visualization is able to address these issues by providing cognitive support to healthcare professionals and facilitating insight into health records.

The objectives of this thesis were to design a visualization of patient-specific medication histories and to implement an interactive prototype, which can be used in daily treatment settings. For this purpose, the characteristics and use cases of existing projects addressing visualization of medication data were examined. Both, projects in literature and medication documentation deployed in Austrian hospitals were analyzed. Furthermore, qualitative interviews were conducted with Austrian doctors, in order to assess their current requirements regarding medication documentation. Both areas of examination showed potential for improvement.

Based on the collected information, we created a list of medication characteristics as well as a collection of related scenarios and treatment-related questions. We further designed a tree-data-structure for prescription-lists, which enables condensed visualizations of large amounts of prescriptions while keeping detailed information available. Moreover, this structure was used in our interactive Javascript-prototype. Our Evaluation confirmed the usefulness of this prototype, especially for registered physicians. This thesis also suggests enhancements and improvements for future work.

Contents

Kurzfassung **ix**

Abstract **xi**

Contents **xiii**

1 Introduction **1**
1.1 The challenge of EHRs 1
1.2 Decision making in healthcare 1
1.3 EHR visualizations 2
1.4 Thesis objectives 3
1.5 Thesis structure 4

2 Methodology **5**
2.1 Literature research 5
2.2 Qualitative interviews 6
2.3 Prototype 7
2.4 Evaluation 8

3 Visualization projects for medication histories in literature **9**
3.1 Projects focussing on medication data 9
3.2 Projects focussing on EHR data 17
3.3 Summary 31

4 Medication documentation in Austrian hospitals **35**
4.1 Interviewees and their context 35
4.2 Medication-related scenarios 37
4.3 Visualization tools in Austrian hospitals 40

5 Conceptual Design and Implementation **51**
5.1 Model 51
5.2 Project structure and frameworks 55
5.3 Data-mapping 55
5.4 Graphical User Interface – composition 58

5.5 Interaction 71
5.6 Filters for structuring and highlighting 73
5.7 Summary 75

6 Scenarios **77**
6.1 Scenario A 77
6.2 Scenario B 82

7 Evaluation and discussion of our prototype **87**
7.1 Session 1 87
7.2 Session 2 88
7.3 Discussion 89

8 Conclusion **91**

9 Future work **93**
9.1 Model 93
9.2 Visualization 94
9.3 Interactivity 95
9.4 Evaluation 96

10 Appendix **97**
10.1 Medication Characteristics found in literature 97

List of Figures **101**

List of Tables **103**

Glossary **105**

Acronyms **107**

Bibliography **109**

CHAPTER 1

Introduction

A large number of hospitals have replaced or started to replace their paper-based patient records with Electronic Health Records (EHRs) within the last years [Rind et al., 2013, p. 209]. Additionally, both clinical processes and research rely more and more on these computer based Hospital Information System (HIS), as large amounts of diverse data can be captured within such records [Zillner et al., 2008, p. 296].

1.1 The challenge of EHRs

However, the introduction of EHRs did not necessarily increase quality of care [Rind et al., 2013, p. 209]. Rind, Plaisant et al., An et al., Zillner et al., and others agree that the amount of data is a general issue of such records. While health records of reasonably healthy people tend to be manageable, visualizing EHRs concerning larger timeframes or a lot of events becomes more and more challenging [Plaisant et al., 1998, p. 79]. EHRs of patients with chronic diseases hold vast amounts of data in particular [Pohl et al., 2011, p. 292] which makes direct processing by humans hardly feasible [Combi et al., 2010, p. 1]. Information of a single patient record might be distributed across multiple tables and screens [Rind et al., 2013, p. 214], which is also one of the factors making it difficult to interpret the visualization of a complete EHR [Zillner et al., 2008, p. 296].

1.2 Decision making in healthcare

Despite the large amount of information being a problem for the doctors working with EHRs, they have to take lots of parameters into consideration when deciding on future patient treatment, as they have to select the best option among many alternatives [Bade et al., 2004, p. 105]. For example, patient status, symptoms, as well as medication- and therapy-histories are all relevant factors in clinical decision making [Rind et al., 2013, p. 209]. Not only is decision making highly important in healthcare, many decisions are life-critical [Shneiderman et al., 2013, p. 65]. What's more, these critical decisions are mostly being made under time pressure, thus extensive analyses of EHRs are hardly feasible [Zhu and Cimin, 2015, p. 2]. As working with high quantities of raw data is highly inefficient, appropriate visualizations are required [An et al., 2008, p. 640].

Additionally, also the high dimensionality of EHR-data, as described by Gotzen and Stavropoulos, poses difficulties and needs simplification to enable efficient handling [Gotz and Stavropoulos, 2014, p. 1784]. According to Rind et al. looking for data is sometimes so tedious that users simply give up and cease searching. Thus data stored for documentation purpose might never be read again [Rind et al., 2013, p. 214]. Additionally, it is not sufficient to simply keep the data available, but necessary to also present it in a comprehensible way [Kosara and Miksch, 2002, p. 141].

1.3 EHR visualizations

The problem described above can be addressed with proper Information Visualization (InfoVis), giving healthcare professionals the required cognitive support [Rind et al., 2013, p. 210]. Generally speaking, a major purpose of InfoVis is gaining insight. Visualization enables and supports recognizing patterns, detecting anomalies and relationships by using the strengths of human perception [Yi et al., 2008, p. 1ff]. When adding interaction to data visualizations the benefit for the user can be further improved. As described by Aigner et al. interaction facilitates insight as well as the users' curiosity [Aigner et al., 2011, p. 105]. Overall, visualization and interaction bridge the gap between the users' mental model and the data. This decreases the cognitive load for the user and supports linking real-world knowledge with the presented information [Yi et al., 2008, p. 4].

In order to do so, the task of creating suitable EHR-visualizations has to be split into smaller manageable parts. In this regard, this thesis focuses on developing a proper visualization for medication prescription data and medication histories, as the usefulness of medication-related data is particularly affected by its representation and implies many medication-specific challenges.

While medication data can help doctors to find suitable therapies for their patients [van der Corput, 2013, p. 2], it is common for emergency departments to lack the time to check exhaustive lists of medications [Ozturk et al., 2014, p. 963]. Even more, Rind et al. and Shneiderman et al. point out that poor interaction design can in fact cause medication errors [Shneiderman et al., 2013, p. 65]. Furthermore, insufficient support of medication reconciliation within the HIS might prevent discovering medication errors such as drug duplications, drug interactions, wrong dosages, or omissions [Zhu and Cimin, 2015, p. 2]. Ozturk et al. also mention the challenge of keeping track of the medications' names and their generics [Ozturk et al., 2014, p. 966].

Additionally, Rind et al. state that not only information about the medications themselves is of interest, but also their relation to other patient-specific values, such as test results [Rind et al., 2013, p. 222]. An et al. even emphasise not to separate different kinds of

EHR data during diagnostic tasks but to use integrated visualizations to show the EHR as a whole [An et al., 2008, p. 640].

There is great potential for visualizations addressing these challenges, as visualizations in medical informatics are less developed than within other areas, according to a report from the US Institute of Medicine from 2012 [Rind et al., 2013, p. 210]. A similar picture was drawn by van der Corput, who stated many medication visualizations being simple logs recording doctors, patients, medicines, and medication intervals [van der Corput, 2013, p. 2].

1.4 Thesis objectives

The goal of this project is to develop an interactive visualization prototype for EHR-specific medication histories. The target users are doctors in their daily treatment settings. While other professions are not excluded from the use of the prototype, its development was only aligned to the doctors' requirements regarding patient-treatment to keep the project feasible. The potential for future expansion of the prototype was obtained as well.

In order to achieve the project's goal, the following research questions were investigated:

1. *When are practicing doctors interested in medication-related information and which information is of interest?*

   This leading-question strives to establish the context and use cases for time-oriented medication-based information in the medical domain. What's more, this question focuses the daily work within the scope of patient-treatment rather than data exploration and statistical evaluation for medical studies or the hospital's controlling department. This question goes more into depth, thus also covering prioritization of medication-related information, the minimal data-set expected by clinicians, as well as currently used medication visualizations – if available.

   Literature research and qualitative interviews with practicing doctors were utilized for examination, which is described in more detail within Section 2 - *Methodology*. The goals as well as the target use cases of the prototype were determined by the results of this research question, which can be found in Section 3 as well as Section 4.

2. *Which visualization techniques are suitable for intuitive visualization of time-oriented data?*

   The medical context was deliberately omitted for this question to allow visualization techniques from other fields of research to be taken into account and influence this project. The goal was to form a list of convenient techniques, analyze their pros and cons, as well as their potential to be flexible and intuitive. Based on the collected information, their applicability in the medical domain was assessed. The reasons for our selected techniques are outlined in Section 5.

3. *How can the most promising visualization techniques be combined and applied to patient-specific medication histories to form a flexible, user-friendly overall-view on medication data?*

   The development of the prototype visualization strived to acquire an overall-view on medication histories (see Section 5). Literature, empirical knowledge, and technical limits influenced the concept and the process of development itself.

1.5 Thesis structure

The findings of our literature research regarding the state of the art of medication visualizations (utilized visualization techniques and visualized medication characteristics) are covered in Chapter 3 - *Visualization projects for medication histories in literature*. The collected information was supplemented by the results of our qualitative interviews with practicing doctors (see Chapter 4 - *Medication documentation in Austrian hospitals*) and used as base for the construction of our prototype, which is described in Chapter 5 - *Conceptual Design and Implementation.* The prototype's evaluation can be found in Section 7 - *Evaluation and discussion of our prototype.*Conclusively, Section 8 - *Conclusion* outlines the results of this thesis. Further ideas as well as suggestions for improvements are provided in Section 9 - *Future work.*

CHAPTER 2

Methodology

To achieve the expected results *literature researches*, *qualitative interviews*, the development of a *prototype* and its *evaluation* were utilized:

2.1 Literature research

The literature research aimed at providing information for the first and the second research question. First, the current state of the art regarding visualization of medication histories was assessed. Additionally, we looked for medication-related workflows and prescription handling by healthcare professionals. Second, visualization techniques for time-oriented data were collected and their characteristics as well as their suitability for medication history -visualization were analyzed.

At first, key-words regarding each of the research questions were identified. Based on these key-words search-terms were created and each search-term was used in multiple literature-databases subsequently. The main databases and search-engines utilized were IEEE-Xplore, ACM Digital Library, PubMed, CatalogPlus, and Google-Scholar. However, the results of Google-Scholar were mostly linked to either one of the previously listed databases. Additionally, the references of literature found in those databases were examined for further papers. We attempted to focus on literature explicitly targeting medication data in a hospital care setting, but because of the small amount of such projects, we also included literature targeting medication-related analysis for healthcare and EHR-visualizations in general. Nonetheless, we analyzed and discussed all projects for a clinical inpatient treatment setting where healthcare professionals are interested in the patient's complete treatment history.

2.2 Qualitative interviews

In order to gain insight in currently deployed medication documentation in Austrian hospitals and to understand requirements as well as use cases regarding medication visualizations, we conducted four qualitative interviews with practising doctors. In order to keep the number of use cases small and the use cases of the interviewed doctors similar, only internal specialists were interviewed. This also increases the comparability of the interviewees. The profession "internal specialist" was chosen, as those doctors are expected to have many patients with large medication histories due to chronic diseases (for example, diabetes), thus these doctors should also be interested in a broad overview. Other professions, such as thoracic surgeon, as described by Bui et al., are more interested in a short period of time within the patient record [Bui et al., 2007, p. 463]. The four interviewed doctors work in four different hospitals situated in two different states of Austria. Although these numbers being relatively small, our results are significant, as the equipment of hospitals is mostly regulated by each state in Austria. Consequently, other hospitals in the same state will presumably give similar results regarding currently used visualization systems. The doctor's workflows cannot be generalized this way.

The interviews were prepared and conducted following Witzel's approach to problem oriented interviews. The characteristics of this approach are: The interviews are based on a previously prepared guidance document and have a very communicative character [Witzel, 1985, p. 229]; the interviewer is unprejudiced and well aware of his theoretical pre-knowledge [Witzel, 1985, p. 230f]; the interviews aim to assess individual, subjective activities. The following four tools are used for the execution of the interviews and the subsequent data extraction: A short questionnaire, a guideline, audio recordings, and post-scripts [Witzel, 1985, p. 236].

2.2.1 Short questionnaire

The short questionnaire as suggested by Witzel contains biographic questions and aims to provide a beneficial conversational gambit. In addition, basic information about the working environment of the interviewee was gathered by us.

2.2.2 Guidance document/guidelines

The guidelines help interviewers to organize their background knowledge, serves as aid to orientation and memory. However, according to Witzel, the guidance document is not used for constructing the dialog and determining the flow of the interview. The interviewee's thread of conversation is in focus instead. The interviewer checks the guidelines in his mind during the interview and 'ticks' every fully discussed research question. In case of the conversation stalling, the interviewer can extract substantial suggestions from the guidelines and phrase these ad hoc.

2.2.3 Audio recordings

As designated by Witzel, we recorded the interviews. Later on, the records were transcribed involving elements of non-verbal communication to express the entire situation.

2.2.4 Postscripts

Witzel suggests to produce a postscript directly after each interview, which should assist during interpretation eventually. Each postscript should contain: All non-verbal elements of relevance, characteristic features of the conversation, self-reflection of the interviewer, and characteristic features of the conversation in regard to solving the research questions. Furthermore, no hypotheses are prepared previous to the interviews and the interviewer has to reflect his behaviour continually.

The subsequent points were considered during the selection, phrasing and usage of questions:

- open questions to encourage the interviewee to give wide, descriptive, but problem-focused answers rather than just saying ‘yes’ or ‘no’
- uniqueness of each question (alternative phrasing does not count as unique)
- clarity of each question
- everyday language; simple wording
- adapt choice of words to interviewee
- only non-judgmental questions
- no suggestive questions
- no questions that can trigger feelings of guilt
- minimal affirmations necessary to maintain conversation, but no empathic comments

2.3 Prototype

The visualization prototype is based upon the information collected in the literature researches and the qualitative interviews. It aims at providing medication histories to practicing internal specialist in their daily clinical work. During the period of development our ideas and concepts were conferred informally with some of the interviewed doctors. Their feedback was considered in the further development.

We decided to use HTML, CSS, and Javascript for the prototype, as these enable flexible designs for the user interface, easily adaptable styling, and high levels of control over appearance. Additionally, multiple plugins and frameworks exist which provide further capabilities for developing a basic prototype.

2.4 Evaluation

A basic qualitative evaluation was conducted with three doctors, who have already been involved in the qualitative interviews. First, the participants were introduced to the interface and the concept of the prototype. Second, questions about the visualization were answered and the prototype was discussed. We did not transcribe the evaluation sessions but took notes throughout the discussions. The results of the evaluation can be found in Section 7 - *Evaluation and discussion of our prototype*

CHAPTER 3

Visualization projects for medication histories in literature

Many visualization projects regarding time-oriented data can be found in literature. There are still numerous projects focussing on time-oriented medical data, but only a small number specialized on medication data. The following section outlines these specialized projects as well as some more general EHR-visualizations, as the latter have to handle medication data too. A short description regarding medication-related aspects is provided per project as well as a brief discussion of the visualization. The listed projects are ordered by their focus on medication visualization for healthcare professionals in daily treatment settings.

3.1 Projects focussing on medication data

3.1.1 Timeline [Zhu et al., 2009]

Timeline aims at providing support for medication reconciliation by helping to merge and display medication data. The data originates from both free-text (e.g., notes) and coded sources. The tool parses the medication information and looks up additional metadata. As the name suggest, Timeline utilizes the timeline visualization technique to display the collected data. For each medication the time and duration is shown via the placement on the horizontal time axis and the extent of the respective shape (see Figure 3.1). Dots represent a single time-instance with zero duration, bars also hold information about the duration. The nature of the event is encoded via different colors, for instance, red representing some kind of stop-point. Furthermore, the degree of uncertainty regarding duration-information as well as medication usage (whether the medication is really taken by the patient or not) is visualized. For example, a green colored bar indicates that all information is known. A blue faded end of the bar depicts an unknown end-time of the medication. Zhu et al. designed eight taxonomy groups to convey the information, which aspects (start time, stop time, active usage) of the data are known and which are uncertain/unknown. The medication's name and the dose of a medication unit (e.g., pill) are displayed next to the medication's dot or bar. Additional information is available in the tooltip, which specifies the data source (e.g., "Cerner new pharmacy order") and provides information from the patient's EHR in textual form, for instance, the medication's name, form, unit dose, and the intake schedule. Zhu et al. also allow users to select a point of reference and display "counting bars" which are basically a simple relative timeline. Thus the project provides both an absolute and a relative timeline simultaneously.

Prescriptions are classified as pre-admission, in-hospital, discharge, and allergy medications. Users can also highlight medications by typing the medication class to highlight into one of four provided text-fields which are similar to common search-fields. The respective medications are color-coded accordingly [Zhu et al., 2009].

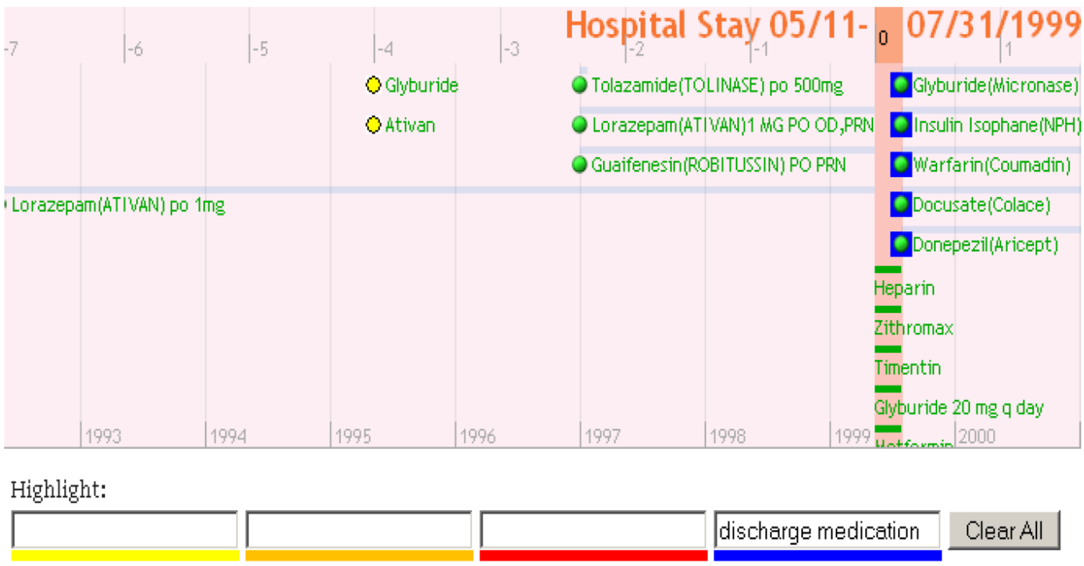

Figure 3.1: Timeline. A screenshot of the Timeline-project [Zhu et al., 2009, p. 4].

Discussion

Zhu et al. created an informative outline of a patient's medication history which especially stands out in displaying the degree of uncertainty per medication entry. Healthcare professionals acknowledged the usefulness of the tool during the initial evaluation done by Zhu et al., however, they also desired additional features, like displaying the medication doses over time, grouping and prioritization regarding data sources or therapeutic classes, and ordering medication entries within a group according to time or risk-level [Zhu et al., 2009, p. 4f].

Zhu and Cimin did a more elaborated evaluation of Timeline as well. During this study Timeline did not replace an EHR-system but was rather used supplementary to the existing system, because the Timeline application only provided medication data. But even when exploring medications, clinicians liked to look at the original text-notes in order to get a better sense of the respective context. Nonetheless, the results of the second evaluation were throughout positive as well [Zhu and Cimin, 2015].

We also noticed from the screenshots provided by the paper [Zhu et al., 2009, p. 4] that medications outside the currently visible time-period are not visible. The user has to zoom-out to ensure no medication is hidden.

- Pro
  - Classification of medications regarding: pre-admission, in-hospital, discharge, and allergy medication
  - Displaying uncertainty
  - Focus on medication data
- Con
  - Some medication data is missing
  - Other EHR data is missing – limited to medication data
  - No Sorting
  - Limited interaction and navigation

3.1.2 Prescription Visualization in Emergency Care [Ozturk et al., 2014]

Ozturk et al. focus on finding prescription information in the database of networked pharmacy benefit managers, creating a well structured timeline chart from all medications active within the last year, and printing this list to be available on paper in the emergency care department. One part of their paper focus on obtaining the data, the other part on visualizing it in an appropriate way.

As pharmacy-managers[1] are the source of information, not the basic prescription data is visualized but the dates of dispensation combined with the duration of the dispensed medicine (see Figure 3.2). To achieve a comprehensible visualization, medication entries with the same name and dosage are grouped and shown on the same horizontal line. Each group of medications occupies one row in the table-structure. The first column contains the timeline of the medication's dispensations and durations, the next column the medication's name, form, and dose per unit (e.g., "LISINOPRIL 20 MG TABLET"). The two next columns contain the links to the dispensing pharmacy and prescribing

[1] Networked software systems used in pharmacies.

doctor. These are listed in separate tables and linked via letters (A, B, etc.) and numbers. Thus the user has to manually look up the pharmacy in the pharmacy-table. This is necessary, as A4 paper sheets provide too little space for all information to be written in one table-row. The last column contains quantity information. The list of medications is ordered so that the newest and active medications are on the top. Furthermore, the names of active medications are printed in bold to enhance this information. Thus the most important medications can be perceived quickly. In addition to grouping medications with the same name and dose, medications with the same name but different dosages are grouped vertically and a bracket connecting their names is shown to emphasize their affinity. However, generics are not recognized and thus not grouped with their related medications.

It has to be noted that the pharmacy- as well as the prescriber-column are only containing the most recent dispensing pharmacy or prescriber. Displaying older information is not supported. As paper does not provide interactivity, users are not able to zoom into the visualization or explore in more detail, which might not be necessary in a time-critical emergency care department [Ozturk et al., 2014].

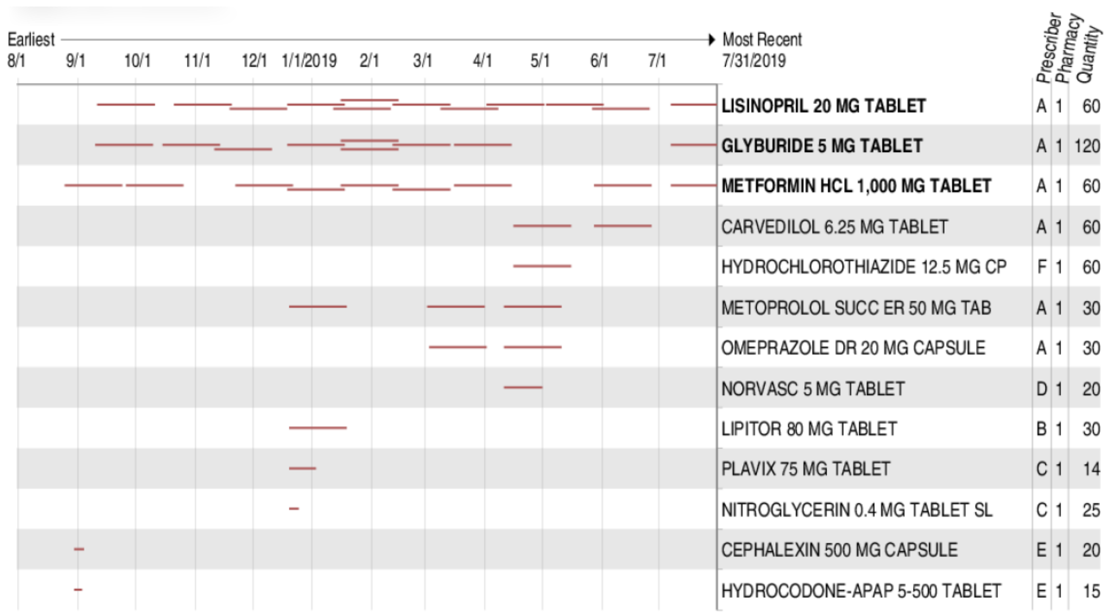

Figure 3.2: Prescription history visualization for emergency care. The timelines on the left-hand side show medication-dispensations and their expected durations for the last year [Ozturk et al., 2014, p. 967].

Discussion

The prescription list of Ozturk et al. provides the most important patient-specific medication information within a very short time to healthcare professionals in emergency care. The project was developed for this purpose, which has to be taken into account during evaluation. It clearly lacks interactivity and detailed medication information – for example, the intake-pattern is not provided (e.g., two tablets a day, or every three days), no statements of explanation are available, only the most recent prescriber and pharmacy are linked, and the timeline has fixed granularity of one year. Even the start-time of medication prescription cannot be provided. While this suffices in emergency care based on the project of Ozturk et al., other departments would require more information.

- Pro
  - Very comprehensible list of medications
  - Show actual medication dispensations
- Con
  - On Paper
  - Focused on use in emergency care
  - Detailed information missing

3.1.3 Medicine Prescription Visualization [van der Corput, 2013]

This project focuses on visualizing prescription information regarding specific patients, analyzing prescription behaviour of doctors or prescription patterns of specific medications. Thus, only prescription information is considered while other EHR data is ignored. Van der Corput's application provides multiple metrics (dose metrics, temporal metrics, relation metrics, context metrics, etc.) for the data as well as the relationships between patients, doctors and medicines. Thus versatile visualization techniques are used in order to cover all characteristics of the data in an intuitive way. For instance, special bar charts are utilized to display the number of patients per doctor and their ratio, sparklines to show the progression of prescription-numbers over time, and a specially designed "row-relation-glyph" has been developed to display relationships between multiple entities (doctors, patients, and medicines). It has to be noted, that the term "medicine" is used for the substance and not for the product within the application [van der Corput, 2013, p. 8].

Van der Corput enables the exploration of thousands of prescriptions, which are composed of a prescribing doctor, the receiving patient, and the prescribed medicine. The visualization aims at answering questions similar to: "How many/which patients have been treated by doctor D with medicine M?" or "When was patient P treated with medicine M1 or M2 and by whom?". Thus, it does not focus on one prescription but on large numbers of prescriptions. A timeline at the bottom of the application allows adjusting the time-span of interest. All remaining data is displayed in three adjacent tables – the "three table view", as called by van der Corput (see Figure 3.3). One table displays all information regarding doctors, the second holds all patient-entities, and the third all medicines (not prescriptions!). The table columns display the number of patients per doctors, number of doctors per patient, number of medicines used/prescribed, rations depending on the current query (e.g., male-female ration), prevalence of medicines, etc. The times of medicine-applications can be displayed per patient via Gantt charts as well.

Grouping of similar entities (e.g., grouping according to the patients' gender) is supported as well as table sorting and filtering. Thus, van der Corput's visualization provides a considerable interaction for exploring and analyzing great quantities of prescriptions. Van der Corput also takes into account that the responsible doctor per medication changes over time, as the doctor who changes the dosage last becomes responsible. Hence, also the course of the dosage is observed and visualized. However, dosages are only implemented as the "defined daily dose" (Defined Daily Dose (DDD)), making dosages of medicines not taken daily an un-displayable exceptional case [van der Corput, 2013, p. 8].

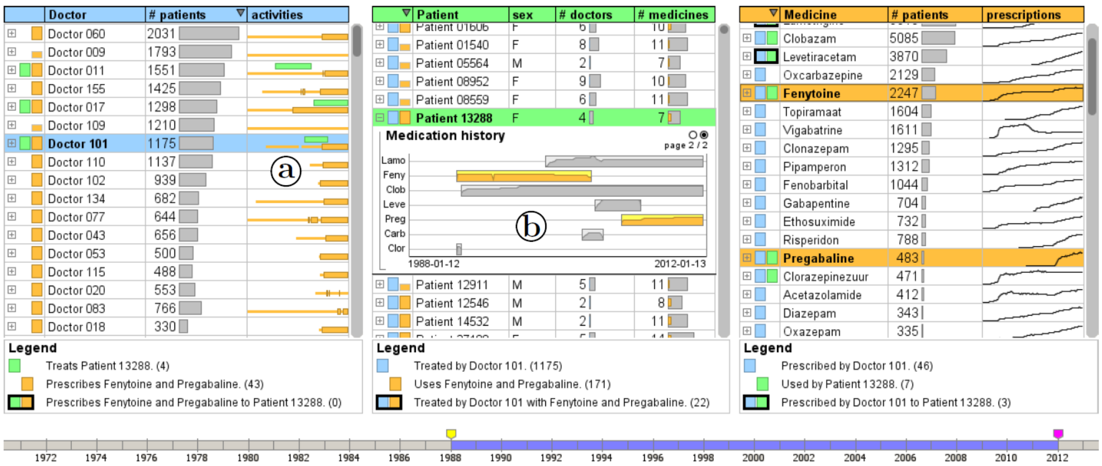

Figure 3.3: Medicine Prescription Visualization. The three-table-view is aimed at providing metrics on large numbers of prescriptions [van der Corput, 2013, p. 23].

Discussion

Van der Corput's prescription visualization is a remarkable tool for exploring the relationships of prescription data and evaluating prescription statistics. It offers multiple well considered visualizations for diverse data and takes numerous medication-specific factors into account (i.e. the changing responsibility of doctors).

Nonetheless, the target use cases of this tool do not include daily clinical work. It would be possible to find all prescribed medicines of a specific patient, but the data would be detached from the rest of the EHR while less important information (for the use case of clinical patient treatment) about prescribing doctors or average usage of the medicines would be too prevalent. Also the fact that medications which are not taken daily cannot be visualized correctly, as only the "daily defined dosage" is displayed, would constitute an immense disadvantage.

- Pro
  - Versatile visualization techniques for different types of data
  - Characteristics of prescriptions were well considered
  - Numerous options to analyze prescription metrics
- Con
  - Medication dosage only displayed usable for medications with daily intake
  - Not for clinical use

3.1.4 MyNYP [Wilcox et al., 2016]

This project stands out as it focuses on medication visualization and was published in 2016, making it a relatively recent project in this scope. More precisely, MyNYP aims at providing medication information to patients in inpatient care in order to support patients to get to know their medications. Therefore, MyNYP does not include other EHR information but provides means for the patient to ask questions or add comments regarding his medication therapy. At the same time, by providing also information about home-medications, patients are encouraged to review and correct the collected data.

In contrast to most other EHR-visualizations, Wilcox et al. decided not to use timelines but a table-structure instead. They argue timelines being easily overloaded visually, even if grouping-metrics are applied beforehand. Additionally, exploration by the patient can be impeded, as less detailed information can be shown on timelines compared to table-views. Looking for a specific name, medication class, or type of administration is also limited on timelines [Wilcox et al., 2016, p. 153]. MyNYP distinguishes between home-medications and hospital-medications. The latter is further divided in three tables: active-medications, medications ordered today, and completed or discontinued medications. These three tables have the same structure and were introduced for hospital-medications to improve the visual appearance, after Wilcox et al. calculated the average number of unique medication ordered per cardiothoracic surgery patients to be 63.5 [Wilcox et al., 2016, p. 153]. The table-structure and content of home-medications differs from those of hospital-medications. The name of the medication combined with its form and dose (e.g., “Aldactone 25 mg tablet”) and a set of instructions combined with the indication of the medication (e.g., “1 tab(s) orally once a day x 30 days Indication – Specify: heart disease”) are displayed per home-medication. Hospital medications provide more details (see Figure 3.4), as they are in full control of the hospital. These tables contain the medication’s class (e.g., “Proton pump inhibitors”), its name (e.g., “Esomaprazole Oral”), the dose (e.g., “20 mg”), its frequency displayed via a simple graph, its administration route (e.g., “IV” for “intravenous”), as well as its uses (e.g., “Used to control rapid heartbeats or abnormal heart rythms”). All information is presented in textual form except for the medications’ frequencies. These table columns hold a graphical visualization (based on an abstract timeline representing a day) of the daily administration schedule or instructions as well as a short textual description. More information is displayed when clicking on a medication's name [Wilcox et al., 2016].

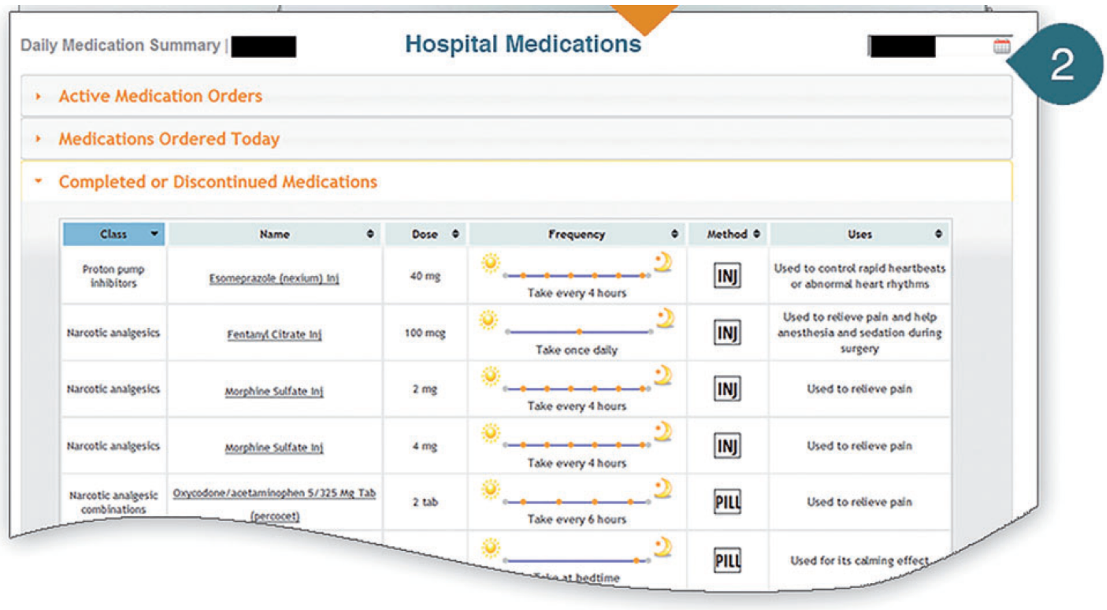

Figure 3.4: MyNYP. The hospital-medications-table of MyNYP is displaying detailed information [Wilcox et al., 2016, p. 150].

Discussion

MyNYP provides great access to medication information for patients. Its table-structure ensures easy navigation without demanding prior knowledge or special training, and arranges the data in reasonable pieces of information.

Easy sorting by different categories constitutes an obvious advantage and would also benefit healthcare professionals during exploration of medication data. Nonetheless, doctors would require more information such as distinct timestamps for start and end of prescriptions, as well as the prescriber. Furthermore, doctors would need to examine three different tables when looking for a specific drug: Home-medication, active-hospital-medication, und completed or discontinued medications. This seems to be too tedious for the stressful hospital environment. Furthermore, during the evaluation done by Wilcox et al. healthcare professionals suggested displaying the pronunciation of the medications' names as well as a picture in order to further facilitate exploration by patients [Wilcox et al., 2016, p. 154].

- Pro
  - Table-structure is easy to understand and use
  - Sorting

  - Detailed information about medications

- Con
  - No other information
  - (target users are patients not healthcare professionals)

3.2 Projects focussing on EHR data

3.2.1 Integrated EHR Visualization [An et al., 2008]

An et al. developed an integrated viewer focused on displaying the progression of EHR-parameters over time. The viewer displays vital sign records, orders, notes, medical image exams, lab test results, etc. ordered horizontally along a time axis. According to An et al. they designed and implemented the system based on the way doctors work [An et al., 2008, p. 642]. The basic elements of the application are “clinical acts”, which are taken from the HL7 Reference Information Model (RIM). Some examples for clinical acts are: clinical examination, administration, diagnosis, or providing treatment. The acts form a unified structure for multi-model EHR data, also allowing relationships (composition, sequel, pre-/post-condition, and relative) between acts. Because of the widespread HL7 standard, the integrated viewer should be deployable in all hospital departments.

The different types of data require multiple visualization techniques. An et al. provided binary waveforms, images, text, and numeric data but also announced possible extensions in the future [An et al., 2008, p. 641]. They also enabled their users to configure how certain data should be displayed (e.g., table or trend-chart). A promising approach has been taken in order to display textual information. As visualizing long text efficiently is hard, doctors can determine keywords, which are displayed in the visualization. Consequently, the most important information can be conveyed fast. Numeric data is either visualized via tables, trend charts, or timelines. As medication dosages are classified as numeric data by An et al., they decided to use timelines in order to display the start- and end-times of medications while mapping the dosage value to the width of the line [An et al., 2008, p. 642]. Thus, changes in medication dosages can be easily perceived by the users. According to the screenshots (see Figure 3.5), an arrow at the end of the timeline indicates that the end-time of the medication is in the future outside of the currently viewed time-span. Furthermore, the exact value of a medication’s dosage (e.g., 125mg) is written at the start-point of the medication’s timeline. The names of medications are displayed in the left data panel forming a little medication/order-list. The name and its associated timeline have the same color, probably to support linking these distributed pieces of information. However, it has to be mentioned that we can only assume the text on the left being the labels for the timelines, as we do not know the language it is written in. We are also not able to tell if any kind of sorting, filtering, or highlighting can be applied [An et al., 2008].

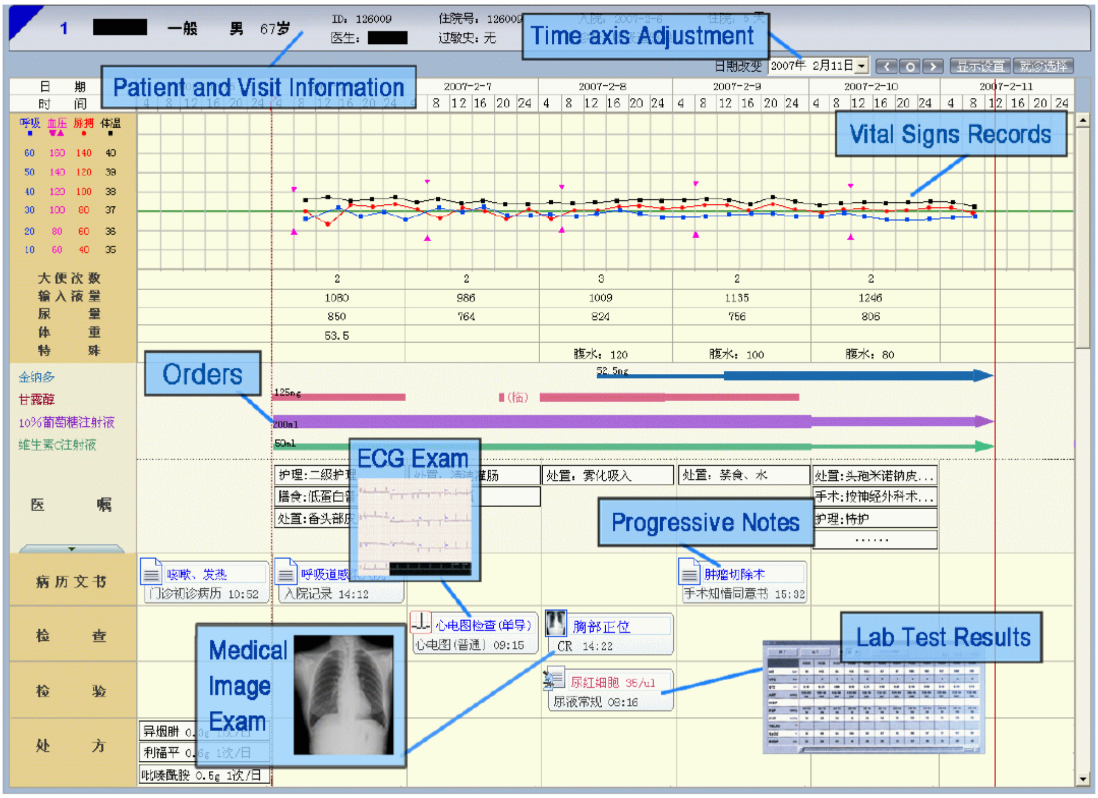

Figure 3.5: Integrated Viewer for EHR data. The timelines in the middle of the picture represent medications (labelled with “Orders”) [An et al., 2008, p. 643].

Discussion

The integrated EHR visualization is an extensive tool able to display most information within an EHR and the possibility to configure the interface according to the users’ needs is a distinct advantage. However, only little information regarding medications is shown. This was also mentioned by evaluating healthcare professionals, according to An et al. [An et al., 2008, p. 643]. Furthermore, as only four medications are pictured in the screenshot, we cannot tell how the viewer would handle larger numbers of medications. A more detailed description regard medication visualization would be desirable.

- Pro
  - Overview including other EHR data
- Con
  - No details regarding medications
  - Not much information regarding interaction techniques etc.

3.2.2 VisuExplore [Rind et al., 2010]

VisuExplore is another extensive visualization project for EHR data built with the java framework “Prefuse”. It aims at visualizing single EHRs for daily clinical use as well as patient cohorts for analyzing therapy effectiveness or similar. In order to reach a broad area of application regarding medical disciplines it offers flexible representations of diverse parameters. In addition, doctors can add, rearrange, and resize visualizations of individual parameters [Rind et al., 2010, p. 3f]. VisuExplore provides multiple means of interaction like semantic zooming, panning, filtering, or grouping. All parameter visualizations are aligned to the horizontal time axis [Rind et al., 2010, p. 3]. The granularity of this time axis adapts automatically to the current zoom-level. Furthermore, four main visualization techniques and five advanced techniques were applied in VisuExplore by 2011, but further techniques were planned for the future. The existing techniques are: line plots and bar charts for quantitative data, event charts and timelines for nominal data, semantic-zoom chart, silhouette graph, horizon graph, and a document browser [Rind et al., 2011, p. 306ff]. The user can choose from these visualization techniques when adding a parameter to be visualized to the viewer. Rind et al. also considered missing information within EHRs, thus intervals with unknown end-date are displayed via an arrow on the right edge of the timeline fading out.

Medications are either visualized as intervals (e.g., via timelines - the representation can be chosen by the user) or – if the start- and end-date information is missing – as single points in time (see Figure 3.6). Rind et al. give an example for the latter case, where they mapped prescribed medications to diamond-shapes filled with a certain color, while not-prescribed medications are represented by empty diamonds. This shape-based visualization also provides a short free-text to be displayed next to the shape. In the given example, Rind et al. displayed the dosage of the medication in combination with the abbreviated brand-name [Rind et al., 2011, p. 306ff]. Additional information is available via tool-tips.

Discussion

The flexibility of VisuExplore stands out, as users have so many options to choose from when configuring the visualization interface. Its potential to give an overview on the complete EHR and to reduce information overload was confirmed by an evaluation by Pohl et al. with Austrian doctors [Pohl et al., 2011]. Interestingly, during this evaluation healthcare professionals stated VisuExplore being best suited for outpatient care of patients with chronic diseases. They accredited less usefulness for inpatient care, as patients do not stay in contact with the hospital for long. However, they recommended utilizations for training or for explaining the progression of health to patients [Pohl et al., 2011, p. 296f]. But perhaps the attitude of the evaluating doctors regarding the usefulness in inpatient care has changed since, as the Austrian electronic health record, which is available across all hospitals, is about to launch six years after the evaluation. This should make far more health-data accessible per patient in inpatient care. Independently, medication information is mainly provided via free-text that comes along the shape (point

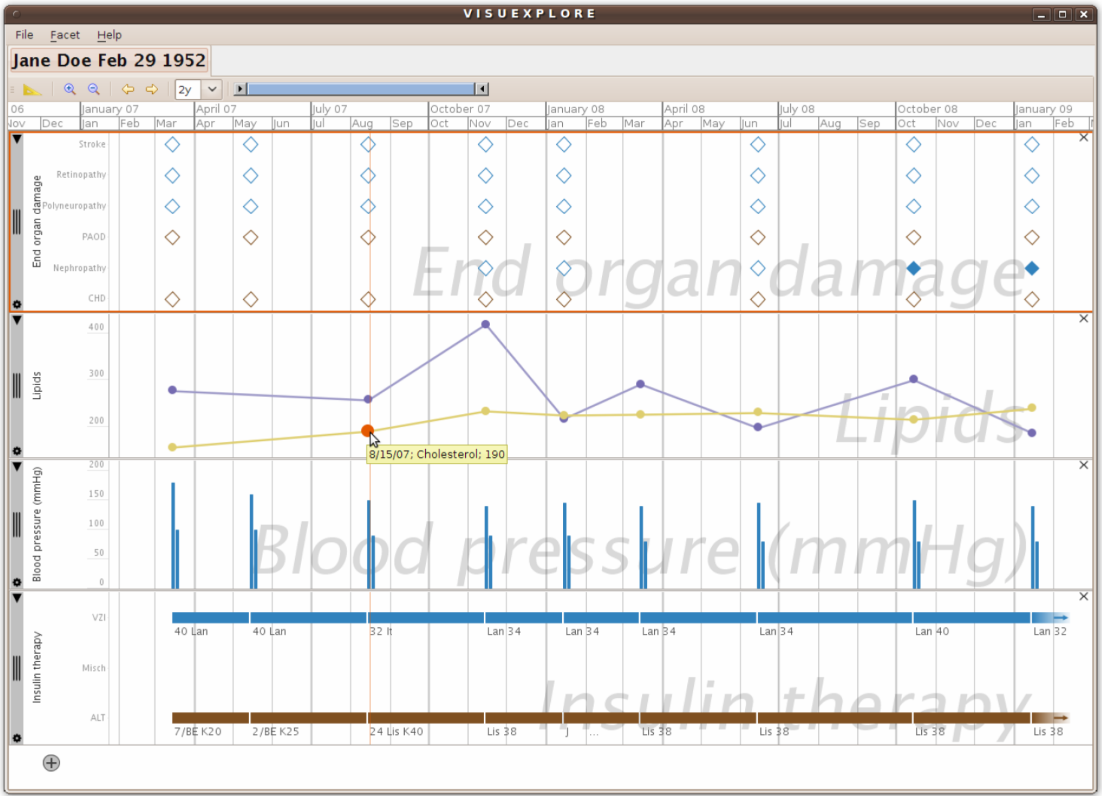

Figure 3.6: VisuExplore. The top section shows events with single time-instances, in the bottom the timelines of insulin-therapy can be seen [Rind et al., 2010, p. 3].

in time) or timeline (time interval). There is still potential for encoding more. Also no information is given in this paper on handling medication-specific characteristics such as generics.

- Pro
  - Overview including other EHR data
  - Versatile visualization techniques for different types of data
  - Configurable by the user
  - Considers unknown end-time of medication intervals
- Con
  - Medication specific characteristics are not addressed within the general approach

3.2.3 LifeLines [Plaisant et al., 1998]

Is a visualization system for EHRs which was developed in the 1990s by Plaisant et al. It aims at providing an overview of a complete EHR "at a glance" and includes information regarding problems, allergies, diagnoses, medications, etc. Related information is grouped in "facets" – for example, all information regarding medications is grouped in one facet (see Figure 3.7). LifeLines displays a horizontal timeline-bar for each data-element which conveys the valid-time of the element. A timeline at the top of the view shows the time-steps. Relationships between items can be visualized via their colors. Rind et al. declare LifeLines as fundamental project for the group of visualizations focusing on nominal patient data, because of its design and extent [Rind et al., 2011, p. 303]. The project is referenced many times in literature, often serving as source of inspiration. LifeLines supports multiple types of EHR-data (allergies, medications, etc.), provides zoom-functionality and interaction to display more detailed information or navigate to the area of interest.

Regarding medication information, LifeLines display the prescriptions duration using its horizontal timeline-bars. The length of the bar can indicate the expected duration for active medications. The duration is calculated using the dosage and the number of refills. In addition, medication dispensations can be displayed on this bar as well as refill-requests or approximated refill-request-dates. Hence, LifeLines can show if refills are executed too early or too late, which can further be used to indicate over-use or under-use of medications. Plaisant et al. suggest encoding the medications dosage in the height of the timeline-bar, as many medications have a predictable range of dosage. This leaves the color of the bar for encoding the related indication or the medication classification. Plaisant et al. also mention mapping the drug's costs to the bar's color.

LifeLines groups medications of the same class when zooming out, thus freeing display space and giving a better outline of the data. For example, multiple applications of Propanolol are combined in the group "Betablocker" [Plaisant et al., 1998, p. 79].

Discussion

LifeLines is an extensive visualization, as it strives to display all heterogeneous EHR data in one overview. Therefore, it accomplishes to provide a considerable outline of the health record. However, regarding medication information it has to be noted that the pictures provided by Plaisant et al. are lacking detailed information. According to the pictures the names of medications are displayed right next to their timeline-bar, but no additional exact information is provided in the overview. André et al. also criticize that LifeLines only shows that "something" happened at a specific time when zoomed out [André et al., 2007, p. 102]. The exact dosage or the exact dates of prescription and refills would be important in particular. Furthermore, the order of the elements as well as the option to sort them dynamically are neither described in the paper, nor visible in the visualization's pictures. Thus, we are unable to tell, how a healthcare professional could look for specific information in the medication's facet. Scrolling though a long

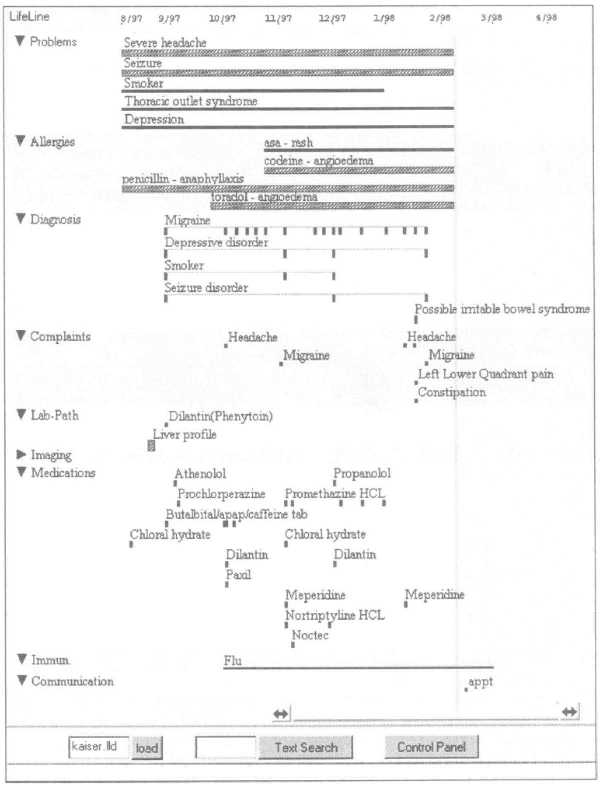

Figure 3.7: The LifeLines interface. EHR-data is grouped in facets (Problems, Allergies, Diagnosis, ...), which can be collapsed individually [Plaisant et al., 1998, p. 77].

list of medications while looking for one entry seems highly inefficient, especially as the medications' names are not listed beneath each other similar to a table but are distributed horizontally to wherever their timeline-bar starts. The pictures further indicate that medications outside the currently visible time-range are completely invisible. The user would need to pan or zoom to find such elements.

- Pro
  - Overview including other EHR-data
  - Interaction – zoom & detail
  - Medication grouping
  - Relationships to indications, some other medication-specific info
- Con
  - No details given
  - Medications outside current time-range are invisible

3.2.4 Midgaard [Bade et al., 2004]

This visualization project for time-oriented medical data aims at supporting healthcare professionals in diagnosing and treatment planning. Thereby, Bade et al. focus on intensive care units in particular, but the tool can be utilized in other domains as well.

Midgaard displays qualitative scales via height-coded timelines, which are derived from LifeLines color-coded timelines. This approach saves the expenses to find meaningful and intuitive color-mappings. Midgaard's visualization adapt very well to changes in height of the display-space (see Figure 3.8) . Timelines show more or less details according to the available height. Different visualization techniques are used for different levels of detail, ranging from small connected bar-charts forming a timeline to detailed curves displaying exact values. Furthermore, Midgaard provides qualitative-quantitative hybrids, e.g., combining quantitative data, like vital-signs and enhancing those with qualitative regions indicating values that are too high or too low. Midgaard can also display the trustability of data-points (a vertical green bar above data points) or their measurement deviations (filling the region of the data-point with grey color). Additionally, Midgaard can show high-frequency data using an advanced Mural-visualization including supplemental statistical values.

Bade et al. implemented an interesting interaction technique for data exploration. The user can modify the visible time-range via three timelines. On the main timeline with large granularity (e.g., months) the selected area can be dragged and scaled ("brushed") to change the main area of interest. The selected time-range is available in the other timelines. On the second and third timeline-interfaces (the third being the main data-view) distortion borders can be added. This means areas of interest can be scaled up by dragging the border, while areas out of interest can be hidden by scaling them down. This enables focus and context regions. Additionally, providing overview is realised by showing the data in all three timelines at different levels of abstraction [Bade et al., 2004].

Although medication visualizations are not mentioned within the paper visualizing prescriptions would probably follow similar patterns as displaying the blood pressure: height-coded timeline mapping the dose of the medication and the name of the medicine displayed at the beginning of the timeline.

Discussion

Midgaard presents medical data in an intuitive and appealing way, encoding important qualitative information via height and color. What's more, the visualizations adapt very well to the available height. The utilization is neither limited to the intensive-care department nor to the healthcare sector, but this general approach therefore limits the support of specialised data. In this case, medication dosage as well as the medications start- and end-date could be visualized via the introduced height-coded timelines, but medication specific grouping, dispensations, administration patterns, or relationships would be difficult to visualize.

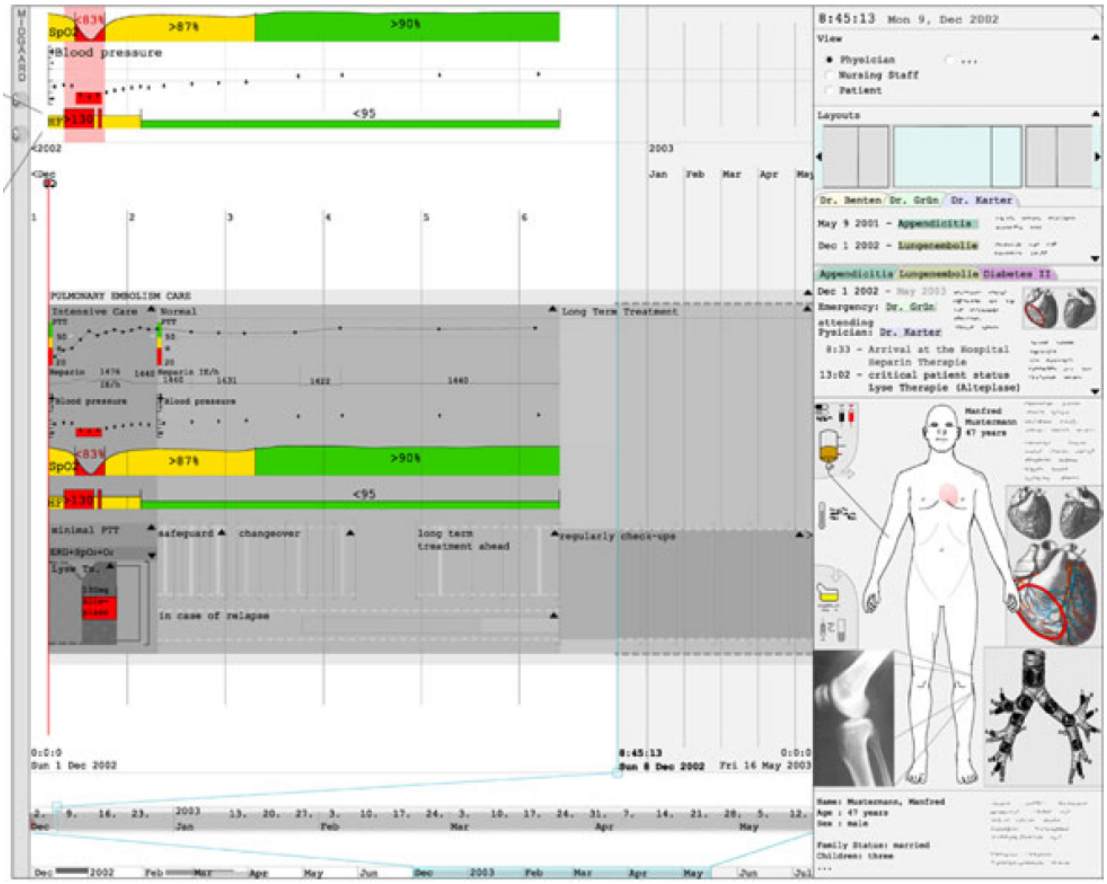

Figure 3.8: Midgaard. The interface of provides timelines on the left-hand side and a dynamic body-map on the right-hand side [Bade et al., 2004] taken from [Aigner et al., 2011, p. 230].

- Pro
  - Great possibilities adjusting the time-range of interest
  - Intuitive and enriched visualization of qualitative and quantitative data
- Con
  - Medication-specific details hardly displayable

3.2.5 KNAVE II

KNAVE II is an enhanced version of the KNAVE-project (Knowledge-based Navigation of Abstractions for Visualization and Exploration [Shahar and Cheng, 1999]) [Combi et al., 2010, p. 327] providing knowledge-based interactive visualization and exploration of individual patient data accumulated over time [Martins et al., 2008, p. 18]. As the name suggests, KNAVE emphasizes abstractions in order to reduce the information overload for users and facilitate decision-making [Shahar and Cheng, 1999, p. 1]. The KNAVE II project aims at supporting healthcare professionals viewing patient data at the point of care [Martins et al., 2008, p. 20].

The users can define and select abstractions for their data. KNAVE II accesses domain-specific knowledge-bases, controlled-vocabularies, and temporal-abstraction knowledge to provide numerous abstractions. The user is able to select temporal-queries, which results are shown in the main view (see Figure 3.9) [Combi et al., 2010, p. 328f]. The main view is composed of multiple smaller, vertically stacked panels containing the visualization of specific parameters. Each of those panels has its own horizontal timeline for navigation and displays the data according to the domain-specific abstraction, for instance, via bar-charts, timelines, or line-plots. It is also possible to show some statistics (e.g., maximum, average, minimum, etc.) for these parameters. On the left-hand side of the panel's time axis view data labels are positioned, while navigation buttons are positioned on the right-hand side.

Interestingly, KNAVE II supports switching between absolute timelines and relative timelines. When a relative timeline should be used, the user only has to select an event to be used as point of reference. All time units then change to +/–time units [Combi et al., 2010, p. 330].

Discussion

Utilizing domain-specific knowledge to visualize medical data and letting the user choose the abstractions to apply or show appears to be a valuable step in the right direction. The evaluation of KNAVE II done by Martins et al. confirms that this tool enables healthcare professionals to explore faster and improves the correctness of exploration-results in comparison to paper charts. They also reported superior user satisfaction levels [Martins et al., 2008, p. 31f]. Unfortunately we did not find any explicit information regarding the way medication data is or could be handled in KNAVE II. Martins et al. mention the use case of displaying anti-hypertensive medication doses in the same timeline as the patient's blood pressure, however, this use case is not picked up in the rest of the paper. Nonetheless, it would probably be necessary to list all medications within one panel or use some other form of aggregation, as each panel takes a significant amount of vertical space. Thus, listing more than eight medications in separate panels would presumably fill up the entire working area.

- Pro
  - Overview including other EHR data
  - Takes domain-specific knowledge into account
  - Selectable abstractions for different use cases
  - Extensive navigation, switching between absolute and relative timeline

- Con
  - Usage of screen-space probably not efficient enough for displaying long lists of medication combined with other EHR-parameters
  - (No information regarding incorporation of medication data found in literature)

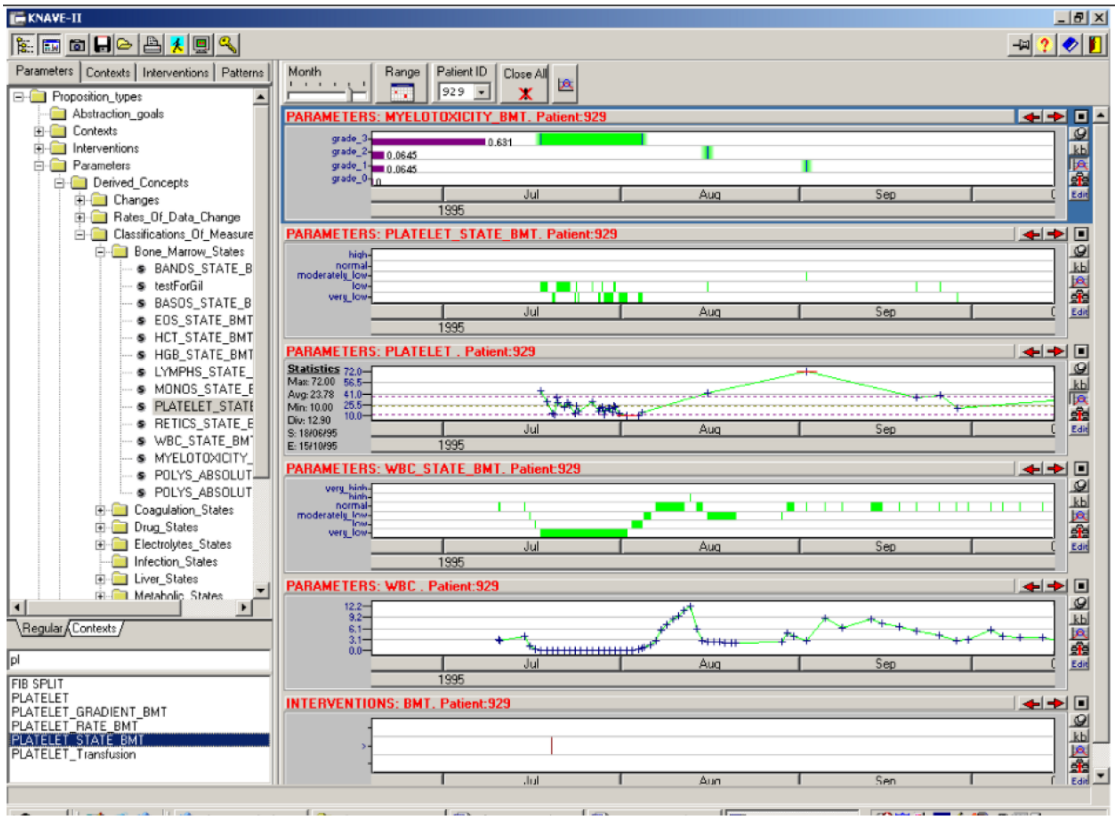

Figure 3.9: KNAVE II. The user can select queries on the left-hand side, the results are visualized in the timeline-views on the right-hand side. [Combi et al., 2010, p. 329].

3.2.6 VIE-VISU [Horn et al., 2001]

VIE-VISU visualizes fifteen health-related parameters - regarding circulation, respiration, and fluid balance - of a single patient and their progress over time. The visualization is glyph-based, with each part of the glyph representing a specific parameter such as the heart rate, the fluid intake and outtake, or the total respiratory rate. The information is encoded in different shapes, ratios, and colors. The progression of these parameters over time is conveyed by displaying a sequence of glyphs [Aigner et al., 2011, p. 202] The resulting glyph is relatively straightforward to interpret even with minimal training and enables the user to easily spot changes over time (see Figure 3.10).

This visualization project does not include medication visualization, as it focuses solely on the fifteen parameters mentioned above. However, this approach to health-data visualization is so extraordinary, that we decided to point it out as alternative to more wide-spread visualization techniques. Nonetheless, due to its highly specialized target use case, we are not able to provide a discussion regarding medication visualization.

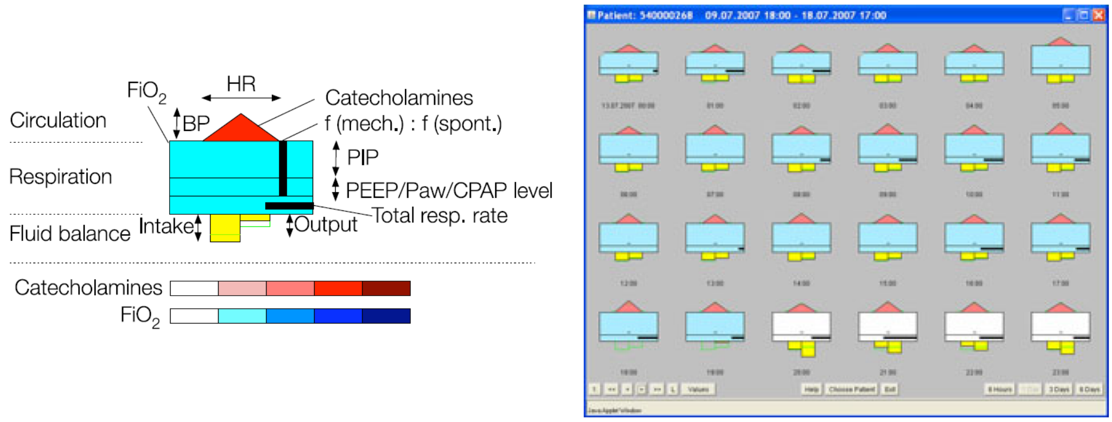

Figure 3.10: VIE-VISU. All information is encoded in a custom glyph (explained on the left-hand side). By displaying multiple glyphs the progression of the health-status over time can be visualized [Horn et al., 2001] taken from [Aigner et al., 2011, p. 202].

3.2.7 TimeLine [Bui et al., 2007]

TimeLine aims at providing a problem-centric visualization of individual EHRs. The project addresses accessing data, mapping data, and displaying it. Different types of medical data are visualized based on a knowledge-base providing data classification, inclusion rules, and visual metaphors [Bui et al., 2007, p. 462f]. The tool shows a chronological sorted medical problem list – e.g., hyperglycemia, hypertension, etc. When one of the problems is selected, the associated timeline is shown in the timeline view (see Figure 3.11). The graphical timelines use icons to represent medical data: document-icons, thumbnails for images, and note-icons with short text. Timelines and line-plots can be displayed as well. On the top of the timeline-view containing health-record-data a context-timeline is positioned, which can be used to navigate to the area of interest. Thus the horizontal positions of elements in the timeline view correspond to their valid-time. The vertical position of elements is associated with their data-class. A hierarchy is used to classify data. This hierarchy is displayed on the left of the timeline view holding labels for different rows, for instance, "Imaging" with the subgroups "Image Tracking" and "MR imaging". The user can control the amount of data-classes displayed by collapsing or expanding the levels of the hierarchy tree. Furthermore, when the user selects an item in the timeline view, more information regarding this item (tables, text, etc.) is shown in the data viewer.

Bui at al. introduce non-linear spacing of events along the time axis to accomplish a more compact and readable view. Thus, long time spans without any events are collapsed to free display space (e.g., only display a 5-pixel gap for months of inactivity), while numerous activities at the same point in time are grouped in a folder. In the latter case, only the folder icon is shown in the timeline. The grouping is performed from left to right (from past to the present/future) so that more current activities are rather not taken into a group-folder [Bui et al., 2007, p. 470]. TimeLine further provides querying and filtering options to the user.

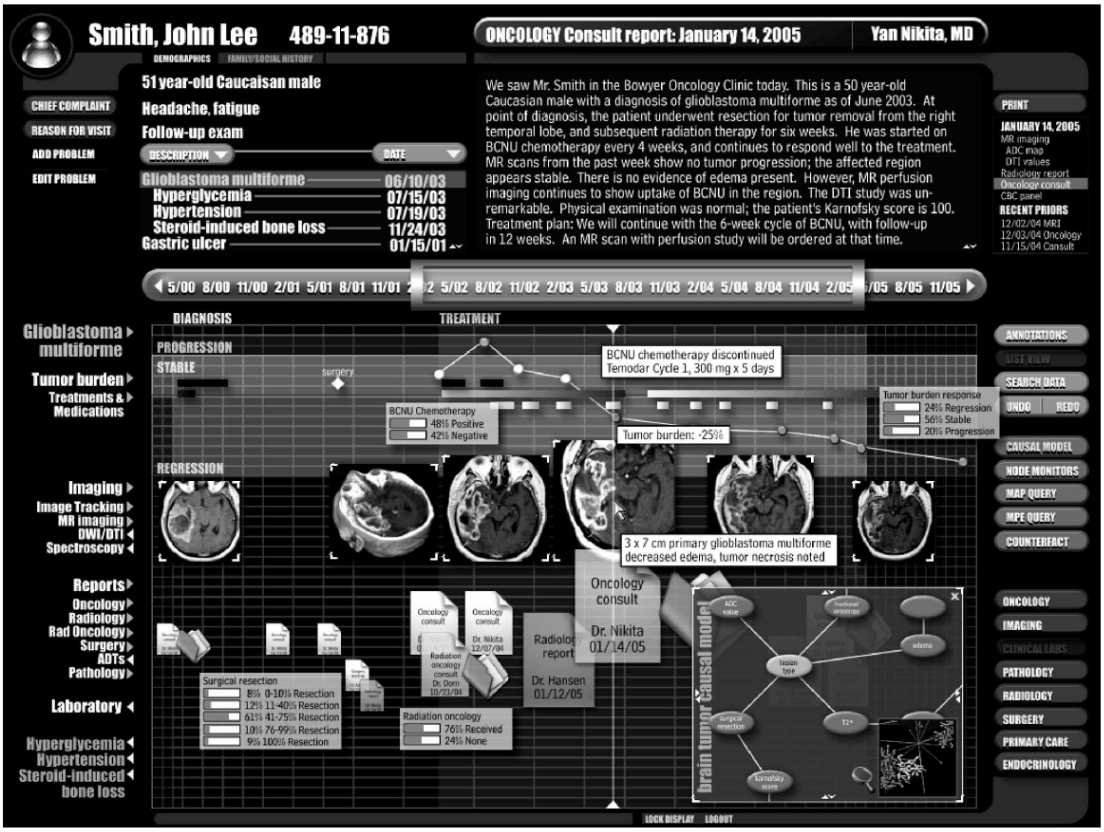

Figure 3.11: TimeLine ([Bui et al., 2007]). Medication timelines can be seen on the top of the main data-area [Bui et al., 2007, p. 464].

Discussion

TimeLine is an extensive tool for viewing EHRs with convenient approaches to saving screen space. However, when it comes to displaying medication data, nearly no information is shown. As medication visualization is not discussed in the paper, we have to base our analysis on the provided screenshot. According to the image, timelines are used to represent the medication's existence in time. But no more information is displayed in the timeline-view. Neither name, dose, prescriber, nor medication class are available. As a result, the user can only deduce from the given timelines, that some sort of medication was applied at the specific time. At least the tooltip seems to contain the medications name, its dose and application, as we derived from the tooltip regarding chemo-therapy: "BCNU chemotherapy discontinued; Temodar Cycle 1, 300 mg x 5 days".

Furthermore, the screenshot reveals that TimeLine does apparently not use any color-coding. The entire interface is held in black, white, and grey-tones. Bui et al. also do not mention any color-coding or color-mapping throughout the paper.

- Pro
  - Overview including other EHR data
  - Strategies for saving screen-space, user controls what information to hide
- Con
  - Hardly any detailed information in the timeline view. It is necessary to select an item to get more information from the data-view.

3.2.8 Chittaro's Visualization for Mobile Devices [Chittaro, 2006]

Chittaro developed visualizations for EHR-data on mobile platforms – particularly PDA-devices. His project supports multiple visualizations for four different types of data: temperature, blood pressure, medicines, and events. While bar charts are used to display temperature data, events are represented by simple crosses, and administration of medicines are displayed as circles (see Figure 3.12). The color of the circles indicates, if multiple medication applications are aggregated into a single circle (blue) or not (green). As all data is aligned to the horizontal time axis positioned near the bottom of the screen, the horizontal position of a medication's circle refers to the time of its administration. The vertical position of the circle corresponds to the text-label of the medication, thus all circles on the same vertical line belong to the same medication. However, because of the small screen, only little text can be shown for the medication's name. Thus, regarding medication data, Chittaro's visualization does only provide the medications names and time of administration [Chittaro, 2006].

Discussion

Chittaro created a compact visualization, presenting a rough overview on a patient's EHR. Some useful approaches were suggested for aggregating information. Naturally, displaying more details would be desirable, but this is mostly limited by the screen-size of the displaying device. Overall, when developing desktop applications other approaches are more promising.

- Pro
  - Overview including other EHR data

  - Scaled for mobile devices
- Con
  - Lack of details because of limited screen space

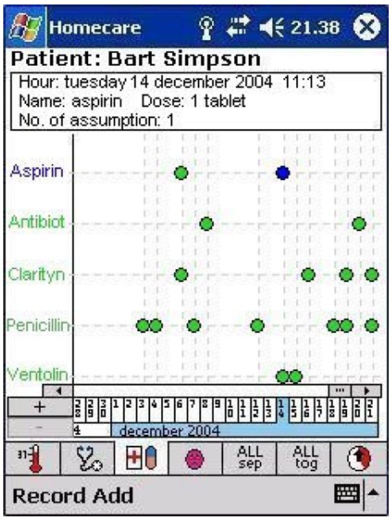

Figure 3.12: Chittaro's mobile Visualization. The medication visualization in Chittaro's application for mobile devices [Chittaro, 2006, p. 485].

3.2.9 CPDV [Faiola and Hillier, 2006]

The critical care patient data visualization system (CPDV) aims at providing an outline of a patient's health-status "at a glance" to doctors in intensive care units, as these departments deploy vast amounts of patient-monitoring data. Treatment data, such as medication therapy, physical therapy, and other clinical interventions, is taken into account as well. Physicians can specify the time periods, time-granularity, and data-sources of interest. In order to enhance relationships in the visualized data, related variables are presented adjacent to each other (e.g., medication data and corresponding physiological data). Each parameter is visualized in a separate view, but multiple views can be stacked vertically. Rearranging views and zooming are supported as well (see Figure 3.13). While not more than eleven days of a patient's history can be visualized with CPDV, the granularity of data points can range from 30 seconds to 30 minutes, which is tailored to the conditions in intensive care environments. Unfortunately, although medications are mentioned once, the paper does not present any information on medication visualization.

3.2.10 Time Line Browser [Cousins and Kahn, 1991]

According to Rind et al., this visualization project from 1991 is a pioneering tool for exploring time-oriented patient data. Therefore, and as the Time Line Browser is

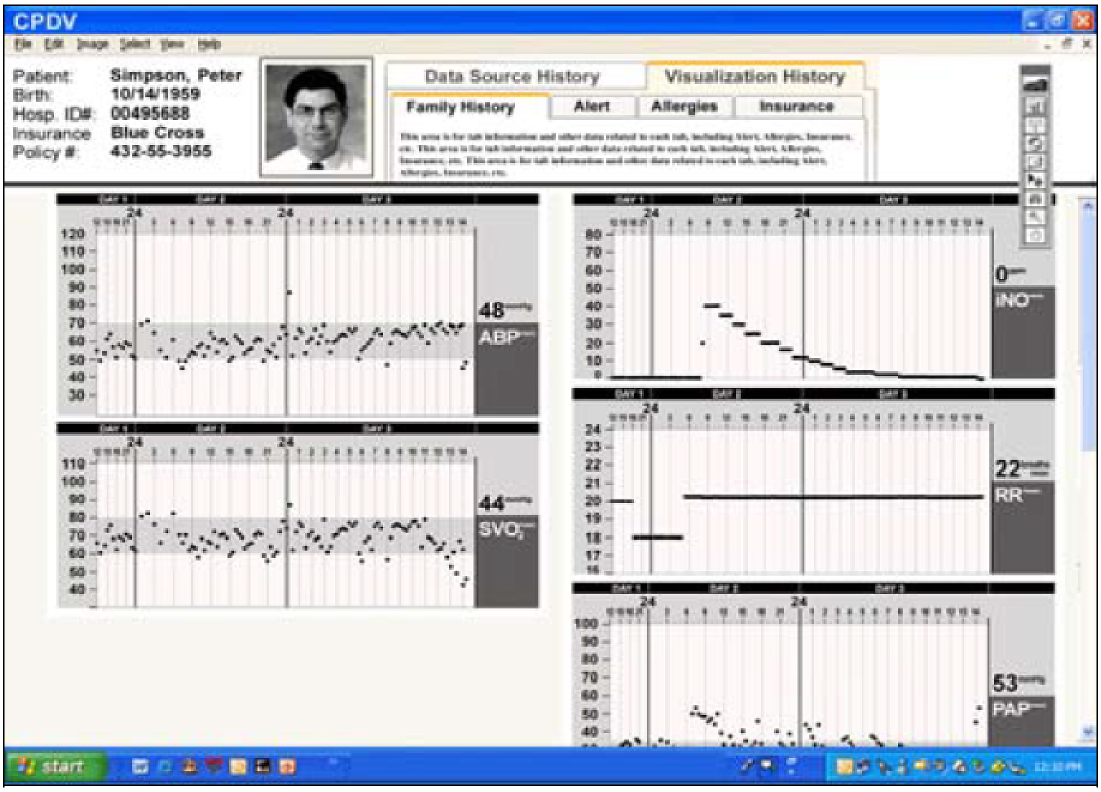

Figure 3.13: Critical care patient data visualization system (CPDV). The basic interface of CPDV is displaying multiple charts for differet parameters [Faiola and Hillier, 2006, p. 5].

referenced in many other papers, the project has to be mentioned in this section as well. It works solely with quantitative data, which is displayed via scatter plots or line plots along a horizontal time axis. However, according to Rind et al., the design is too generic and not easy to use, as the paper focuses on underlying concepts [Rind et al., 2011, p. 303]. Additionally, medication data cannot be solely encoded as quantitative data, making further analysis of the Time Line Browser irrelevant for our work.

3.3 Summary

This outline of visualization projects for medical-data illustrated the uniqueness of each project. Timeline focuses entirely on medication data but is missing some medication details and interaction functionality like sorting. The prescription visualization by Ozturk et al. was developed for utilization in emergency care and only provides basic medication information to be printed on a sheet of paper. The medicine prescription visualization by van der Corput is useful for analyzing prescription behaviour of doctors or patterns in medication prescriptions, but does not seem to constitute a tool for daily clinical work. MyNYP depicts a visualization for medication exploration but its target-users are patients instead of healthcare professionals. Furthermore, visualization projects for EHRs often do not cover medication data explicitly but use a more general approach (Integrated EHR Visualization 3.2.1, VisuExplore 3.2.2, LifeLines 3.2.3). Some focus on approaches to EHR-visualization (e.g., VIE-VISU 3.2.6, Midgaard 3.2.4) or strive to incorporate domain specific knowledge in EHR-visualizations (e.g., KNAVE II 3.2.5). Others are specialized on something else (e.g., DecisionFlow for large amounts of sequence data [Gotz and Stavropoulos, 2014]) but happen to mention medication data incidentally. The latter projects were not taken into the final report, though Time Line Browser has simply been added to the list, as it s fairly often reference by other papers as source of motivation, thus we also wanted to describe its relevance in our scenario of interest.

3.3.1 Medication related characteristics according to literature

One objective of the literature review was gather information about medication-related characteristics, its relationships, priority, etc. However, such information was hardly discussed within the analyzed literature, thus we had to derive it from the descriptive text regarding visual interfaces and available screenshots. The extent of characteristics covered by visualizations varied vastly. While many tools only display basic parameters, like medications' names, start-time, end-time, and dose in their main view (e.g., Integrated Viewer 3.2.1, VisuExplore 3.2.2) other encode more or other information, for instance, costs (LifeLines 3.2.3), the prescriber (Ozturk et al. 3.1.2), some kind of classification (MyNYP 3.1.4), and even uncertainty or trustability of data-points (Midgaard 3.2.4).

But not only the number of available characteristics differs. Some characteristics hold different data across multiple projects. For example, in some projects "dosage" is referring to the total daily dose, in others it refers to the dosage-per-unit (dosage-per-unit is explained in Section 4.3.5). The "name" is also used differently and holds either the name of the medication, the name of the substance, or a combination of values, such as the medication's name and form. More details of our findings regarding medication characteristics are available in the list 10.1.

3.3.2 Visual approaches to display medication data

Nearly all reviewed projects utilize timelines to display a patient's medication. Visualizations with this approach do not provide as much detailed information. In particular, the systems for EHR-visualization are using a generic event-model which does not provide a specific medication data-container with respective attributes. Nonetheless, the timely context of a medication and thus its relation to other medications or diagnoses are easy to identify within a timeline. MyNYP 3.1.4 and van der Corput's prescription visualization 3.1.3 stand out as they are not timeline-based. Both visualizations utilize a table-structure to provide very detailed information and support sorting natively – something that seems to be mostly forgotten in timeline-based views. And doctors explicitly demanded sorting/ordering-functionality as stated in the paper of Zuh et al (see 3.1.1). On the other hand, the projects utilizing tables do not aim at supporting doctors during their clinical tasks. Therefore, each visualization technique's eligibility depends heavily on the context of use.

Overall, we showed distinct differences across current medication visualization projects and the use cases they target. Thereby, we revealed that only little medication characteristics are actually displayed in the main interface. Most visualization tools are providing limited information, limited interaction, or are simply not designed for use in a daily clinical treatment setting.

CHAPTER 4

Medication documentation in Austrian hospitals

In order to assess the current state of the art in Austrian hospitals, we conducted qualitative interviews as described in Section 2.2. Additionally, the doctors' use cases and the relevance of medication characteristics were examined. This section introduces the interviewees and presents our findings.

4.1 Interviewees and their context

This section gives a brief description of the interviewees and their respective hospital context (see Table 4.1). It has to be noted that the names of the interviewees as well as their institutions have been anonymised.

Table 4.1: Our interviewees. All interviewed doctors, their speciality in medicine, as well as the hospital they are currently working at are summarized in this table.

name	speciality	institution
Adam	internal specialist	A
Benjamin	internal specialist	B
Christopher	Cardiologist	C
Daniel	internal specialist	D
Vera	general practitioner	-
Willi	internal specialist	-

4.1.1 Adam

Adam is an over 60 year old doctor in Hospital A. As he is chief of the department, he is working in six different wards and multiple outpatient departments of the hospital, for example, the ward for internal medicine and the urgent care unit. He has been working in this hospital for decades and witnessed the slow development and progression of the computer system. However, doctors use computers mainly to write or dictate reports. The patients' clinical course is documented directly on the fever chart. This also includes all forms of medication data. In other words, paper records and electronic records are used simultaneously, but medication data is solely stored on paper.

4.1.2 Benjamin

Benjamin is in his mid-fifties and has been working in Hospital B for over 25 years. He is now reducing his work in the hospital and focuses more on his doctor's office. He is working in the department for cardiac rhythm diseases/disorders, thereby most patients are sent by external doctors for special investigations. The department he is working in still utilizes paper charts. The hospital has a computer system as well, but this designed to be used for writing reports and management.

4.1.3 Christopher

Christopher is about 30 years old and has nearly finished the cardiologist-training. He is has been working in the current hospital for more than four years and has switched between different departments regarding to his training (cardiology, oncology, gastroenterology, etc.). Surprisingly, the computer system of this major hospital is only used for tasks, such as writing a doctor's letter, referrals, discharge letters, and looking up patient information during ward rounds. The paper record still constitutes the main collection of patient data in this hospital. Thus, medication data is exclusively documented on the fever chart and some of this information is transferred to discharge letters. Unfortunately, this interview had to be kept brief, as Christopher was short on time.

4.1.4 Daniel

Daniel is a doctor working in multiple departments of internal medicine. He is around 50 years old and has been working in the same hospital for many years. Therefore, he has witnessed the introduction of the software system and it's progression from an unusable to a workable system. The electronic fever chart has been established about three years ago. The hospital information system deployed in this hospital and some additional software provide all components needed. Now, no paper patient records are in use anymore.

4.1.5 Vera and Willi

An additional interview was conducted to clarify medication attributes and medication handling in Austria. Vera and Willi are a general practitioner and an internal specialist.

The two doctors – both in their mid-fifties – were interviewed simultaneously. In contrast to the previous interviewees both are solely working as independent physicians. As this interview focussed on the medication attributes instead of hospital-workflows this does not bias the overall result. Furthermore, when we reference "all doctors" or "all interviewees" during the analysis, we exclude this additional interview.

4.2 Medication-related scenarios

The interviewees described different scenarios in which medication information is required in different levels of detail:

a) **Patient admission:** Doctors get to know the patient's medication history for the first time.

b) **Patient transfers:** When the patient is transferred to another department or care facility, the medication history has to be forwarded as well.

c) **Doctors switching wards or called to unfamiliar wards:** Healthcare professionals commonly know the patients in their own department, but when called to another ward they first have to learn about the respective patients.

d) **Doctors re-familiarizing with a patient:** Doctors returning from their compulsory period of rest after a night shift or simply arriving the next day need to get an overview, especially regarding recent updates.

e) **Ward rounds:** During ward rounds the medication history of each patient is audited. This practice differs among doctors and hospitals. Daniel always checks the complete list of active medications while Adam appears to inspect them partially. However, as they work in different hospitals suchlike variations can be expected for different contexts.

f) **Patient admission in emergency care:** As Adam also works in urgent care he also mentioned patient admission after accidents. Healthcare professionals need a fast outline of the patient's history including medication data.

We ordered the list so that the top element corresponds to the scenario with the least patient information known by the doctors while scenario (e) corresponds to the scenario with most information already known. Thus, we expect the required level of detail to overall decrease in the scenarios from top to bottom. Nonetheless, it has to be kept in mind that this is not universally applicable but depends on multiple factors.

The emergency care scenario was put at the end of the list, as it does not fit in the context of internal medicine. There are already some other projects focussing on medication visualizations for emergency care, such as [Ozturk et al., 2014].

4.2.1 Questions focussing medications

Depending on the situation healthcare professionals are looking for specific information in the scenarios mentioned above. We aggregated and listed medication-related questions mentioned by the interviewees:

a) **Which medications are currently prescribed?**
Not only to get a picture of the patient's current treatment but also in order to prevent double-prescriptions.

b) **Which medications have already been tried out for a certain disease/problem/indication?**
This question is composed of multiple sub-questions:

- What products were used?
- What dosage was used?
- When and for how long?
- How effective have the medications been?
- Who prescribed the medication and who modified the prescription?

c) **Why has a certain medication been prescribed to the patient?**
As stated by Christopher, when going through the medications of an unknown patient, it is relevant to know why a certain medicine has been prescribed. There are medications with trivial indications, such as antihypertensives (the patient is obviously treated because of too high blood pressure) or medicine for reducing the cholesterol level. In such cases, no additional statement is required. But the indications for other medications such as antibiotics or anticoagulants are not that trivial. For instance, it makes a difference if antibiotics are prescribed to treat a small infection on a minor body part or a major abscess in the abdomen. And anticoagulants might be prescribed because of increased risk of stroke or because of a thrombosis and risk of pulmonary embolism [Christopher, 16:41].

The examples above show diagnoses being indications for specific medications (high blood pressure -> antihypertensive), but diagnoses can also be contraindications for specific medications. For example, as medicines reach our kidneys through the metabolism, kidney disease is a contraindication for numerous medications [Adam, 24:40].

d) **For how long has a certain medication been prescribed to the patient?**
Some medications are not meant to be taken everlasting, but patients often miss this information. Christopher mentions the example of anticoagulation medication being prescribed after stent implantation, which could be discontinued after a year. However, when the patient does not know or remember this restriction and does not visit a doctor, the anticoagulation medication might still be taken multiple

years after surgery. On the other hand, for some medications the duration is not important, such as gastric protection medicine [Christopher, 00:53].

e) **Who created/modified a certain prescription?**
This information is not only indispensable by law but also useful for healthcare professionals. As described by Daniel, nobody is obliged to look at this information, but as senior physician he especially checks the prescriber of extraordinary prescriptions. He is then able to contact the responsible colleague for clarification [Daniel, 1:01:09].

f) **Has the patient already received a certain medication in a specific dosage?**
For instance, when an antihypertensive medication has already been given at a higher dosage, the doctor can skip to this dosage and does not have to try out lower doses which have already failed before. Despite hypertension mostly not being critical and treatment stabilizing commonly after some days, such information would fasten treatment and spare trouble for doctor and patient [Christopher, 06:00].

g) **Why has a certain prescription been discontinued? Why was medication A swapped for medication B?**
The answers for these questions might hold valuable information about effectiveness, (in-) tolerances, allergies, and cross-effects of medications [Adam, 04:40].

h) **Questions related to issuing a prescription:**
Some questions related to the process of prescribing medicine came up during the interviews:

- Does the patient already have this or a similar medication?
- Is the patient allergic to the medication's substances?
- Does a specific medication interact with one of the active medications?
- Are the medication's side effects dangerous for the patient?

4.2.2 Patient cohorts vs. single EHRs

According to all doctors, comparisons of multiple patients regarding their medication histories are not conducted in daily clinical work, but are more likely utilized during studies (for instance, finding a medicine's side effects before approval) or special statistical analyses [Adam, 26:30; Benjamin 30:38; Christopher, 14:43; Daniel, 1:00:47]. They all stated each patient being treated and focussed individually. Benjamin also emphasized that a medication might work on one patient but might have no or less effect on the next [Benjamin, 30:38]. As a result, we focused our visualization prototype on displaying single EHRs rather than patient cohorts.

4.3 Visualization tools in Austrian hospitals

4.3.1 Current medication documentation

In the hospitals of Adam, Benjamin, and Christopher both computer systems and paper records are utilized simultaneously. The computer systems are mainly used for writing medical reports, doctors' letters, and hospital-internal referrals but do not deploy an extensive patient record. The paper records and particularly the paper fever chart still depict the basis for daily work. Thereby, medication information is primarily entered on the fever charts. Medication data is hardly transferred to the computer system before a patient's discharge.

In Daniel's hospital a complete information system is deployed, thus paper records do no longer exist in his hospital. According to all interviewees, Daniel's hospital can be seen as one of a few pioneer projects regarding the introduction of hospital information systems, while the majority of hospitals are indeed using paper records. The following section will describe the medication documentation in Daniel's system.

4.3.2 Medication visualization in Daniel's HIS

The electronic fever chart is composed of multiple expandable sections, one of them contains the patient's medications. The fever chart has a horizontal time axis split into days. The user can configure the number of days to display, Daniel's setup shows five days total: today, two in the past, and two in the future. The medications are listed in a table. The first column holds the medications' names, form, and dosage per unit. Each day shown on the time axis is further split into five sub-columns. These columns follow the pattern morning-midday-evening-night-special ("M-M-E-N-S") and hold the intake-schedule of each medication. If a medication was only applied once or does not follow a schedule (like on-demand medication) the "special"-column is used. It is further possible to use placeholders instead of precise dosages. This is used for insulin therapy, as the required dose depends on current blood glucose-values. In these cases a simple "X" is shown instead and later replaced by the actual dose taken. Furthermore, when medications are applied continuously over a period of time (e.g., chemo-therapy injected continuously over 48 hours) the time-period of application is visualized via a horizontal timeline-bar across multiple days instead of the "M-M-E-N-S"-pattern.

Information transfer to nurses Nurses receive the information entered by doctors, prepare and distribute the medications, and also document the status of each administration. The status is visualized by coloring the cells (green = administered, yellow = prepared, red = not taken by the patient) is thereby visible to the doctors. It is possible to pause medications for some days, this is shown via a pause-icon in place of the dose for the specific day.

Categories and highlighting Highlighting is applied to the medications' names for the following types of medications: coagulation-medication (green), analgesic (red), insulin (yellow), pre-admission medication (brown), and discharge-medication (blue) (see Figure 4.1). According to Daniel, the hospital's staff chose these types of medications to be highlighted. Discontinued medications are shown in the list as long as their day of discontinuation is visible in the fever chart. A white "X" in a red circle is displayed in the row of the discontinued medication for that day. When the day of discontinuation is not visible, the medication is hidden. However, it is possible to un-hide discontinued medications via the settings panel of the table-view. Such medications are greyed out and provide info about their time-period of validity. The user has to manually navigate to the period of validity in order to see the former dosage and intake-schedule.

More information, like the prescribing doctor or the indications, is available in the tooltip-text.

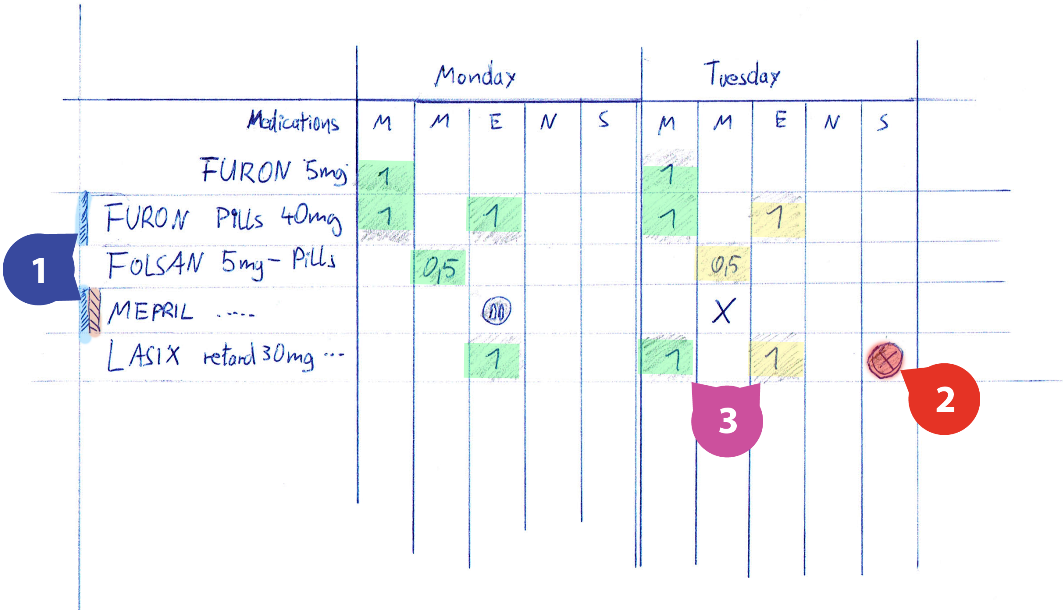

Figure 4.1: A rough sketch of the medication visualization in Daniel's EHR-system.
1) The colored bars highlighting discharge-medications, insulins, etc.
2) A discontinuation-mark on the day of discontinuation.
3) Intake-dosages for the respective time of the day (morning and evening). The green color indicates that the patient has already taken the medication; the yellow color indicates that the medication has been prepared by the nurse but has not been taken yet.

Overall, this medication visualization provides great information on intake-schedules for daily medication, the current status of each scheduled medication intake, as well as highlighting for important medication types. Special cases of medications (continuous applications, dynamic dosage calculation) have also been included. Another important advantage is the integration of the list of medications in the fever chart. This enables the user to display vital-signs (blood pressure) above the medication data for analysis.

However, the tool seemingly aims at supporting the doctors' daily clinical work but not exploration of medication histories. Only a few days are displayed and zoom-functionality is missing. This is especially impractical for checking discontinued medications, as intake-schedule and dosage are only visible when navigating to the former time of application. Furthermore, because of the limited visible time-frame, dosage-changes are hard to track as well. The user would need to memorize the daily dose while clicking through the history. Unfortunately, we are not sure how medications with weekly intakes are visualized. As only days of application are marked, the entire row of a medication taken once a week is presumably empty (supposed that only the six days without intake of this medication are displayed).

4.3.3 Confirming the need for medication history visualizations

During the four interviews multiple occasions and tasks came up which could indeed profit from medication visualizations. First of all, recognizing double-prescriptions was mentioned in every interview. Double-prescriptions are prescriptions of equal substances by different doctors for the same patient, which are active simultaneously. Such incidents occur again and again. Following Benjamin's explanation, this is often caused by doctors not knowing of other medications being taken by the patient or by simply prescribing additional medications without checking unfamiliar ones. Second, effective visualization for proper exploration was favoured by all interviewees, as doctors have to read up on a patient's history regularly. Similar use cases were brought up. For example, Benjamin's cardiac-rhythm outpatient department is often visited by patients who are referred there by their registered physicians. Most registered physicians have already tried different medications but not found a suitable solution. Thus, Benjamin has to check the unsuccessful approaches before starting his own. Furthermore, warnings regarding allergies, interactions and side-effects were also desired by all interviewees. Interestingly, such a system is already deployed in Daniel's prescription-process, but he closes the information-popup about possible interactions and side effects before it has properly loaded. According to him, experienced doctors already know these things by heart for common medications. Daniel himself only checks the popup for medications not familiar to him. Adam also mentioned interaction-warnings being based on theoretical knowledge, which often does not really apply anyway. Moreover, filtering medications according to the indicating diagnosis was requested by Adam. Similar grouping requests came up during other interviews as well.

The tasks described in this section are difficult and tedious to achieve without proper visualizations. This confirms the usefulness of further research and development efforts in this area of application.

4.3.4 Sources of medication information

Currently, the interviewees obtain patient specific medication history data via the patients themselves, designated paper sheets from the registered physician and carried by patients, referral letters, discharge letters, the Austrian national electronic health record (ELGA), and the health record created and maintained by the particular hospital. However, these sources of information are sparse: All interviewees claim patients hardly being able to recite their medication. Benjamin stated names of medications being too complicated for elderly people to remember [Benjamin, 12:20]. As described by Christopher, only one third of all patients actually remember their medications, one third knows roughly the medications' names but not the dosages, and the last third has no clue but refers to their partner being the one keeping track [Christopher, 00:53].

The short analog medication and allergy report created by some registered physicians for their patients – as mentioned by Adam – holds a rough snapshot of the current patient-status. This comes in handy when patients are not able to list their medications. But as a sheet of paper is limited in size, thus no detailed and no history information are contained. Nonetheless, such information can be enough for the emergency department. Referral letters are made to deliver well funded and detailed information from one healthcare professional to the next and serve the receiving doctor as foundation for their further treatment. However, as mentioned by Daniel, not all physicians give an extensive description of the patient's medication history.

Discharge letters are mainly written by hospitals summarizing a patient's hospital visit. This letter should contain everything that has been done in the hospital including treatment with medication. However, as described by Benjamin these letters also do not always contain detailed information regarding medication data because the necessary time for writing such letters is lacking. Instead of listing both successful and unsuccessful tries and their results, most letters only contain effective medications, and other come down to "treatment was applied, patient leaves clinic ameliorated" [Benjamin, 14:00]. The clinical usefulness of such letters for other doctors is limited. Daniel confirms this condition in Austrian hospitals.

ELGA provides the missing information in the future, as the patient's medication history would be available for all hospitals. However, the project went live just recently and hospitals are still working on establishing the necessary linkage and interfaces. Furthermore, it will take some time until extensive health information is available via this electronic record. There are many additional factors, so we will have to wait and see how ELGA works out.

The main source of medication data in the Austrian hospitals of the interviewees is the patient's health record. Information about prescriptions originating from outside the hospital is usually added at patient admission – if available. In three of the four hospitals our four interviewees are working in medications are mainly documented on the paper-fever chart. However, according to Christopher, the documented data is often not sufficient as information is missing or hard to find.

Overall, the sources of information appear to be a heavily limiting factor for medication history visualization. Without available information, nothing can be visualized. Thus improvement of workflows, documentation practice, etc. is required.

4.3.5 Medication characteristics

As we only found shallow descriptions regarding medication and prescription characteristics or attributes in literature (see Section 3.3.1), we consulted our interviewees in order to create such a list.

1. **Substances**
   The active chemical substance (we relate to the active substance simply as "substance" throughout the thesis) determines the effect of the medication. A medication (=product) is composed of at least one **active substance** and multiple **help-substances**, such as binders or coating. Normally numerous manufacturers produce the same medication, which means the medications contain the same active substance. However, the help-substances may vary among these medications. So called combination drugs contain more than one active substance. We distinguish combinations with amplifying effects (all active substances target the same indication) and combinations of substances not targeting the same effect. A common example for the latter group is the combination of an analgesic and gastric protection.

   The help-substances of a medication do not depict a primary selection criterion according to Vera and Willi. Nonetheless, they can be of interest when a medication is not well tolerated by the patient.

2. **Medication's name**
   The name is often composed of the term of the active substance and a manufacturer specific suffix, e.g., "Sertralin Sandoz" (with "Sertralin" being the chemical substance and "Sandoz" being the name of the producing company) or "Sertralin ratiopharm" ("Ratiopharm" being the name of another company producing medication containing Sertralin). But not all medications follow this pattern, some names do not contain any hints regarding the contained substance (e.g., "Adjuvin", which is also containing Sertralin).

3. **Form and method of administration**
   Medications cannot be clearly identified by their name, as some medications are available in multiple forms of administration - short "form": Coated tablet, chewable tablets, pills, capsules, vials, gel, (eye-)drops, etc. Further differences exist within some forms. Vials can be diluted with a NaCl-solution and injected subcutaneous, intramuscular or given intravenous. As a consequence, the method of administration – short "route" – (oral, IV, subcutaneous, etc.) has to be documented as well. Thereby, the form of application influences the way medications take effect. For instance, medications injected directly into the bloodstream are commonly taking effect more rapidly than when taken as pills. Because of this ambiguity the form is often concatenated to the name of a medication.

4. **Dosage per unit**
   The unit of a medication depends on the form of administration. For medications

in pill-form a single pill represents a unit, thus the dose contained in a single pill constitutes the dosage per unit. As many medications are available in different doses per unit, it is necessary to provide the exact dosage per unit to enable identification. For instance: Sertralin Sandoz 50 mg-pills and Sertralin Sandoz 100 mg-pills. The dosage per unit can also be a percentage depicting a concentration (e.g., eye-drops "Timoptic 0.5%"), or of another unit.

When a medication contains multiple substances, each substance has a dosage-per-unit. For example, the medication Eucreas is available as a tablet containing 50mg Vildagliptin and 1000mg Metformin.

5. **Faster/slower effect**
For some medications special variants are available which take considerably less or more time to take effect. The former are indicated via the keyword "RAPID" and are lasting shorter, while the latter, indicated via "RETARD" or just "RET", are long-lasting. Consequently, this information is required for identifying medications as well.

6. **Instructions (frequency)**
The instructions contain detailed information about scheduling medication intake, for instance, "1 vial once a week subcutaneous". This example is a weekly intake-pattern/schedule, but daily intakes as well as single intakes are probably even more important.

The daily intake-pattern commonly used reads as "M-M-E-N". The letters correspond to morning, midday, evening, and night ("night" rather refers to "before going to sleep" than "in the middle of the night") and are replaced by the dosage to be taken at that time of the day: "1-0-1-0" would indicate one pill should be taken in the morning and one in the evening. The last dose is often omitted, as nightly doses are not as common, thus in most cases the representation will look like "x-x-x". It should be noted, that doctors use this representation when talking to each other as well. Although this pattern being probably the most used one, it was surprisingly hardly mentioned in the visualization projects found in literature.

In contrast to daily patterns, single intakes are not repeated and can therefore be represented by the dose alone. Weekly patterns, such as "twice a week", are thereby quite complex, as they introduce uncertainty about the actual day of intake.

7. **Dosage**
The dosage is usually not written on the prescription. It rather has to be calculated using the instructions as well as the dosage-per-unit and depends on the time-frame of reference. Normally, the timeframe of reference is one day. For example, when a 50mg pill should be taken daily at morning and evening (1-0-1-0) the daily dosage would add up to 100mg. If the 50mg pill is switched to a 100mg pill and the instructions are adapted to one intake in the morning only (1-0-0-0) the daily dosage remains the same (100mg). Thus, displaying the total daily dose for daily intake patterns is expressive.

It gets more complicated when considering medications that are not taken daily. For example, what time-frame of reference should be taken in case of a medication being taken twice a week? We can calculate the dosage for a day of intake, but the result would be incorrect for the four days of the week without medication intake. When using a week as timeframe of reference, the total dose would add up to twice the daily dose by simply summing all dosages of the week. While this would correspond to the total dosage taken by the patient throughout the week, we lose information about the distribution. For example, taking the 50mg pill twice a week and taking the 100mg pill once a week would result in the same weekly dose of 100mg. However, one aspect almost enforces the use of daily dosage-calculations: the maximal recommended daily dosages. All medications provide a maximal recommended daily dose in order to prevent doctors and patients from overdosing their medication intake. Doctors know these safety limits by heart, thus they are also trained to recognize overdosed medications in health-records. Mixing daily doses and weekly doses would make recognition of overdoses hardly feasible. Additionally, some prescriptions do not provide the information required to calculate a medication's dosage. This applies particularly to insulin-therapy, as the required dose depends on the current blood glucose-level. Therefore, diabetic patients have personal schematics for calculating the actual dose needed. Consequently, the dosage is unknown until intake and the instructions of the prescription simply point to the patient's schematics. Other medications have similar dependencies, such as Marcumar, which is adjusted to the blood-coagulation value (INR-value) via a patient-specific table.

Overall, mostly dosages have to be calculated based on instructions and appropriate time-frames of reference, but for some medications the dose cannot be determined in advance.

8. **Prescription Duration**
   According to Vera and Willi the duration of prescriptions is not always set and can vary vastly. Some prescriptions might only cover five days (e.g., antibiotics) or even a year.

9. **Number of units per pack**
   The information about the number of units contained in a pack (e.g., 30 pills) has to be filled in on prescriptions, which are to be redeemed at an pharmacy by the patient. According to Adam it is important to fill in the correct number, as some pharmacies reject prescriptions with an invalid number of units per pack. However, this information is not required in hospital environments, as other workflows regarding medication distribution apply. In hospitals, patients receive their medications directly from the ward-nurses or doctors on a daily basis. Only when the hospital-doctor issues discharge-prescription or other prescriptions which the patient has to redeem, the number of units per pack is also required.

10. **Number of packs per prescription**
    The maximum number of packs per prescription is defined by the Austrian health insurance for each medication but has to be filled in by the doctor for prescriptions the patient redeems at a pharmacy.

11. **Expected time of depletion**
    The time when the prescribed pack of medication is depleted can be calculated or estimated and is especially useful to find medication abuse. This is primarily relevant for registered physicians as the patient picks up the medication from an arbitrary pharmacy. The patient can redeem the prescription at a pharmacy and come back to the doctor a week early for the next prescription. If the doctor does not keep track of the expected and actual time of depletion, it is easy to miss such a behaviour pattern. The Austrian ELGA-system should actually support doctors in recognizing medication abuse by providing all medications prescribed by different doctors. As the launch of the ELGA-system has not been completed by the time this paper was finished, we are not able to determine its success. Nonetheless, as hospital staff dispenses only the daily medication dosages per patient, the expected time of depletion does not make sense for hospital-internal prescription.

12. **Price**
    In Austria, for each medication a retail price for as well as a health-insurance-specific price exist. The former is applicable when the medication is not covered by the health-insurance and has to be paid by the patient, the latter is paid by the health-insurance to the pharmacy in case of coverage.

13. **Obligation for prescription**
    Some medications can simply be bought at a pharmacy. Other medications require a prescription and are not obtainable without one. In the latter case, prescription regards to the official (paper-) document filled out and signed by the doctor. These rules apply to all parts of Austria and need to be taken into account when proposing medications to patients.

14. **Side effects, contraindications, interactions, etc.**
    Information on side effects, contraindications, interactions with other medications, and numerous further details are available in books (e.g., "Austria Codex") as well as online (e.g., the online portal of the "Austria Codex"). Christopher brought up the printed book being held available in his department as a backup option, while most other interviewees only mentioned the online-portal being utilized. To provide easy access to this advanced information, simple links to the medication-specific online-site should suffice.

15. **Indications**
    Each prescription has a specific indication – a diagnosis, a symptom, etc. Documenting the indication for each medication makes treatment-histories more comprehensible, but this information is not always recorded according to the interviewees.

Additionally to the prescription's indication the reasons for dosage changes, time of intake, and discontinuation are important to know. We put this attribute late in the list, as it does not depict medication-inherent data but rather a link to some other information recorded in the EHR.

16. **Current stock in hospital**
Daniel does in fact see, if a specific medication is in stock. Thus, Daniel is able to prescribe medications according to their availability. This can be of interest, as hospitals do not necessarily always have the same medications in stock but may switch manufacturers. Adam also mentions the necessity to sometimes switch medication manufacturer of specific medications because of availability. Thereby, these changes caused by availability issues are not meant to be interpreted just like ordinary changes in medications, but are rather temporary. But as the medications' looks differ among manufacturers, patients eventually believe receiving wrong medications.

Attributes 9 to 13 seem to be less relevant for hospital-internal prescriptions, because of the internal workflows.

Classifications

Different classifications can be applied to medication prescriptions. This section describes medication classifications that came up during the interviews. Interestingly, all interviewees mentioned numerous classifications used by them simultaneously. Thus, the classification listed below should not be seen as exclusive-categories. For example, Christopher clusters the medications in his medical report in the following way: coagulation-medication, antibiotics, antihypertensive, and everything else.

a) **Method of administration**
As described by Christopher, intra-venous medications are highlighted or displayed separated from the rest of the medications.

b) **Substance-group/effect**
Adam and Christopher emphasized coagulation-medication being of most importance and thus needing grouping and highlighting. Christopher's second group (far behind coagulation) is depicted by anti-infectiva (antibiotics, virostatics, and antifungals). Daniel's system further highlights medications for diabetes and analgesics.

c) **Relation to the hospital-visit**
Medications taken during the hospital visit are categorized as "in-hospital" medication. All medications taken before the visit are called "pre-admission" medications, while medications active after the hospital visit are so called "discharge"-medications. Medications can belong to more than one group, e.g., a pre-admission drug can

be continued throughout the visit as in-hospital medication and also prescribed as discharge medication to be kept active after discharging the patient.

d) **Prescription-duration/type of scheduling**
Many medications are prescribed to be taken for long time. Such medications are called “permanent medication”. Doctors provide the necessary information regard intake-schedule via the prescription-document. In contrast to permanent medications healthcare professionals can order a “single administration”. Thus, the medication is administered only once. The third variant is to prescribe medication “on-demand”, which can easily be illustrated with analgesics. The doctor prescribes a specific analgesic, but the nurse only administrates this medication when the patient is in pain.

e) **Active - inactive**
Distinguishing active and inactive (discontinued or paused) medications is a necessity for healthcare professionals. It has to be pointed out, that this classification is relative to the point in time looked at. Displaying currently active medications is trivial resulting in a snapshot of the current situation. But when exploring medication histories back in time, the active medications change.

4.3.6 Peculiarities of the hospital/healthcare domain

Hospitals do not depict ideal environments, thus not everything is going according to plan. In this section imperfections mentioned by our interviewees related to medication handling in hospitals are described.

The **planned time for medication intake and actual time of intake** can diverge vastly. The following example was given by Benjamin: Patient P should take medication M at midday, but has a medical appointment at that time. Therefore, the patient is not in his room but waiting in front of the examination room. It is not unusual for patients to wait an hour or more until being examined and the examination might take another hour. Afterwards the patient waits one more hour until he is brought back to his room. As a result, the medication is taken in the afternoon rather than at midday. When the medication consists of pills waiting at the patient’s bedside, it is hardly feasible to track the exact time of intake. And despite the exact time of intake mostly being out of interest, it has to be kept in mind that non-emergency departments do not have the staff or equipment to document the exact time of intake for all patients.

On the other hand, all interviewees reported **intensive care units (ICU) being equipped superiorly** both technically and personnel-wise. Additionally, patients in the ICU are not leaving their beds but are monitored via computers constantly. This enables exact tracking of vital signs, medications, as well as medication effects on vital signs.

Configurability and customizability are a necessity when designing software for hospitals. Christopher described each ward having its own fever chart structures and style of documentation. For instance, some are highlighting intravenous medication in red others are using a table structure and sorting to group similar medications. Furthermore, Daniel emphasizes everybody being able to adjusting their interface individually, customizing the visibility of components according to their preferences and workflows.

An interesting factor influencing the validity of medication prescription histories was brought up by Vera and Willi. Multiple medications – products by different manufacturers – use the same substances in order to achieve the same effects. Nonetheless, Austrian doctors prescribe specific medications rather than the underlying substances. According to Vera and Willi, pharmacies sometimes give out medications different to those prescribed by doctors but containing the same substance. This is mainly done because of availability. As the underlying substances match, this is mostly alright, but it creates a gap between reality and documentation, which can further lead to confusion. It has to be noted that suchlike scenarios are not limited to pharmacies. For instance, general practitioners can also prescribe a different medication (product) than initially assigned by the hospital.

CHAPTER 5

Conceptual Design and Implementation

5.1 Model

Based on the information collected during the interviews, we established the following data-model for our prototype. The words printed in bold within the text are thereby referencing objects of our model. For better understanding the description, we also added a simplified class-diagram: Figure 5.1.

Prescription

A prescription specifies, which **medication** (=product) should be given to a specific **patient**. Both medication and patient are thereby unambiguous. Additionally, the prescribing doctor has to specify the prescription's **instructions** on how and when the medication should be taken by the patient. But as these instructions can be updated over time, the prescription holds a list of subsequent instructions. Thus, instructions are not modified directly, but rather replaced by new instructions. The old instructions remain in the list, as the progression of instructions is important. The instructions are thereby ordered chronically, as only one instruction-item can be active at a time. This allows us to show how a certain prescription changed over time.

Instructions

The instructions hold details about the **intake-pattern**, the intake **route** (intravenous, per-os, intramuscular, etc.), and the **doctor** who actually set up these instructions. Especially in hospital-settings, multiple doctors change a prescription's instructions over the course of a patient's hospital visit because of changing conditions. Thus the

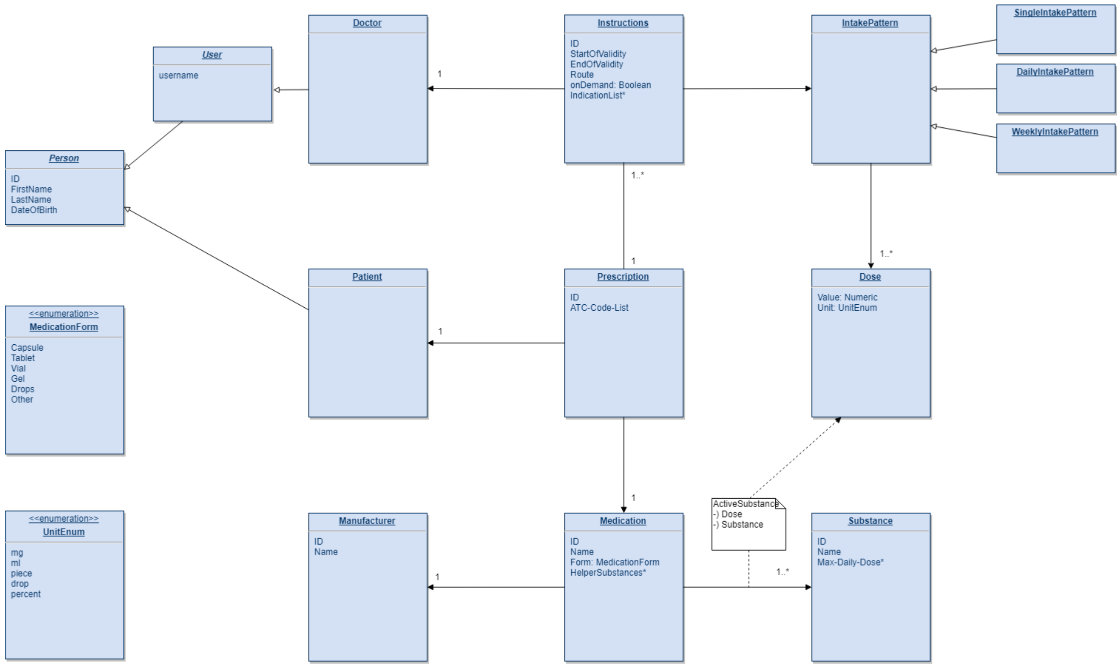

Figure 5.1: Data model. A simple version of the data-model implemented in our prototype.

prescribing doctor has to referenced in the instruction-item rather than the prescription itself.

As instructions can be replaced by newer ones each instruction-item has a period of validity. The start-of-validity has to be defined for each set of instructions, while the end-of-validity will often not be set to a specific date. As the progress of a patient can hardly be estimated precisely, it makes sense to leave the end of validity open and check the patient's conditions regularly. When the patient's health status changes, doctors adapt the prescriptions accordingly via a new set of instructions. Consequently, the end-of-validity is either defined in the instruction-item itself (when initiallising the particular instruction) or is determined by the start-of-validity of the subsequent instruction-item. This allows insight into the preceding plans and expectations of each prescribing doctor: Was the medication meant to be stopped at a specific date, or was its validity not restricted from the beginning.

Furthermore, medications can be prescribed "on-demand", which is implemented via the onDemand flag of each instruction-item. For instance, doctors regularly prescribe pain-medication on-demand, so that nurses are able to dispense it when the patient's pain is getting too intense. The documentation of medications dispensed on-demand can further indicate the development of the patient's health status.

As each set of instructions is based on some reasoning done by the prescribing doctor, documenting and keeping indications available is important for understanding the decision-process during exploration. Consequently, we added a list of indications to the instructionobject, but only implemented a simple version. The indications of our prototype are string-keywords, keeping a more complex approach using standardized codes for diagnoses, free-text, as well as relationships to other entities for future work. More details regarding the implemented indication-keywords are available in Section 5.4.2(> Prescription-Timeline-view).

Intake-Pattern

The intake-pattern specifies the actual dose and frequency of medication intake. We implemented the most important patterns: single-intake (only holds a single dosage) and daily-intake. The latter is composed of four dosages, each representing one item of the "M-M-E-N" pattern. A weekly pattern was also implemented by combining seven daily intake-patterns, but this approach fails for vague instructions like "twice a week", which are regularly used and allow the patient to adapt their intake-schedule to their liking. Thus, weekly as well as irregular patterns have to be considered in future approaches as well.

Medication

A prescription always specifies which exact medication should be taken by the patient. Thereby the medication refers to the actual product produced by a pharmaceutical-company. The main characteristics of a medication are: its name, the active-substances, its manufacturer, and helper-substances. Not only active-substances are stored per medication, but also the dose of each active-substance.

We skipped the helper-substances in our implementation, as these are not primarily important and should foremost be available in detailed medication descriptions found in medication archives.

Substance

The (active-)substances represent the actual chemical substances. They are characterized by their name and normally a maximal daily-dose is stated for these substances in the medication's information leaflet as well as medication archives, websites, lexicons, etc. We also planned on representing the maximal daily-dose for each substance, but saved it for future work, as this matter is more complex than adding a simple maximal-dose. The maximal doses stated in the sources listed above come with an extensive list of exceptions and special regulations based on the patient's age, various diagnoses and symptoms, duration of intake (how long the medication has already been used by the patient), the patient's responsiveness to the treatment, etc. Just showing the standard maximal-dose would thereby risk displaying an incorrect value, which did not seem acceptable. Calculating the correct maximum would require all this information being encoded for automatic processing.

Dose

Our dose-object holds the numeric dosage-value as well as the unit of the dose. For our simple prototype we used an enumeration to represent different units and only provide those we came across regularly: milligram, millilitre, microgram, piece, drop, percent, unit (“IU”, represents a international unit for the effects of a specific substance, e.g., utilized for insulin-dosages), as well as combinations such as milligrams per millilitre and unit per millilitre.

It is important to note that one prescription normally holds multiple doses with different units. As described in the previous Section 4.3.5, a medication has a dosage-per-unit for each active-substance, for instance, one Eucreas tablet 50mg/1000mg contains 50mg Vildagliptin and 1000mg Metformin. In addition to the dosage-per-unit the intake-dosage is defined in the intake-pattern. For the given example of tablets the intake-doses would use the unit “piece”: 1-0-2-0 would stand for 1 piece in the morning, 2 pieces in the evening. The total-daily-dose taken by the patient is calculated based on the dosage-per-unit and intake-dosage for each instruction-item. This calculation is simple for single-intakes and daily-intakes, as dosages can be multiplied – for our example the dosages would total to 150mg Vildagliptin and 3000mg Metformin per day. But for weekly intake-patterns it is not possible to calculate a general total-daily-dose. Therefore, we calculate the maximal-daily-dose for such intake-patterns instead (this refers to the maximal dose that is taken by the patient based on the prescription, which is not equal to the maximal-daily-dose recommended for a specific substance as described in Section "Substance" above).

Now we look at some common scenarios and how these would be realized in our model:

- Switching medications:
  Switching to another medication (product) would mean first discontinuing the current prescription and creating a new one. This matches the current workflow in Austria closely, as doctors would cross-out the prescription and write a new one.

- Changing dose:
  Lowering/increasing the dose can be achieved by updating the instructions (technically: adding a new instruction-item which renders previous instructions invalid.

- Discontinuing prescriptions:
  Prescriptions can be discontinued by setting the dose to zero or specify the end-of-validity date.

Overall, we think our model is fairly suitable for representing prescriptions and their characteristics. Nonetheless, there are still several elements that have to be expanded in the future.

5.2 Project structure and frameworks

Our prototype is composed of Javascript, HTML, and CSS. As, all functionality is implemented in Javascript, we relied on some frameworks and plugins to reach our goals:

- D3.js [1]
- ColResizable [2] - making table-columns resizable
- jQuery ContextMenu [3] - A plugin for creating context-menus.
- jQuery Treetable [4] - A plugin for creating a tree-table out of a basic html-table.
- underscore.js [5] - This plugin was only used for comparing Javascript-objects for equality

Overall, the prototype is basically an HTML-website with lots of Javascript. Therefore, it can simply be run with any local webserver.

5.3 Data-mapping

We implemented a simple data-access-layer (DAL), which reads csv-files holding example-data for the prototype. The content is parsed into the model-entities, resulting in a list of prescriptions. The list of prescription as loaded by the DAL is not used directly in the visualization. Such lists can hold large numbers of prescriptions, which have already been inactive for years. Furthermore, one medication and its generics might have been prescribed numerous times during the past throughout different prescriptions. A list holding all prescriptions could easily exceed the available display-space. For example, the prescription-visualization by Ozturk et al. (see 3.1.2) fills multiple A4-sheets of paper with prescription-list-items.

In order to reduce the required space and the information-overload we introduced a hierarchy-structure (tree-structure), which allows us to group similar prescriptions and create a condensed summarization for each group. We decided on using the following prescription-characteristics for the hierarchy-levels:

- substance
- medication's name

[1] https://d3js.org/ (01.02.2018)
[2] https://github.com/alvaro-prieto/colResizable (01.02.2018)
[3] https://github.com/swisnl/jQuery-contextMenu (01.02.2018)
[4] https://www.jqueryscript.net/table/Treeview-Style-Hierarchical-Table-with-jQuery-D3.js-Treetable.html (01.02.2018)
[5] http://underscorejs.org (01.02.2018)

- activeness

Figure 5.2 shows an example of such a tree-structure for nine medications containing two different substances.

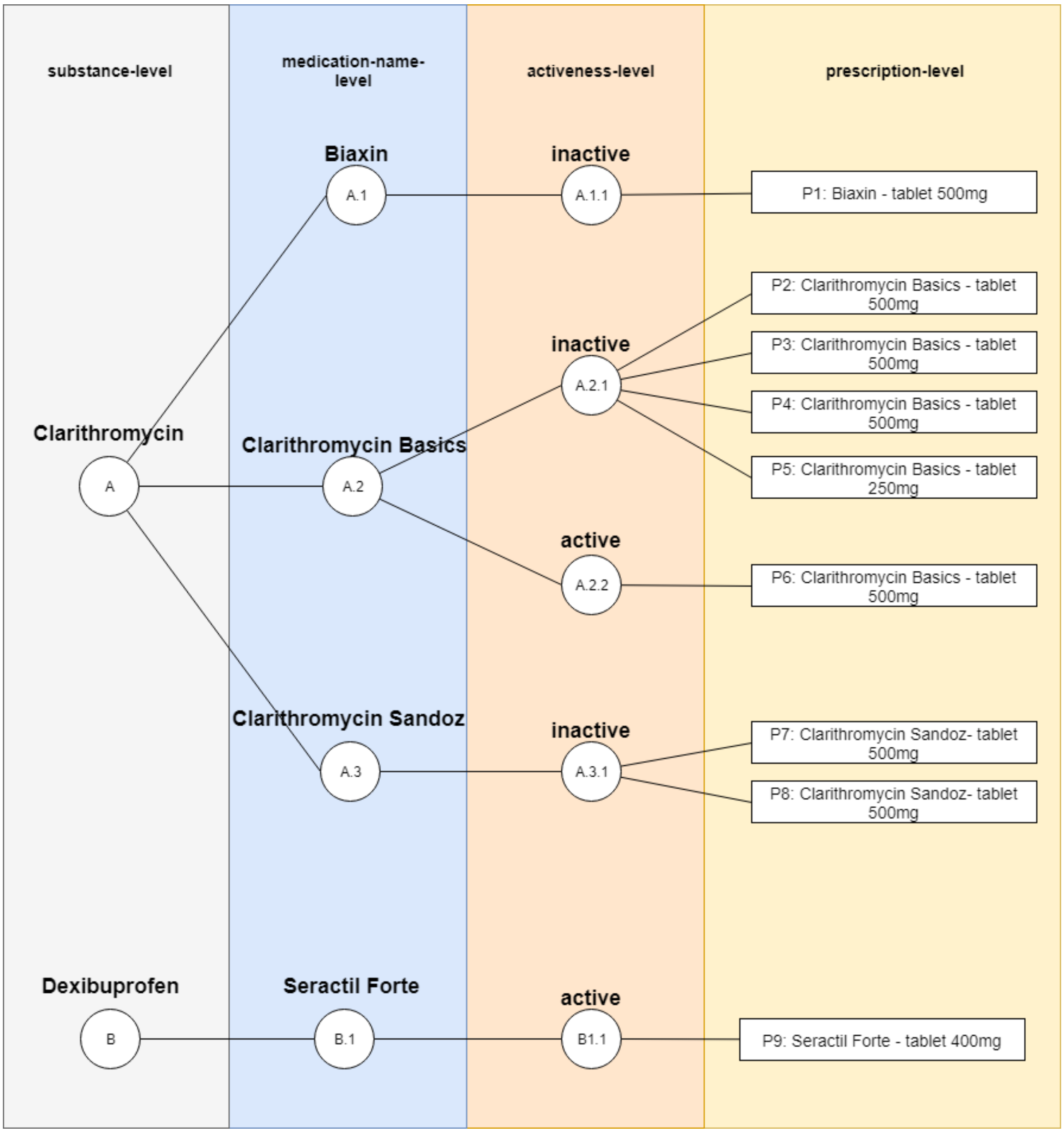

Figure 5.2: Hierarchy-structure. Example hierarchy-structure for nine prescriptions (P1 – P9) with two different active substances (A, B).

All prescriptions containing the same substance were grouped to form the hierarchy's base-level. This was done because of three reasons: 1) The medication's active substances are accountable for the medication's effects on the patient. Each substance has a specific

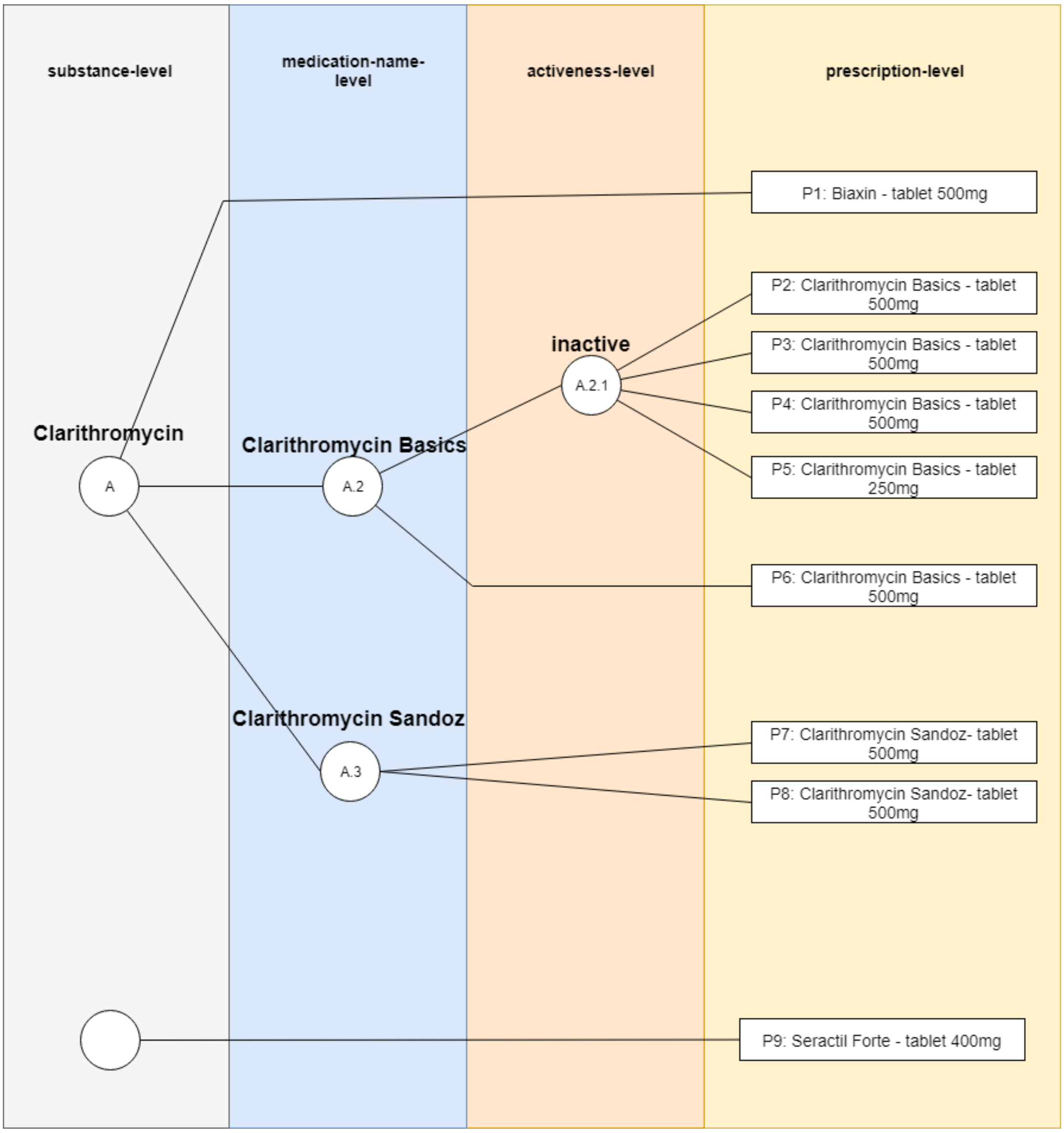

Figure 5.3: Flattened hierarchy-structure. The flattened hierarchy-structure of the previous example (see Figure 5.2) after flattening was applied. The number of nodes is drastically reduced to lower the visual overhead.

effect which does not change across medication products (generic drugs use the same substances). 2) Normally, numerous medication products of different manufacturers contain the same substance and are therefore (mostly) interchangeable. 3) Although some names of medication products are based on the active-substance contained (substance-name + manufacturer-name), a lot of times a medication's name does not reference its substance (see Figure 5.2 prescription P1). As the effects are determined by the substance, the name of the substance is more significant than the actual name of the medication product.

For the next hierarchy-level prescriptions are grouped by names of the prescribed medications. This works especially well for frequently prescribed medications and medications which are available in various doses per unit. For instance, when a patient was prescribed a specific medication five times in the past, these prescriptions would be grouped and summarized in a single item, thus reducing the number of items from five to one. Furthermore, all prescriptions created by switching between different dosed medication variants of a specific medication can be condensed as well. Given the example in Figure 5.2, tablets of the same medication with either 250mg (P5) or 500mg (P2-P4) per unit are grouped in a single item (see Figure 5.2 medications A.2).

We further group prescriptions by their activeness. Thereby, we use the current date as time of reference for calculating a prescription's activeness.

The leaf-nodes of the hierarchy-tree are depicted by the actual prescriptions. While swapping the hierarchy levels and expanding them is definitely useful, we kept the hierarchy-tree small and static for our prototype.

However, the resulting prescription-tree can have multiple nodes having only one single child-node (see Figure 5.2 nodes A.1, A1.1, A.3, A.3.1, B, B.1, B.1.1). We can optimize the data-structure by flattening such nodes without losing information or flexibility. We defined a minimal number of child-nodes per tree-level: substance – 2; medications' names – 2; activeness – 3. When the minimal number is not met nor exceeded, the node is removed from the tree and its child-nodes are appended to its parent node. The result of flattening the tree-structure for the example in Figure 5.2 is shown in Figure 5.3.

Flattening the tree-structure is especially useful for our table-structure, which is described in Section 5.4.2 (> The Prescription-(Tree-)Table).

It is important to point out a special case in our data-structure. Medications which contain multiple active-substances belong to multiple substance-nodes. Consequently, they appear more than once throughout the tree. This has to be taken into account during visualization.

5.4 Graphical User Interface – composition

In order to apply the common Focus+Context visualization technique, we split the graphical interface into a context-area as well as a focus-area (see Figure 5.4).

5.4.1 Context-area

The context-area can further be split into 4 parts: **patient-information**, **total-time axis**, **context-time axis**, and a **controller-panel** for time interval selection (see Figure 5.5).

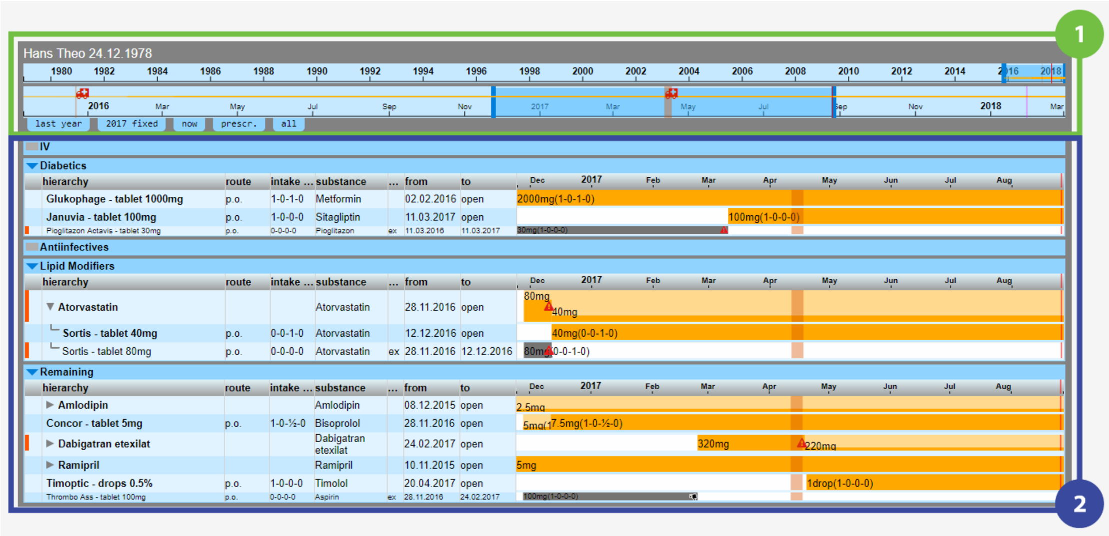

Figure 5.4: The interface of our medication history visualization. Context area (1) as well as focus area (2) are marked.

Patient information pane

- This pane holds a reference to the patient, whose medication history is visualized. Showing such information is necessary to ensure the correct record is open and providing context information like the patient's age. Additionally, the patient-identification (name, number of the medical-case) can be used for looking up additional information or asking colleagues.

- Our prototype only displays the patient's name and date of birth, as this section is not part of the project's focus. More information would be advisable, such as patient-status, allergy-warnings, etc.

Total time axis

- As showing the complete patient-history is not suitable for all tasks, the user can select a certain period of time to focus on. The total time axis component represents the unchangeable time axis of reference for further zoom- or focus-operations. This horizontal time axis is positioned beneath the patient information pane and utilizes the total width of the window. The start and end points of this time axis were selected to be the patient's date of birth and one month in the future. While in special cases it can make sense to show a larger period of time (showing prenatal health-status or the status of family members), we decided our total time-width to be a sufficient range for our prototype in order to cover most use cases.

- The height of the total time axis is kept low, as it is only intended as point of reference in time. This time axis can be utilized to select the time-period of interest intuitively via simple brushing techniques. This directly modifies the period of time shown in the **context time axis**. The selected time-period can be recognized by a color-highlighting and the vertical-selection-handles on the borders of the highlighted section.

Context time axis

- The context time axis is similar to the total time axis, but only displays the period of time, which is selected in the total time axis. Thereby, the time axis ticks and labels are adapted according to the available space (from yearly ticks up to daily ticks).
- The context time axis is positioned right beneath the total time axis and is both brush- and zoomable. The selected time-period is highlighted via color as well. Only the period selected in the context time axis is actually shown in the focus-view.

We decided to use two time axes as patient records can cover dozens of years which makes both navigating and keeping track of the overall picture hardly achievable. When only a few days are of interest, the selection would merely be visible on the total-time axis for such an extensive record. The context time axis provides flexibility during exploration and supports the mental model of the user. For example, Christopher is interested in three months of the last year of a patient's health record. Selecting one year on the total time axis of a 70-year-old patient is manageable, but the selected time-period is simply too small for further use. However, this year is now shown in the context time axis, which makes all months visible. Now the user is able to select one or multiple months easily while also seeing the adjacent months on the context-timeaxis. Thus, shifting by a quarter of a month becomes easy as well.

To further simplify the selection of time-periods of interest, we added the controller-panel.

Both time axes are initially not showing prescription-information. But when a specific prescription is hovered in the prescription-table, the respective duration is displayed in both time axes-views via a simple timeline-bar (This behaviour is further described Section 5.5.4).

Controller-Panel

- The controller-panel is positioned right beneath the context time axis, holding buttons for time interval selection. These buttons can be configured by the users and give them the capability to activate their most-used time-selections without brushing. This can fasten work significantly, as selecting the periods on both time axes via brushing requires more time and is not as accurate.

- Example for a useful configuration:
  Context time axis: show the last month; focus-view: show two days in the past and two in the future.

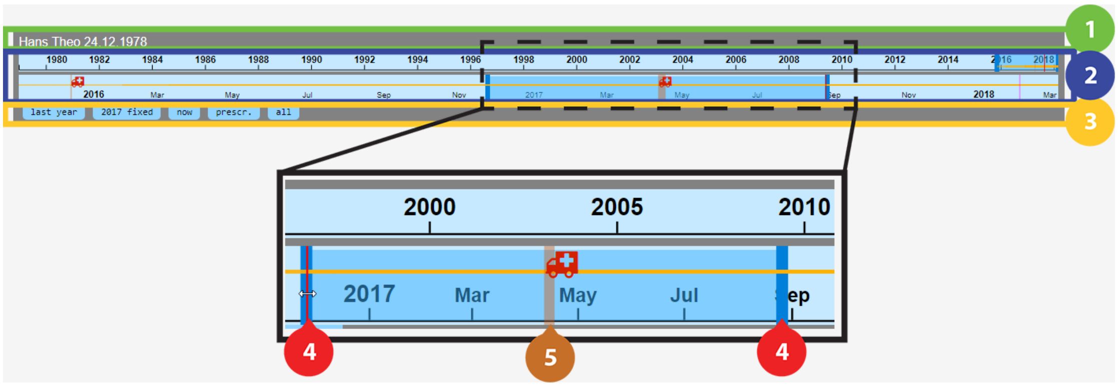

Figure 5.5: The context-area. The context-area consisting of the **Patient-Information-Pane (1)**, the **Total-time axis and the Context-time axis (2)**, as well as the **Controller-Panel (3)**. In the enlarged segment showing parts of the Total-time axis and the Context-time axis, the currently selected time-frame can be recognized by its light-blue overlay and the blue-vertical borders to its left and right end (4). These borders can be dragged by the user to resize the selected area. The area can further be dragged in order to pan along the time axis.
The enlarged segment also shows a mark highlighting a hospital visit (5), which can be recognized by the icon representing an ambulance.

5.4.2 Focus-area

Collapsible panes

The focus-area holds the actual prescription-data split into several sections according to user-specific filters. Each result set of the filters is shown in a separate collapsible Pane, similar to the facets implemented in LifeLines (see Section 3.2.3). Each pane has a header showing the name of the respective filter (e.g., “IV” for intravenous-medication, “Antiinfectives”, etc.) and a triangle indicating the current state (expanded – collapsed) of the pane (see Figure 5.6). Clicking the header toggles the state.

As the medication categories of interest change according to the doctor’s current task, this design enables the user to quickly hide unnecessary data and free display-space for medications of interest. When a filter does not return any matching prescriptions, the pane is collapsed per default and the empty result-set is indicated via a grey rectangle replacing the header’s triangle. The filters are described in more detail in Section 5.6. We used a table to structure the data inside each collapsible pane and combined the layout with a timeline-design.

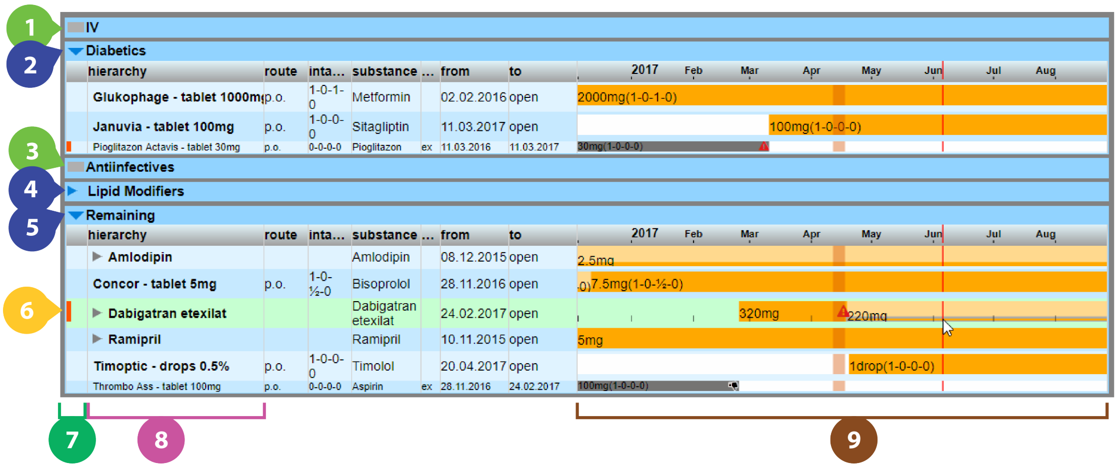

Figure 5.6: The focus-area with five collapsible panes (1-5).
The panes 1 and 3 do not contain any prescriptions, therefore they are collapsed and a grey rectangle is shown next to their name. Panes 2, 4, and 5 contain prescriptions, therefore a blue triangle is shown instead. The prescription-tables of pane 2 and 5 are visible, as the panes are expanded.
The currently hovered row (6) is highlighted with a green color. Furthermore, the highlighting column (7) of this table-row (first column) holds a red highlighting bar.
The header of the highlighting column (7) is empty. If a prescription does not match any highlighting-filter, its highlighting column is empty as well.
The hierarchy-column (8) holds either the substance-name, the medication's name, the activeness ("active", "inactive"), or the medication's name in combination with the medication's form and dosage-per-unit.
The timeline-column (9) contains the prescription-timeline-views and the column-header holds the time axis-ticks instead of a column-name.

The Prescription-(Tree-)Table

We decided to use a table-structure for our visualization because of the following advantages:

- well known to users in the healthcare-domain
- easy to understand
- detailed information with obvious structure
- simple and flexible handling:
  - hiding columns on demand enables the user to reduce visual- and information overhead while focussing on the relevant data
  - adapting the size of columns and changing their order based on content and the user's need

  - easy interactive sorting and filtering

- the hierarchy-tree-structure introduced in Section 5.3 can be represented in the table-structure

What's more, many previous visualization projects are lacking these advantages. Nonetheless, it has to be noted that we did not implement interactive sorting and filtering in our prototype because of the required effort.

We provide table-columns for most prescription-characteristics (e.g., name, route, form, substances, from-to-dates, etc.) and columns for combinations of multiple characteristics (e.g., route / form). Additionally, three special columns were added: Highlighting, hierarchy, and timeline (see Figure 5.6 nb. 7, 8, and 9). The column-visibility can be modified via the context-menu of the table-header. The table uses vertical borders between the columns for better structuring. We omitted horizontal borders and applied zebra-striping instead, in order to prevent cluttering the view with line-elements. The zebra-striping is done using different light-blue-tones, as these colors are not too harsh and – what's more – are not necessarily associated with any particular syntax. In contrast, red, yellow, and green tones are normally used for encoding data-characteristics.

Highlighting Users can define rules for highlighting similar to setting up filters for the collapsible-panes. For example, highlighting of insulin-medication and antibiotics is often applied in hospitals, according to our interviews. Thereby, setting up separate collapsible-panes for every medication type of interest is not sufficient, as the number of such medications is limited for most patients. This approach would therefore lead to many empty or nearly empty collapsible-panes, cluttering the screen and making it hard to gain insight. Additionally, these medications mostly belong to a more extensive group of medications (e.g., antiinfectives > antibiotics; diabetic-medication > insulins), so separating those more specific types of medication from their groups would also remove interesting context information. Consequently, highlighting special prescription-rows instead of separating them from similar ones is more promising.

We decided on a more discrete highlighting, which is clearly visible when looking for it, and just prominent enough to be noticed from the corner of the eye, as the highlighting should not be distracting from other information. The selected approach is similar to the highlighting applied in Daniel's list of medications. The highlighting-column in our table is filled with vertical colored bars, each referencing a matching filter-rule (see Figure 5.6 nb. 6). Thereby, the number of highlightings displayed at once is limited by space and also programmatically, as showing more than 5 colored bars at once becomes too messy. For prescriptions without any matching highlighting filters the highlighting column is empty. Utilizing a separate column for highlighting instead of integrating the highlighting into other elements of a prescription-table-row allows users to resize the area of highlighting according to their needs and also switch its position within the table.

Hierarchy As implied earlier, we actually implemented a tree-table structure (see Section 5.3), as our prescription-table holds hierarchical data. Basic table-designs are not able to display this hierarchy and would consequently reduce the benefit of our visualization. Therefore, we use a tree-table design, which indicates the tree-structure via indenting the rows representing child-nodes relative to their parent row. Actually, we only indent the elements shown in the hierarchy-column instead of complete rows. The users are able to hide child-nodes by clicking on their parent item.

This introduces two types of rows in our prescription-table. On the one hand, the tree-nodes, which are a parent to some other node, and leaf-nodes, which do not have child-nodes themselves. The former are either substance-nodes, medication-name-nodes, or activeness-nodes; each holding a list of prescriptions (the list contains all prescriptions that are descendants of the node). We are referring to these nodes as "merged-nodes" or "merged-rows" from now on, as they hold the information from multiple prescriptions. The rows of the second row-type are referencing one actual prescription each and will be referenced as "prescription-rows" from now on.

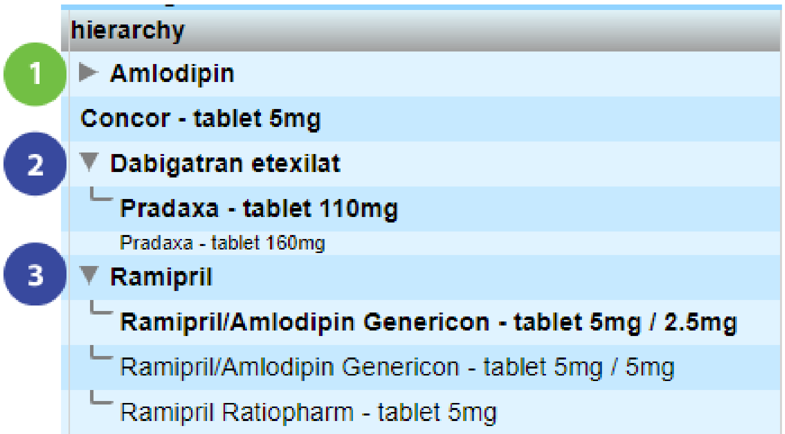

Figure 5.7: An example of a hierarchy-column.
The visibility of hierarchy-levels can be controlled via the hierarchy-column. The rows marked with (1), (2), and (3) are merged rows. Element (1) (Amlodipin) has some sub-elements, which is indicated via the grey triangle (arrow) to its left, but the sub-items are collapsed. The sub-items of "Diabigatran etexilat" (2) and "Ramipril" (3) are visible, which is indicated by the grey triangle pointing down. The visibility of sub-items can be toggled by clicking on the label of their parent.

a) **prescription rows**
The prescription table is primarily designed for prescription-rows, as each column corresponds to a prescription-specific characteristic. The columns referring to instruction-specific characteristics are filled with values of the latest instruction-item. The from/to date-columns are thereby filled with the start-of-validity of the first instruction-item and the end-of-validity of the last instruction-item. The hierarchy-column shows the medication's name, its form, and its dosage per unit, which should be enough information to identify the medication product.

b) **merged rows**
The column-values for merged-rows have to be calculated - if possible. For example, we do not display an intake-pattern or the route for merged-rows, as it is hard to show a summarizing representation for multiple prescriptions without cluttering the table. The user can simply unhide the child-nodes of the respective merged-row to display this information. The from/to date-columns correspond to the earliest start-of-validity and the latest end-of-validity among all prescriptions of the merged-row.

Table 5.1 shows all currently available columns of the prescription-table and descriptions of their respective content depending on the row-type.

Prescription-Timeline-view

The timeline-column is the most complex column in the prescription table (see Figure 5.6 nb. 9), as multiple types of data are combined and displayed in their temporal context. For displaying temporal information we decided on using a horizontal timeline similar to the context-view, as currently used fever charts in Austrian hospitals are always utilizing this orientation. Thus, prescription-timelines could easily be aligned or blended with other temporal information such as the patient's temperature or blood-pressure. We decided to show the timeframe from the patient's date of birth up to at least one month into the future (or any date in the health-record exceeding this point in time). This timeframe should suffice for most health-records, but use cases requiring even larger timeframes definitely exist. We refer to the borders of our timeframe as "min-date in the dataset" and "max-date in the dataset".

In addition to making the prescription-timeline compatible with state-of-the-art fever charts, we aimed at providing more detailed information directly within the timelines than previous approaches:

- duration of a prescriptions validity-period
- durations of the instructions' validity-periods
- dose over time: exact dose relative to the min/max dose for the specific patient
- intake-pattern over time
- activeness of the prescription
- indicating the reasons for instruction-changes

Table 5.1: Columns of the prescription-table
This table specifies the column-content for prescription-rows and merged-rows.

columns	**prescription-row**	**merged-row**
activeness	Contains "ex" when the prescription has been discontinued in the past. Otherwise empty.	Contains "ex" when the prescription has been discontinued in the past. Otherwise empty.
ATC-codes	A list of all applicable ATC-codes	A list of all ATC-codes applicable to at least one of the prescriptions
form	e.g., tablet, vial, powder, drops,...	-
form/route	A combination of the medication's form and route	-
From-date	The start-of-validity of the prescription's first instruction-item	The earliest start-of-validity date across all prescriptions of this row
Hierarchy	Displays the medication's name, its form, and dose-per-unit	Displays information according to the type of the merged-row: Substance-name; medication's name; "active", or "inactive". Clicking on the content of this cell hides or un-hides the child-rows of this merged-row.
Highlighting	For each matching highlight-filter, a vertical colored bar is shown	For each highlight-filter which matches at least one of the prescriptions, a vertical colored bar is shown
Intake pattern	Holds the intake-pattern of the latest instruction-item	-
Manufacturer	The medication's manufacturer	-
Medication	The name of the medication	The medication's name for medication-name-rows; empty for other types of merged-rows
Route	Holds an abbreviation of the medication's route, e.g., "p.o.", "IV", ...	-
Substance	A list of all active-substances of the prescribed medication	The substance-name for substance-rows; empty for other types of merged-rows
Timeline	Displays a prescription-timeline-view for the prescription of this row	Displays a prescription-timeline-view representing all prescriptions of this row
To-date	The end-of-validity date of the latest instruction-item	The latest valid end-of-validity date across all prescriptions of this row

Duration of validity The duration of validity is indicated by a simple timeline-bar, starting at the start-of-validity of the first set of instructions and ending at the end-of-validity of the latest instructions. If the end-of-validity has not been specified - leaving the instruction open-ended - the timeline-bar ends at the max-date in the dataset instead. Thus, the timeline-bar ends at the maximal x-position. A blue arrow pointing into the "future" indicates the prescription being open-ended for now (see Figure 6.1). This "duration-bar" fills the entire height of the prescription-timeline view and is colored in a light-orange tone.

While the timeline-bar shows the prescription's validity-period in an intuitive way, the information becomes invisible, when a time-frame is selected, which is not intersecting the prescription's duration. In that case, the prescription-timeline-view would be empty. In order to at least provide the period of activeness, we display a text-label holding the start- and end-date (see Figure 5.8 nb. 6).

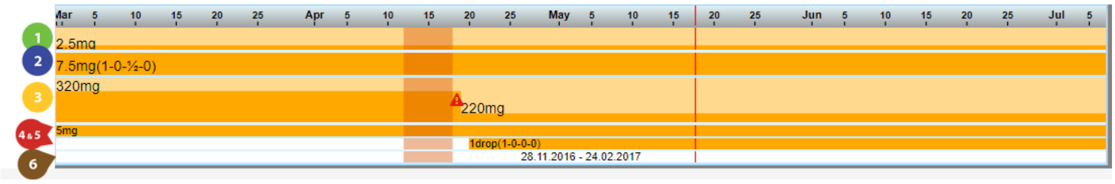

Figure 5.8: Prescription-Timeline-View.
This figure shows the prescription-timelines of six prescriptions.
(1) The first row is actually a merged-row, as no intake-pattern is displayed after the dose. It has a daily-dose of 2.5mg, but the patient has already received a higher dose at some point in his health-record. Therefore, the dosage-bar (intense orange) only fills about 10% of the timeline's height.
(2) The second row is a prescription-row with a dosage of 7.5mg per day. This dosage actually is the patient's maximal dosage of the respective prescription, as it fills the entire height of the timeline-bar.
(3) The third row was resized, thus its height exceeds the height of previous rows. For timelines of this height, the dosage labels are not shown in front of the dosage-bars, but above them, to enhance the visibility of the bars. At the same time, the maximal-dosage-bars do no longer fill the entire height of the timeline, but only about 80% to leave space for the text-labels. Its dosage changes in the selected timeframe, as depicted by the change in height of the dosage-bar and the text-label stating the updated dose (220mg). Additionally, the icon shown before the dosage-decrease indicates, that something unexpected led to dosage-reduction.
(4)+(5)+(6) Rows four, five, and six present the minimal height (heights are discussed in Section 5.5.2) for timeline-views. Dosage-bars of such timelines are always filling the entire height, as height-differences would hardly be distinguishable.
(6) The prescription's duration of this row lies outside the currently selected timeframe, therefore no timeline-bar is visible. Instead, the prescription's validity-period is shown in a text-label in the middle of the timeline-view.

Duration of instruction, dose & intake-pattern over time In addition to the duration of validity of an entire prescription, the duration of validity for each instruction-item is of interest, especially as we are able to calculate the dose for each instruction-item separately. We use a timeline-bar for each instruction-item ("dosage-bar"), utilizing its length to encode the duration of validity and its height to encode the medication's dose. The height is thereby calculated the following way: The maximum dose of all instruction-items of the given prescription will take the full height of the prescription-timeline-view. The smallest dose > 0 takes roughly 10% of the view's height. All dosages in-between the maximum and the minimum are scaled linearly. This ensures that all dosages over time are visible and their relation to the min/max-values can easily be derived. Nonetheless, identifying the exact dosage is hard due to the small size of the timeline-views in the table and due to no vertical axis being displayed. A separate axis for the medication's dose would be hard to read as well, therefore we simply use text to display the exact dose above the dosage-bar together with the respective intake-pattern (e.g., "7.5mg (1-0-1/2-0)") (see Figure 5.8 nb. 2). The text-label is moved horizontally when panning along the time axis, so that the dose-information stays always visible in the timeline.

The dosage-bar is shown in front of the duration-bar, as it is more important and provides more detailed information. In order to distinguish these timeline-bars, the dosage-bar has an intense orange-color.

Health-records can cover many decades but some prescriptions are only valid for a couple of days. The duration-bar of such prescriptions would not be visible when zoomed out, as their length would not exceed one pixel. To prevent these prescriptions from being missed by the user, we set the minimal duration-bar-width to be five pixels. This trade-off regarding accuracy in behalf of providing a complete outline of the patient's prescriptions is well justified. Users are always able to simply zoom in, in order to see an exact and more detailed representation. Simultaneously, announcing this approach to the users is crucial to prevent confusion.

Like the two types of prescription-table-rows (prescription-row and merged-row) we have to differentiate prescription-timelines for a single prescription and timelines for multiple prescriptions (merged-timelines). The description above applies to single-prescription timelines. However, we cannot use the prescription's instruction-items when multiple prescriptions should be represented in one timeline, as instruction-items of different prescriptions might overlap. Consequently, an additional processing step is necessary. Thereby, the total dose across all prescriptions is calculated for each start- and end-date per instruction-item, resulting in date-dose-pairs. These date-dose-pairs depict a sequence when sorted according to their date, which can be visualized along the time axis (see Figure 5.9).

It has to be noted, that dosage-bars are not able to convey the exact dosage-values for weekly intake-patterns. The most accurate representation for weekly intake-patterns would consist of single dosage-bars on each day of intake per week, which would result in significant holes along the time axis. While this would match the actual dose-distribution, the dosage-bars would become invisible when zoomed out and the holes would decrease intuitiveness. At the same time, more abstract intake-patterns like "two times a week" would be inaccurate as well, as the exact days of intake are not defined. We decided to

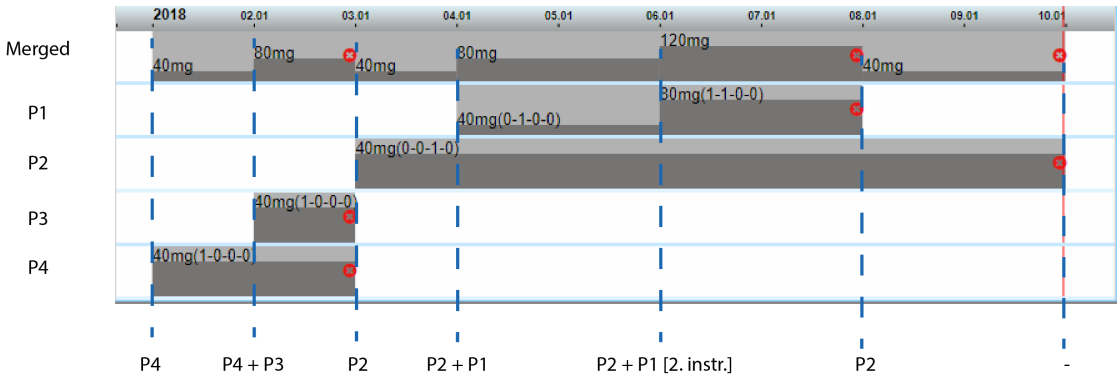

Figure 5.9: Merging instructions.
The first row ("Merged") combines all prescriptions (P1 – P4). This figure outlines the procedure of merging multiple prescriptions into this one merged timeline-view. The dashed vertical lines were added to mark the points in time, for which date-dose-pairs are calculated across all prescriptions. These pairs hold the total-dose for the given date as well as all prescription-instructions, which contribute to the respective dose. The text labels below the dashed lines state which prescriptions contribute to the date-dose-pair.

address the complexity of weekly intake-patterns by encoding the maximal daily-dose a patient receives within a week in the height of the dose-bar and this maximal-daily-dose in the associated text-label. To prevent the user from thinking the patient receives this dosage every day, it is necessary to make the weekly intake-pattern easily recognizable. Thus, a text-label also displays the short-description of the weekly-pattern (e.g., "2 x w") and the dosage-bar is surrounded by a dashed line (see Figure 5.10).

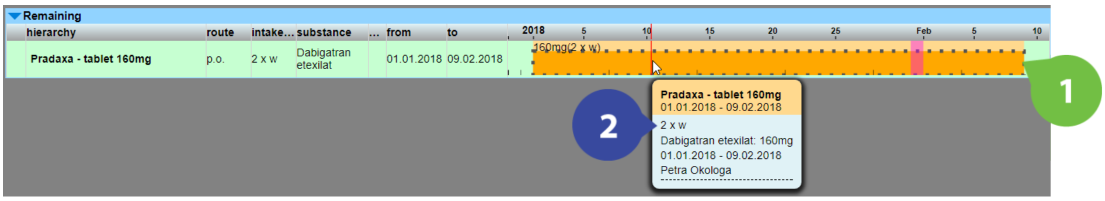

Figure 5.10: Weekly intake-pattern in the timeline-view.
A prescription with a weekly intake-pattern. The dosage-bar is surrounded by a dashed line (1) to make it recognizable as weekly intake-pattern throughout the timeline. Furthermore, the intake-pattern column holds the short-description of the weekly pattern ("2 x w"), which is also displayed in the dosage-information text in the timeline-view as well as in the tooltip (2).

Activeness Being able to distinguish currently active and inactive medications is essential for healthcare professionals, particularly when dealing with extensive lists of medications. Similar to the approach of Ozturk et al., we show the medication's name (inside the hierarchy-column) in bold for currently active prescriptions. Thereby, we classify prescriptions as "active", if the end-of-validity of the latest instruction-item exceeds the current date.

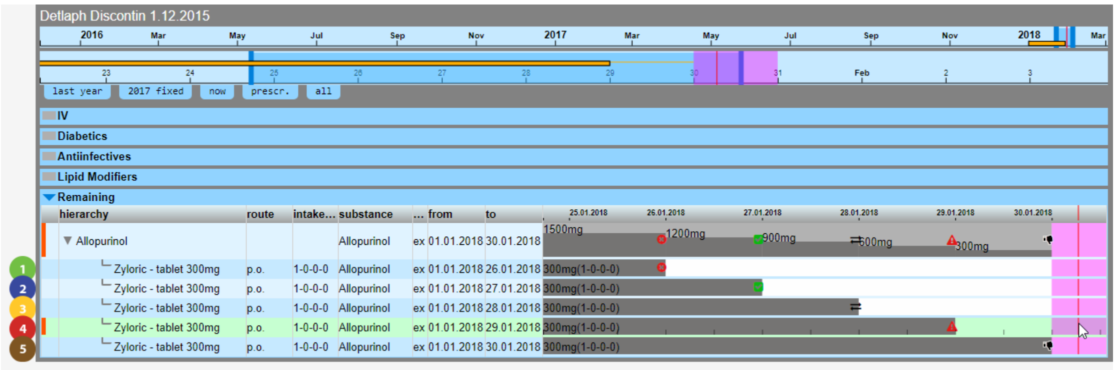

Figure 5.11: Examples for indication-icons.
The five discontinued prescriptions in this example demonstrate the icons marking the cause for discontinuation. The top-row (“Allopurinol”) is a merged-substance-row, representing all of the five prescriptions in one timeline. The icons from top to bottom are representing:
1) no specific indication for discontinuation given: default cross inside red circle
2) treatment was successful: check-mark inside green box
3) medication was replaced by another one: two parallel arrows pointing in opposite directions
4) occurrence of side-effects: warning sign – exclamation mark in red triangle
5) the medication’s effects were insufficient: a “thumbs-down” icon

In addition to using the font-styling to indicate activeness, the duration-bar is colored light-grey, the dose-bar dark-grey for inactive prescriptions. To highlight the time of discontinuation, we added small icons on the respective positions in the prescription-timeline-view (see Figure 5.11). The icons are discussed in more detail below.

Indicating the reasons for instruction-change The indications for a set of instructions are implemented as a simple list of keywords for now. Showing these keywords inside the timeline-view would clutter the view and occlude the timeline-bars, therefore we decided to use small icons to represent indications. However, showing one recognizable icon for each indication-keyword is hardly feasible, because these keywords can depict complex data such diagnoses, symptoms, other medications, therapy-status, etc. Additionally, the high number of icons necessary per instruction-item would clutter the view as well.

To cope with these difficulties we decided to show not more than one icon per instruction-item and introduced an icon-configuration, enabling the users to assigning their own icons for indication-keywords. Users are further able to prioritize icons, so that the most important information is conveyed for sure. Examples regarding indication-keywords, possible icons, and their priority can be seen in Figure 5.11 and Table 5.2.

On-Demand medications When an instruction-item is marked as “on-demand”, the prescribed dose is not necessarily equal to the dose actually taken. To make such on-demand instructions distinguishable from standard instructions, we colored them purple

Table 5.2: Indication keywords and icons
Some indication-keywords and the icons we assigned to them. They are ordered by their priority, with the highest priority-icon being on the top of the table. Users are able to configure these icons according to their needs and preferences. Furthermore, icons can be prioritized. When multiple keywords with icons exist for a given instruction-item, the icon with the highest priority is displayed.

keyword	Icon
side_effect	
insufficient	
replaced	
successful	
discontinued	

instead of orange. Additionally, the text “o.d.” is appended to the dosage-information and the intake-pattern of the instruction’s text-label (see Figure 6.3)).

5.5 Interaction

5.5.1 Tooltips

In order to provide more detailed information without cluttering the view, we implemented tooltips that are shown when the duration-bars of either instruction-items (for prescription-rows) or date-dose-pairs (for merged-rows) are clicked. Some examples can be seen in Figure 5.12. The following information is shown dependent on availability:

- medication’s name, form, and dose-per-unit
- period of validity
- activeness of the prescription – the activeness is also indicated by the color of the tooltip-header: grey = inactive, orange = active. When the prescription is inactive, “ex” is displayed in the tooltip-header supplemented by the indication-keywords of the last instruction-item.
- intake-pattern

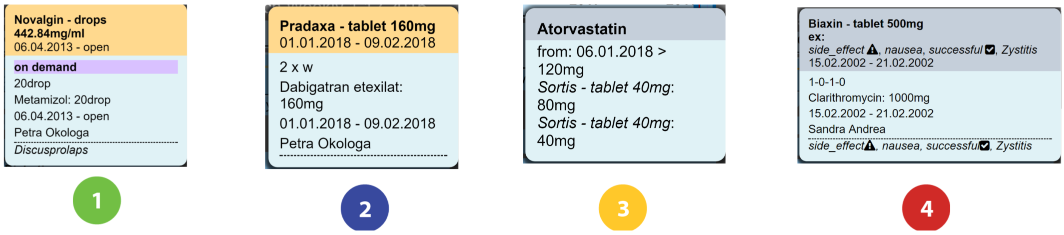

Figure 5.12: Examples of tooltips. Four tooltips for four different prescriptions (the tooltips were resized to match in height for this demonstration) are shown.
1) Tooltip of an active on-demand prescription. The parameters of the selected instruction-item are shown below the colored tooltip-header. The indication-keywords of the instruction-item are listed on the bottom of the tooltip.
2) Tooltip of an active prescription with weekly intake-pattern (first row of the instructions-section shows the short description of the intake-pattern “2 x w”).
3) Tooltip of a merged-row (substance-row). The substance-name is displayed in the tooltip-header. Instead of an instructions-section, the tooltip provides information on the selected date-dose-pair. All instructions of other prescriptions, which contribute to the given total dose of 120mg are listed in this section.
4) Tooltip of an inactive prescription. The indications of discontinuation are listed in the tooltip-header together with their respective icons. The instructions-section below the tooltip-header shows the indication-keywords as well, because the discontinuing instruction-item was selected for this tooltip.

- active substances and their total-dose
- period of validity of the clicked instruction
- prescribing doctor
- indication-keywords and their icons
- on-demand prescriptions
- for date-dose-pairs (merged-rows) multiple instruction-items of different prescriptions can contribute per date. Thus, all contributing instructions are listed with their respective share.

5.5.2 Hiding columns, resizing rows - context-menus

Users can resize columns and hide columns of the prescription-tables to make room for information of interest. While the former is achieved by dragging the borders of a column, the visibility can be controlled via a context-menu, which is shown when right-clicking the table-header.

Furthermore, users can resize the prescription-table-rows vertically. We implemented four pre-defined heights to choose from via another context-menu: large, medium, small, and minimal. The height can be chosen for each row individually. Larger heights allow a less cluttered representation, by displaying the text above the timeline-bars. The minimal height does not allow the dosage to be height-encoded in the timeline-bars, but saves space while still providing duration-information (see Figure 5.8 nb. 4,5, and 6). Overall, these interaction techniques can be classified as detail-on-demand visualization.

5.5.3 Zoom to prescription

To ease navigation it is possible to directly zoom to a prescription's duration in the focus-area via the timeline-context-menu. We also implemented an option to zoom to a duration +/- two days, in order to make some context-information around the period of validity visible. This allows to also see events that happened directly before and after the prescription's duration.

5.5.4 Hovering: reaction in context-view and vertical helper line

When the mouse is hovered above a prescription-timeline-view, the duration of the respective prescriptions is displayed in both timeline-views in the context-area (context time axis and total time axis). This allows retrieving the prescriptions-duration also when zoomed in on a short period of time within the focus-view. Furthermore, borders of the prescription's instructions are marked in the context-timeline-views and the currently hovered instruction-item is highlighted in a different color (see Figure 5.11 and Figure 6.2). Thus, users are able to see, if the hovered instructions have been changed and how long they were valid compared to previous or subsequent instructions.

To support orientation across all timeline-views (within both context- and focus-area), a vertical helper-line is drawn on the currently hovered point in time. As this line is constantly drawn and updated, users can easily find the point in time of interest when switching their focus from one timeline to another.

5.5.5 Resizing

The prototype can adapt to the available display space, thus it fits different screen-sizes and is also adapting to changes in size dynamically, for example, when the browser-window is resized by the user. This was achieved through CSS-styles and Javascript-functionality. However, the prototype was not designed for mobile devices, thus the prototype is hardly usable for widths below about 800px.

5.6 Filters for structuring and highlighting

Prescription-filters can be defined by users in order to setup multiple prescription-tables for different prescription-classes in their interface or highlight prescription-table-rows. We have not implemented an interface for defining such prescription-filters yet, but the filters are already working as intended.

We use a simple rule-based approach for setting up filters. Users can specify expected values for prescription-parameters (name of the medication, name of the substance, ATC-codes, activeness, etc.) resulting in parameter-specific rules. These rules can further be combined into rule-sets via Boolean-operators (e.g., “and”, ”or”). Rules and rule-sets can later be evaluated for specific prescriptions.

Despite the interviewed doctors being not familiar with ATC-codes, this medication classification is useful for setting up prescription-filters. For example, filtering all diabetic-medication can be accomplished by looking for ATC-codes starting with “A10”, while antibiotics can be identified by codes starting with “J1”. However, we have to note that some substances do not have such intuitive ATC-codes. For instance, the substance Amlodipin, which is prescribed in order to lower blood-pressure, is not found in the ATC-code-group of antihypertensives (“C02”), but in the group of calcium channel blockers (“C08”). While the assignment of Amlodipin to this group is correct as well, it is not as intuitive and complicates filtering for antihypertensive-medications.

5.6.1 Table-filters

Table-filters consist of a prescription-rule-set, the filter’s name, and a parameter indicating if all of the patient’s prescriptions should be considered or only those, which have not matched any previous table-filters yet. For each defined table-filter a collapsible-pane is created in the focus-view of our prototype. The header of the collapsible-pane shows the name of the filter, the matching prescriptions are shown in the prescription-table of the pane. If no prescription matched, the collapsible-pane is collapsed and its empty result-set is indicated by a grey rectangle next to the filter’s name.

The additional parameter, which indicates if all of the patient’s prescriptions should be considered, is significant for structuring the prescription-data, as it allows controlling the intersection of filter-result-sets. For example, doctors might be interested in a group of all medications with intravenous intake and a group of all antiinfectives. In order to get all remaining prescriptions that are in neither of these two groups, this option is activated. As a result, the doctors get three groups of prescriptions: intravenous, antiinfectives, and all remaining prescriptions (see Figure 5.6 nb. 5 - "Remaining").

5.6.2 Highlighting-filters

Similar to table-filters, highlighting-filters consist of a prescription-rule-set and a name, but in addition, each filter defines a CSS -class. The highlighting-filters are applied to all prescription-rows in all prescription-tables. For each matching filter a highlight-marker is added to the prescription-row’s highlight-column and the filter’s CSS-class is applied to it (see Figure 5.6 nb. 6 and 7). Consequently, changing the appearance of each highlight-marker can be easily achieved by editing the style sheet.

5.7 Summary

We created a data-model for prescriptions, which covers more than just the most important characteristics of medications as well as prescriptions and is able to represent the progress of prescriptions over time. Furthermore, a tree-structure for prescription-lists was constructed, which introduces multiple levels of granularity and detail within a allegedly “flat” list of prescriptions. This structure enables us to visualize numerous prescriptions in a compact form while keeping the option to go into detail whenever needed. The visualization combines the clear structuring of classical tables with intuitive timeline-visualizations. The latter displays not only the temporal prescription-information but also more sophisticated information such as dose, activeness, intake-pattern, and indications. Even more detailed information is provided via tooltips. Additional ways of structuring and highlighting prescription-data were introduced in order to further improve insight in large numbers of prescriptions.

CHAPTER 6

Scenarios

The presented scenarios were created with the help of two physicians in order to get a realistic medication history. The scenarios are not based on a specific person. Some common diagnoses and conventional corresponding medication treatments are described. We deliberately did not add timestamps and exact dates in order to not distract from the prescriptions.

6.1 Scenario A

6.1.1 Health record

Hypertension

The patient was found to suffer from hypertension, thus *0.5 tablets of Ramipril Ratiopharm 5mg per day* were prescribed by the physician. After two weeks, the dose was increased to *1 tablet per day*, as blood pressure was still too high. After another two weeks, the medication was replaced by *Ramipril/Amlodipin Genericon 5mg/5mg 1 tablet per day*, to further decrease blood pressure. During summer, about half a year later, the patient complains about dizziness, thus the dose is decreased by switching to the similar medication *Ramipril/Amlodipin 5mg/2.5mg*. Just as before, the validity of the prescription is not restricted by the doctor at the time of prescribing.

Diabetes

Simultaneously to hypertension, the patient suffers from high blood-glucose levels. As a base-therapy *1000mg Glukophage 1-0-1 (daily intake-pattern)* is prescribed open-ended. But as sugar-levels are getting worse after three years, *Pioglitazon Actavis 30mg 1/day* is added. However, after another year of taking *Pioglitazon* the patient reports swollen legs, which is probably a side-effect of *Pioglitazon*. Therefore, that medication is replaced by *Januvia 100mg 1/day*.

Stroke

In older age, the patient suffers a stroke. To treat the stroke, *Thrombo Ass 100mg 1/day* is prescribed (a heamodilution) to reduce the risk of thrombosis by reducing blood coagulation. This medication is anti-inflammatory, pain-relieving, and antifebrile as well. Additionally, the cholesterol-level should be lowered via *Sortis 80mg 0-0-1*. However, three weeks later negative effects on the liver function are registered, a typical side-effect of treatment with this medication. As the 80mg-tablet cannot be split in half, the medication has to be replaced by *Sortis 40mg 0-0-1* to reduce the daily-dose.

Atrial Fibrillation

Three months after the stroke atrial fibrillation is detected, hence *Thrombo Ass* is not strong enough anylonger. *Thrombo Ass* is replaced by *Pradaxa 160mg 2/day*, but after two months severe bleedings prompt to reduce the dose to *Pradaxa 110mg 2/day*. Furthermore, *Concor 5mg 1/day* is added, which is a Beta-blocker lowering the heart-beat. As the heart-beat is still too high two weeks after the diagnosis was made, the dose is increased to *1-0-1/2 per day*.

Ocular Hypertension

The patient's ophthalmologist prescribes *Timoptic 0.5% 1-0-0* to reduce the intraocular pressure.

6.1.2 use case

In this scenario, the doctor does not know the patient and wants to become acquainted with the medication history. Thus, intolerances, side-effects, (in-)effective treatments, and current medications are of interest. We now present how the given health-record is visualized in our project. The user starts by selecting the timeframe which holds the entire available prescription-data.

The user selects a timeframe which allows to see all available prescription-data (see Figure 6.1). Due to our table-filter-configuration, the active intravenous prescriptions are listed in the first collapsible pane. As the pane is collapsed and shows a grey rectangle, it is obvious that no such prescriptions exist currently.

Right below, the diabetic-medication is displayed in a separate collapsible pane. It is easy to recognize that no insulins have been prescribed yet, as insulins would be highlighted by a purple vertical bar in the highlight-column, as setup in our filter-configuration. However, *Pioglitazon Activis* is highlighted with a red bar, which marks medications that caused side-effects or other sorts of trouble. Regarding the diabetic-medication, the grey color of the marked prescription *Pioglitazon Activis* indicates, that the prescription has actually been discontinued, with the exact time of discontinuation being available in both the table-column and the timeline-view. The tooltip specifies the troubles caused by the prescription being swollen legs. The position of the icon representing the prescription's troubles reveals that the prescription was probably discontinued after these troubles appeared. The duration-bars of the diabetic-prescriptions indicate that the troubling prescription was probably replaced by *Januvia*. The dosage-bars indicate, that the dosages of the diabetic prescriptions have not been changed over time, thus the patient was presumably responsive to the treatment and his diabetes quite stable.

Atorvastatin – the next row inside the pane of lipid modifiers– is actually a substance-row, combining the information of two prescriptions. Just as seen for *Pioglitazon*, the red highlight-marker indicates that something unexpected happened. The user zooms-in in order to get a better view on the lipid modifiers (see Figure 6.2).

The dosage-bar reveals that the dosage was dropped over a year ago when troubles occurred, but has not been changed since then. More information can be accessed when expanding the sub-rows showing the actual prescriptions as well as activating the tooltips (cause: bad liver function). Additionally, it is relatively easy to spot that *Thrombo Ass* was prescribed at the same time as the first medication containing *Atorvastatin* due to the aligned timelines. We expect these prescriptions being interrelated in some way. The tooltip confirms this assumption, as the prescriptions' indications match (in this example: stroke). Given the relationship of these prescriptions, users are instantly able to see, that *Thrombo Ass* has been discontinued in the meantime due to inefficiency (hinted by the thumbs-down-icon), while *Atorvastatin* is still active. As discontinuing one of two interrelated prescriptions while keeping the other would be odd, we are now looking for prescriptions replacing *Thrombo Ass*. Positioning the mouse-pointer at the date of discontinuation of *Thrombo Ass* sets the vertical helper line to this point in time, which can be used to find matching prescriptions (see Figure 6.1). This leads us to *Concor* and *Dabigatran etexilat*, as both were started when *Thrombo Ass* was discontinued. Sorting according to the date, which the prescriptions were started on, would definitely be helpful in this situation.

From this point on, the remaining prescriptions can be tracked and explored as prescribed above. Searching for this information in a textual-report among pages of lab-test-results, examination-requests, etc. would be much more tedious and less efficient.

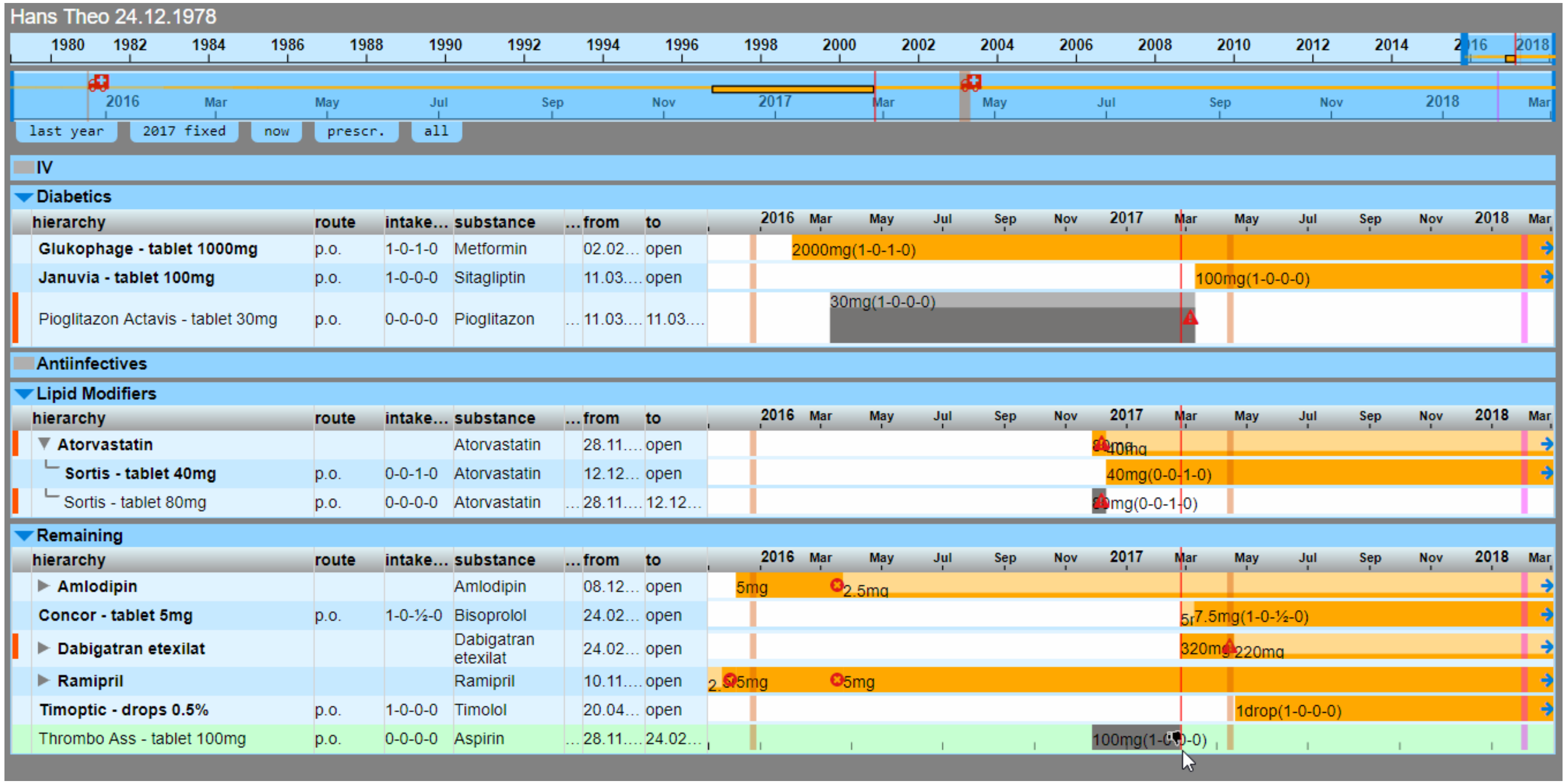

Figure 6.1: Scenario A - basic interface. The basic interface for scenario A when zoomed out to see all prescriptions in their full extent. The red highlight-bars on the left side of the rows marking prescriptions which troubled the patient in some way are clearly visible and easy to notice.
The period-of-validity of *Thrombo Ass* is displayed in the timelines of the context-area, as the row of the prescription is hovered. The red vertical helper line enables to easily find other prescriptions that align with the discontinuation of *Thrombo Ass*.

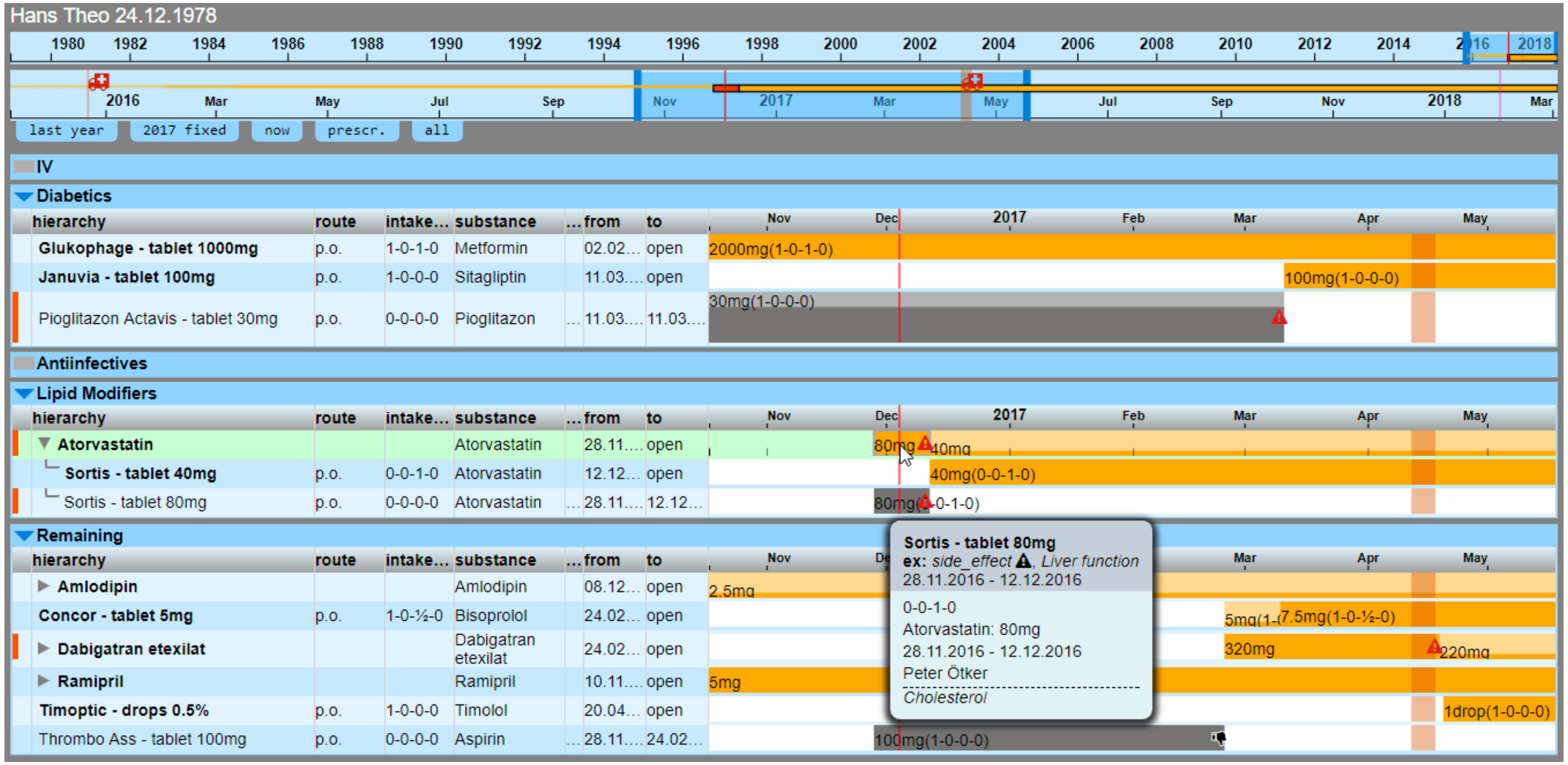

Figure 6.2: Scenario A - zooming. The basic interface of scenario A was zoomed slightly to better see the two prescriptions containing *Atovastatin*. The tooltip for the already discontinued *Sortis*-tablet prescription is visible and reveal the caused troubles: Bad liver function. More details about the instructions are listed below (intake-pattern, total-dose, period of validity, prescribing doctor, ...).
As the user hovers the merged-row of *Atovastatin*, its duration-bar is also displayed in the timelines of the context-area. The duration of the first prescription merged in this row is thereby colored in red.

6.2 Scenario B

6.2.1 Health record

Hypothyroidism

Because of hypothyroidism the patient takes *Euthyrox 100mcg 1-0-0-0 daily.* This medication has been prescribed when the diagnosis was made about eight years ago and is still active today.

Acute gout

The patient was found to suffer from an acute gout-attack and was prescribed *Voltaren 50mg 1-1-1-0* to relieve pain. Additionally, *Pantoprazol 40mg 1-0-0-0* was prescribed for gastric protection – a standard supplement for analgesics. On the third day *Allopurinol 300mg 0-0-1-0* was added to decrease the uric acid levels. The next day, the pain relieving medication (*Voltaren*) could be reduced due to the patient's recovery to *1-0-1.* A full week after the diagnosis had been made, *Voltaren* could be discontinued. Consequently, the gastric protection was no longer needed and therefore discontinued as well. *Allopurinol* was kept active for three months in order to ensure low uric acid levels.

Unfortunately, another gout-attack occured about six months after the first. Consequently, *Allopurinol 100mg 0-0-1* was prescribed. This time, the prescription was not discontinued after three months but kept active, as further episodes of gout are to expect without medication.

Hypertension

Due to chronic hypertension the patient is taking *Candesartan 16mg* 1/2*-0-0 since about 7.5 years.* But the pain-medication taken during the first gout-episode increased the patient's blood pressure, thus the dose is increased as well to *1-0-*1/2. In addition *Amlodipin 5mg 1-0-0* is prescribed. On the fourth day of the gout-episode, when the pain is relieved drastically, the dose of *Candesartan* can be decreased to 1/2*-0-*1/2. Two days after *Voltaren* is discontinued (day 10 of gout-episode 1), *Amlodipin* is discontinued as well. The *Candesartan*-prescription is set to its former dosage of 1/2*-0-0* on day 14 of the gout-episode.

Discusprolaps

The patient further suffered from a Discusprolaps, which was treated in the hospital. To relieve pain *Neodolpasse 1-0-1* (1 = one bottle of infusion) was prescribed. *Nexium 40mg powder 0-0-1 IV* (intravenous) was added as gastric protection. After three days of treatment, the IV-medications are switched to per-os medications. *Seractil Forte 400mg 1-0-1* replaces *Neodolpasse*, *Novalgin drops* are additionally prescribed *on-demand, with a maximal dose of 3 x 20 drops per day. Pantoloc 40mg once a day* replaced *Nexium.* To further relax muscles before going to sleep, *Sirdalud 4mg 0-0-0-1* is prescribed as well.

Diabetes

During the gout-period the blood-glucose levels get out of hand due to stress. *Eucreas 50mg/1000mg 1-0-1* and *Diamicron 30mg 3-0-0* are prescribed, but as the decrease of glucose-levels during the next days is not sufficient, the dose of *Diamicron* has to be increased to *4-0-0*.

During the hospital visit because of the discusprolaps, doctors notice high blood-glucose levels. Therefore, the respective medications have to be adapted to the current health-status. *Insulatard 0-0-0-6 IU* is added. This insulin is *injected subcutaneous*. The respective unit is an international unit for insulins. After three days the dose is increased to *0-0-0-10 IU*, and after two more days it is increased again *to 0-0-0-12 IU*.

Cystitis

The patient suffered numerous times from cystitis. These were treated with antibiotics containing the substance *Clarithromycin*. The medication *Biaxin 500mg 1-0-1-0* was prescribed during the first episode of cystitis. Treatment was successful, but the patient complained about nausea, a common side effect of this medication. During the following three episodes *Clarithromycin Basics 500mg 1-0-1-0* was prescribed instead. No side effects were reported for these prescriptions. Episodes 5 and 6 were treated with *Clarithromycin Sandoz 500mg 1-0-1-0* because of availability of the medication. The last episode was again treated with episodes *Clarithromycin Basics 500mg 1-0-1-0*. Each time, the antibiotics were taken for *five consecutive days*.

6.2.2 use case

In this scenario, the user (a doctor) already knows the patient to some degree but is not acquainted with the whole health record. In contrast to Scenario A (see Section 6.1), the user starts zoomed in at the current date focussing on a timeframe of five days in total - a typical zoom-level for inpatient treatment (see Figure 6.3).

The pinkish marker in all timeline-views is highlighting today, thus everything on its right is actually representing plans for the future. Some things are especially easy to recognize: First, all prescriptions are either not changing across the timeframe of interest or their period of validity is outside the selected timeframe entirely. More generally, we could deduce the patient's health status being quite stable, based on the current course of his medications.

The user diagnoses the patient to suffer from cystitis and is therefore interested in currently prescribed antibiotics. As antiinfectives, the parent medication group of antibiotics, are frequently of interest, a table-filter was set up in the past, which allows showing such medications in a separate pane. Additionally, a highlight-filter is used to mark antibiotic-medication in blue. Consequently, the doctor can easily identify antibiotics that have been prescribed throughout the patient's life. In this case, the collapsible pane for antiinfectives only holds one substance-row "*Clarithromycin*", which summarizes only inactive prescriptions, as recognizable by the name being not written in a bold font and by the prescription-timeline-view only containing text-labels stating the period of validity instead of timeline-bars. In addition to the blue highlighting-bar, a red highlighting-bar shows that some kind of trouble was caused by the merged prescriptions. As the doctor is about to prescribe antibiotics to the patient because of the current cystitis, it is important to know about the documented troubles in the past. Therefore, the user expands the merged substance-row "*Clarithromycin*". This un-hides its four child-rows, consisting of three prescriptions and one merged medication-name-row. As only the first prescription-row (*Biaxin*) is marked with the red highlighting-bar, the user can identify this prescription being the only one related to the documented troubles.

Before going into more detail regarding the latter prescription, all remaining sub-rows of "*Clarithromycin*" are revealed, which totals in seven prescriptions of three different antibiotic-products. To get a better sense of the prescription's distribution, the user selects a wider timeframe of the last year via one of the controller-buttons (see Figure 6.4). Due to the timeline-bars in the timeline-view of each row it is easy to notice only one of the seven prescriptions falling within the newly selected timeframe. Therefore, the selection is increased until all antibiotics-prescriptions can be seen along the timeline (see Figure 6.5). Due to this zoom-level the timelines reveal the distribution and duration of previous antibiotics-treatment as well as the respective applied dose. It has to be noted that the prescriptions' dosage-bars are only visible because of our minimal width of 5px, as none of these prescriptions' durations exceeds six days. The exact durations can be easily read from the from-/to-date columns.

Furthermore, the icons representing the indications of discontinuation reveal that all these treatments ended successfully (tick inside a green box). Only Biaxin shows the warning-icon (exclamation-mark inside red triangle) instead. The user can access information about the documented troubles of this prescription in the tooltip – in this case *Biaxin* caused nausea (see Figure 6.6).

All this information can be used for creating new treatment plans.

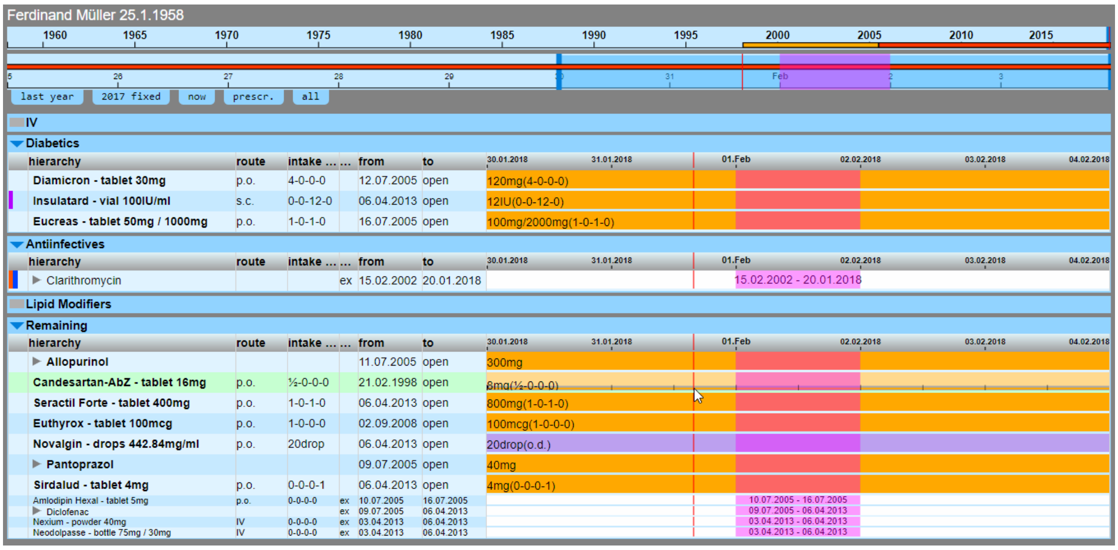

Figure 6.3: Scenario B - zoomed to 5 days. The starting configuration for Scenario B (see Section 6.2): only five days are displayed. Today's date is position in the middle of the timeline and highlighted in pink.
In the total time axis the duration of the hovered prescription is visible (orange bar + red bar) as well as the duration of the hovered instruction-item (red bar).
The on-demand prescription can be recognized by its purple timeline-bar (*Novalgin drops*).
The red highlighting bar in the highlighting-column of *Clarithromycin* reveals troubles with one of the merged prescription. The blue highlighting bar indicates antibiotics.

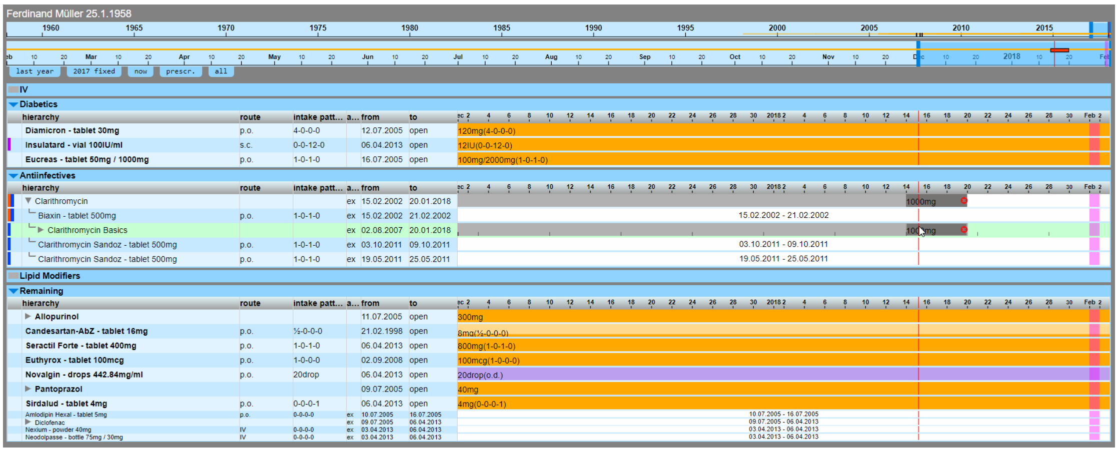

Figure 6.4: Scenario B - displaying the last year. The user expanded the merged-row *Clarithromycin* and selected the last year to be shown. Due to the red highlighting bar, *Biaxin* can now be identified to have caused some kind of troubles.

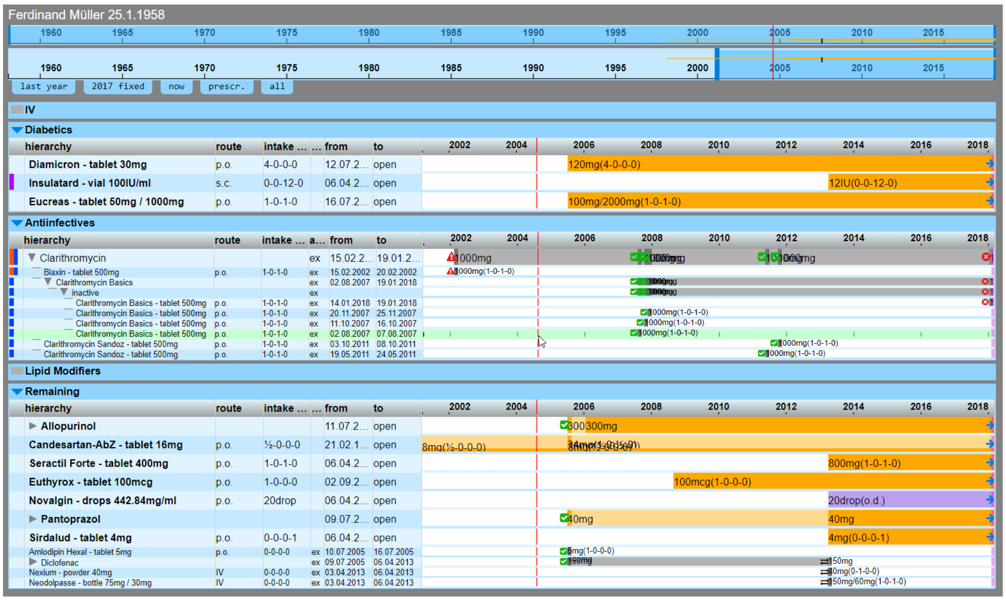

Figure 6.5: Scenario B - all antibiotics-prescriptions. A larger timeframe then in the previous Figures (6.3, 6.4) has been selected. The timeline-bars of all antibiotics-prescriptions are now visible. The green icons indicate successful prescriptions.

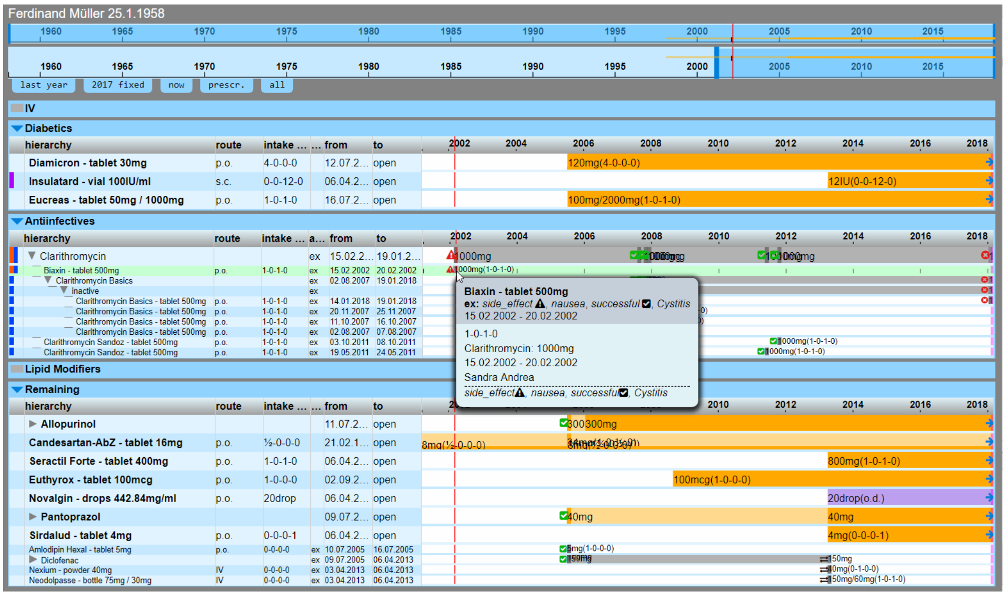

Figure 6.6: Scenario B - the tooltip. The tooltip of *Biaxin* reveals more details, such as the prescribing doctor (Sandra Andrea) and the side-effect (nausea). It also indicates that the prescription was successful despite the side-effects.

CHAPTER 7

Evaluation and discussion of our prototype

We conducted two qualitative evaluation sessions with three doctors who have already been involved in the interviews: Christopher, Vera, and Willi. In each session the prototype was presented and its concepts as well as ways of interaction were shown on the basis of our two example-patients. After the introduction the thoughts and questions of the interviewees were discussed openly. The prototype was used throughout the evaluation to further explain characteristics of interest and test various supported workflows and line of thoughts. We did not create transcripts but took notes during the evaluations, which were analyzed afterwards. The sessions were held quite brief because of a lack in time by the interviewees. Consequently, further more in-depth evaluation sessions would be required in the future.

7.1 Session 1

The first evaluation session was held with both Vera and Willi. Their feedback was throughout positive, especially as their current computer-system does not offer anything similar for handling medication histories. Both emphasized the usefulness of our prototype for daily questions they encounter. For example:

- getting all currently active medications – if needed filtered by diagnose or effect
- finding out, if a certain medication has already been prescribed previously
- identifying medications which were inefficient, brought up side-effects, or were simply not tolerated by the patient
- getting an overview of medications and their temporal context

The first question that came up during the introduction to prescription-rows referred to the differences between rows. Vera spotted rows that did not specify the medication's form nor its dosage-per-unit and was curious about the allegedly missing information. After introducing merged-rows and explaining our hierarchy-concept, both interviewees were quite enthusiastic about the data-structuring. They approved that substances are more expressive when getting an overview of a medication history.

We explicitly addressed the height-encoded dosage in the timeline-views, as we were concerned that dosage-bars were expected to correlate in height across all table-rows. However, both doctors agreed that such correlation would neither be expected by them nor feasible in a meaningful way, as dosages of different medications vary heavily and do not allow to deduce the intensity of their effect. For example, a 2000mg tablet *Glukophage* is completely normal, while a normal daily-dosage of *Euthyrox* ranges from 25 to 200 micrograms.

Willi suggested displaying all medications for which interactions, side-effects, and intolerances are known for the respective patient. This should in fact already be supported fairly well by our prototype via configuring a table-filter regarding instruction-keywords ("side_effect", etc.). However, we did not have such a table-filter setup during this evaluation.

Overall, the discussion was positive and the usefulness of the prototype was confirmed. Nonetheless, it has to be kept in mind that Vera and Willi are independent physicians, thus their working-environment, settings, workflows, and daily questions are probably differing from those in hospital environments.

7.2 Session 2

The second evaluation session was held with Christopher. He gave very positive feedback, but also some useful remarks. As he is mainly using paper records in daily work, the concept of having a condensed view of all medications appealed to him from the very beginning of the evaluation. Paper records simply do not provide such a representation of the prescription-history. For Christopher the dose as well as the intake-pattern was of particular interest, thus he favoured displaying most prescription-table columns. He also liked the highlighting of those prescriptions, which caused some kind of troubles, because of its efficiency. Christopher confirmed, that it is important to see such marks (referring to the highlighting-column) independent from the zoom-level in the timeline-view. Although we did not have much time for our session, Christopher quickly understood the concept behind our design and was able to recognize the syntax of our visualization.

Nonetheless, according to him, the visualization would be more useful for physicians working outside of hospitals, as his ward is too busy for in-depth analyses of medication histories. Doctors of his ward do not have enough time to explore a patient's health record at the moment. While the visualization would still be able to bring some benefits (highlighting of issues, listing all medications, grouping, etc.), it would probably not be utilized to its full potential, as stated by him. Furthermore, Christopher requested some additional medication groups in the main view, such as anticoagulants on the top of the list and analgesics. Technically, this is already feasible through additional table-filters, however we would need to find suitable rule-sets for these categories first. This emphasizes the usefulness of customizable filters and interfaces.

Overall, while the second evaluation session was throughout positive as well, it showed the need for more in depth-evaluations in hospital settings as well as for registered physicians.

7.3 Discussion

Due to the positive feedback we are confident that our prototype depicts a step in the right direction regarding visualization of medication histories. Based on the evaluation, we accomplished creating a somewhat intuitive interface providing essential medication data. We also succeeded to compress medication data and thereby reduced the required height for displaying a complete outline of a medication history via our prescription-tree-structure (Y-axis of our interface). However, our prototype does not compress the data on the temporal-axis (X-axis). As many health records show long time-periods without any medication events (such as adding, modifying, or discontinuing prescriptions) followed by relatively short periods with numerous events, major parts of our prototype display non-changing prescriptions. While users are able to zoom into the areas where changes occur, it would be more beneficial to provide means to compress the progression of prescriptions and only show areas of change.

Furthermore, our prototype comes with some flaws, such as overlapping-text in the prescription-timeline-views and missing panning-functionality within timelines of the focus-area. These issues are mainly related to our implementation and should therefore be manageable in future work.

Interestingly, one of the evaluating doctors mentioned that such a visualization tool would be more useful for registered physicians and less usable in hospital-settings due to a lack in time (see Section 7.2) A similar statement came up during our interviews before developing the prototype. Another doctor distinguished between the settings in a hospital and a doctor's office, stating that he would explore more intesively when working in his office. Consequently, our prototype might be better suited for registered physicians for now, as it is mainly focused on exploration. Once a detailed visualization for small timeframes (e.g., five days) is optimized and functionality for creating and modifying prescriptions is available, the attitude of these doctors might change.

Another factor limiting the usefulness of our prototype is depicted by healthcare professionals themselves. According to our interviewees, large amount of medication-related information is not properly documented. For example, lists of medications are incomplete, therapies that were tried out but found to be inefficient or unsuccessful are not even documented, reasons for medications are not specified, etc. It is obvious that this information would also be missing in our visualization, thus leading an incomplete representation of a patient's prescriptions. Furthermore, the interviewees reported situations in which patients or doctors are not able to stick to the documented medication plan, leading to a gap between documentation and reality. Thus, the benefits of our prototype are directly depending on workflows and processes that are outside of its scope.

When compared to previous projects, which were discussed in Section 3, our prototype is covering more medication characteristics. Additionally, we provide prioritisation as well as grouping of prescriptions and ensure that discontinued medications stay visible throughout exploration. Although some characteristics are not supported (e.g., displaying uncertainty information or dispensations), we believe to provide a more flexible and complete picture of a patient's medication history for daily treatment settings than preceding projects. Nonetheless, numerous potentialities for expanding the usability, functionality, as well as the capabilities of the prototype exist (see Section 9).

CHAPTER 8

Conclusion

This thesis addressed the challenges of creating an interactive visualization of a patient's medication history for practicing doctors in daily treatment settings. We showed that previous projects visualizing medication data are either providing limited interaction, limited information, or are not designated for such settings. Furthermore, medication characteristics were not defined or described, leading to medication-related terms being used for different aspects throughout the projects. The assessment of currently deployed medication history visualizations in Austrian hospitals revealed that the majority of hospitals is currently not utilizing an electronic list of medications. We only came across one computer visualization within the examined hospitals, and that one barely supports exploration of medication data.

In order to create an improved visualization of medication histories, we based our implementation on the following research questions and their respective results.

1. *When are practicing doctors interested in medication-related information and which information is of interest?*

   We identified multiple scenarios and medication-related questions, which would benefit from exploration of medication histories. What's more, a list of 16 medication characteristics was created, which provides a description for each characteristic and a rough evaluation of its relevance for daily use cases.

2. *Which visualization techniques are suitable for intuitive visualization of time-oriented data?*

   This question was mainly examined via literature research, but also influenced by currently deployed medication visualizations. We decided on combining tree-tables and timelines, whereby prescriptions are split up into multiple tables. We did not provide a discussion on different techniques in this thesis, but outlined the reasons for our selected techniques in Section 5 - *Conceptual Design and Implementation*.

3. *How can the most promising visualization techniques be combined and applied to patient-specific medication histories to form a flexible, user-friendly overall-view on medication data?*

   Based on the collected information, a visualization prototype was implemented. A tree-data-structure is utilized for lists of prescriptions, which enables creating a more compressed outline of medication histories while keeping detailed information available on demand. The combination of tables and timelines provides extensive coverage of medication characteristics. Furthermore, users are able to customize the data-structure as well as the interface. Beside navigation through medication histories, the prototype covers important means of interaction, such as filtering and highlighting. Customizing the data-structure is supported as well.

The feedback received during the evaluation of our prototype was throughout positive and confirmed it to cover all important aspects in an intuitive way. However, the prototype might currently be more useful for registered physicians than for hospital-doctors, as the latter are frequently too stressed to explore health records in detail. Additionally, the prototype depends on doctors providing a complete medication documentation and keeping it updated.

We also showed the potential for improvement and extension of our prototype for future work.

CHAPTER 9

Future work

As there are numerous aspects to enhance and expand, we split this section into four parts. Each part deals with a different component of our visualization project: the **data model**, the **visualization techniques as well as their composition**, the **interactivity** of the user interface, and the **evaluation** of our prototype.

9.1 Model

- **relationships of prescriptions**
  The prescriptions in a health record are not simply co-existing, but are often in some form of relationship to each other. Some examples which were also mentioned in the scenarios described in Section 6: A replaces B; A follows B; A supplements B; A is given parallel to B but aims for other effects on the organism (analgesic + gastric protection); etc. Representing these relevant relationships in the data model would greatly expand the informative content of the model and open ways to further provide this data to healthcare professionals. Thereby, both traceability and transparency of the medication history would be improved.

- **expanding the support of indications**
  Prescription-indications are essential to understand medication histories. For now, we implemented a simple keyword-approach for each set of instructions. However, indications are much more than just some keywords, for example: Diagnoses, symptoms, treatments, other prescriptions, and allergies. Thus, linking prescriptions to their diagnoses prevalent in the health record would enable users to filter prescriptions per diagnoses, analyse patterns, etc. Of course, this applies not just for diagnoses but for all kinds of indications.

- **adding medication intakes to the model**
  Our current model covers the prescriptions as configured by the doctors. However,

this might differ from the actual intake-behaviour. Showing the true intake-data in relation to the prescriptions' configuration would therefore benefit healthcare professionals. Some examples that came up during our interviews: Patients might be unable to take the medication at the planned time, shifting the time of intake by several hours or patients might refuse medication intake. Naturally, this is mainly feasible for hospital environment, where medication intake can be tracked by hospital staff. Such data would hardly be available for outpatient treatment. For hospital environments additional information about a medication's status could be included as well, such as "prepared for intake", "taken", or "cancelled". And intake-data would be especially useful for on-demand medications, as prescribed-dose and actually taken dose are usually varying vastly. The doctors involved in evaluating our project would appreciate exact data on this matter, as they are currently deriving the patient's health status from such information.

- **more sophisticated support for uncertainty in intake-patterns**
  We focused on frequently used daily-intake patterns in the form of "M-M-E-N" as well as single-intakes. Although we also provided a simple weekly intake-pattern by setting the dose for each day of the week, more flexible patterns would be useful. Such patterns are often defined as "twice a week" or similar, thus, letting the patient decide on the actual days. But uncertainty can also be introduced in daily-patterns by not specifying the time of intake (e.g., "once a day"). As suchlike prescriptions are useful in many ways, supporting this kind of uncertainty has to be an objective for future work.

- **more medication-specific characteristics**
  While we made great efforts to collect an extensive amount of important and representative medication-/prescription-characteristics, we had to skip some during implementation (e.g., helper substances) in order to reduce expenses. Furthermore, additional characteristics might come up within future research or new characteristics could be added. Therefore, attention should be paid and the model should be expanded respectively in future work.

9.2 Visualization

- **supporting more intake-patterns and medication characteristics**
  Users can only benefit from extending the supported intake-patterns and medication characteristics mentioned above (see Section 9.1), when these are represented appropriately in the user interface. Therefore, finding suitable visualizations for the respective data is a necessity (e.g., uncertainty in intake-patterns and additional medication characteristics).

- **integrating other health-record data and its relationships to prescriptions**
  On the one hand, only displaying medication data can be quite helpful for focussing

on data of interest, but on the other hand important context information is missing. The latter involves data regarding the patient's health, other treatments, diagnoses, etc. which are often closely related to prescriptions. Consequently, displaying additional healthcare-data next to or in combination with prescription information can improve the visualization's convenience. For example, showing symptoms and diagnoses along the timeline could enhance their relationship. However, as mentioned by multiple interviewees, not all kinds of health-record-data can be set in correlation with medications.

- **visualizing relationships in-between prescriptions**
  We already mentioned modelling relationships between prescriptions being desirable (see Section 9.1), but properly visualizing such information would be necessary as well. We left the difficult task of finding intuitive representations while not cluttering the view for future work.

9.3 Interactivity

- **zooming and panning in focus-view**
  Unfortunately, we were not able to implement panning and zooming in the timeline-views of the focus-area, because of troubles with the framework D3.js. As suchlike interaction is of essence for any prospective project, we mention it explicitly in this chapter.

- **dynamic distortion of time-scales**
  Often health records contain long periods of time without any healthcare related events. These periods can be followed by a hospital visit of a few days, during which numerous events and changes in recorded data occur. This period might again be followed by years without any changes. During exploration of health records, these periods are hardly of interest, but take up most of the available space on the timeline. The timeline would provide a more compact outline, by increasing the size of periods of interest and decreasing the size of periods without significant events. Consequently, years without change could be displayed within a centimetre on the timeline, while a hospital visit of two days could take up significantly more space. We call this modifications "distortion of time-scales", as the size of years and days can be changed as desired across the timeline and proportions are no longer fixed. Similar interactivity has already been implemented successfully in Midgaard [Bade et al., 2004] in Section 3.2.4.

  Overall, this could increase information-density and provide an enhanced overview to healthcare professionals.

- **improving flexibility and configurability**
  There are numerous aspects of the interface with potential for improvement. First of all, the prescription-table configuration (columns visibility, size, etc.) could be made task-specific, for example, having a table-configuration for basic daily work and

another configuration for exploration. Switching between multiple configurations would clearly be useful in order to cover all of the user's workflows. Second, presets regarding the height of prescription-rows would provide more flexibility. Furthermore, enabling customization of other components, such as color-mappings for the timeline-bars, could improve intuitiveness and encourage usage.

- **on-demand configuration of filters (highlighting and table-filters)**
For now, filters can be configured before starting the prototype. In the future, a dynamic configuration for all kinds of filters would be more useful. This includes adding new prescription-tables on demand as well as adapting the applied highlighting to the user's current needs.

- **sorting tables dynamically & modifying the prescription-hierarchy-tree**
Sorting tables according to medication characteristics would definitely be helpful to healthcare professionals. For example, in order to better understand the order of prescriptions, sorting the prescriptions according to their start-of-validity date would be reasonable. Additionally, allowing the user to modify the prescription-hierarchy-tree dynamically could be useful, such as adding and removing hierarchy-levels (e.g., prescriptions per prescribing doctor) on demand. This could facilitate data exploration by structuring prescriptions according to the user's question.

9.4 Evaluation

More extensive evaluations of our prototype would be desirable. The evaluation conducted by us is hardly representative for the healthcare sector because of the low number of participants, scenarios, and example data.

CHAPTER 10

Appendix

10.1 Medication Characteristics found in literature

We collected all medication characteristics mentioned in the projects found in literature (see Section 3) and created the following list. It has to be noted that not all of these items are explicitly defined or introduced within the respective papers, thus we are not always able to give a detailed description

- **Name**
  Not as trivial as it might seem, the name can be the underlying substance (see van der Corput's project [van der Corput, 2013]) or the product. Sometimes the form of the medication as well as the dose of its unit is combined with the name (e.g., "*medication's name* tablet 30mg").

- **Form**
  Specifies the physical form of the medication: pill, intra-venous injection, etc.

- **Intake Schedule**
  The intake schedule holds detailed instructions specified by the treating doctors on when to take a how much of what medication for how long, for instance, "one pill every four hours" or "once daily for 30 days". MyNYP [Wilcox et al., 2016] (as discussed in Section 3.1.4) and Timeline [Zhu et al., 2009] (as discussed in Section 3.1.1) both provide such information.

- **Dose**
  Some visualizations display the total dose per day (e.g., the Integrated Viewer [An et al., 2008] discussed in Section 3.2.1), others are only showing the unit-dose (Timeline [Zhu et al., 2009] as seen in Section 3.1.1), which specifies the dosage contained in a single pill or similar. Another group of tools is only displaying

a relative dose (e.g., LifeLines [Plaisant et al., 1998] discussed in Section 3.2.3). Many projects displaying the total dose do not provide information on the intake-schedule, thus the compilation of the dosage is unknown. On the other hand, tools only displaying the unit-dose require the intake-schedule in order to calculate the total-dosage.

- **Prescriber, Pharmacy**
  Surprisingly, the prescriber is only mentioned by van der Corput (see Section 3.1.3) and Ozturk et al. (see Section 3.1.2). The latter also provides the dispensing pharmacy.

- **Start-/End-Date**
  Start- and end-time of prescriptions are mostly encoded via timelines or in case no duration is given via simple shapes marking time-instants on a time axis. Nonetheless, MyNYP [Wilcox et al., 2016] (see Section 3.1.4) appears to not include this information.

- **Trustability/Uncertainty**
  Especially information about a prescriptions duration or start-time can often bot be determined precisely. Thus a certain degree of uncertainty is linked to this data. Approaches to visualize such aspects were only found in Timeline [Zhu et al., 2009] (as discussed in Section 3.1.1) and Midgaard [Bade et al., 2004] (as discussed in Section 3.2.4).

- **Medication Class**
  There exist multiple classifications for medications. MyNYP [Wilcox et al., 2016] (see Section 3.1.4) uses classes corresponding to the medications' effect (e.g., inhibitors or analgesics) while the tool Timeline [Zhu et al., 2009] (see Section 3.1.1) classifies medications according to the source of their prescriptions (e.g., in-hospital or pre-admission). These classifications are not meant to be substitutes but can be used simultaneously.

- **Reason/Indication/Uses**
  Only MyNYP [Wilcox et al., 2016] (see Section 3.1.4) provides a short description of a medications indication (the respective column is called "Uses") such as "used to relieve pain" [Wilcox et al., 2016]. This description is meant for patients, thus it would hardly be interesting for clinicians. Nonetheless, it depicts the reason for a specific medication. The respective information for clinicians would probably be a diagnosis or some vital signs.

- **Dispensations/Refills**
  LifeLines [Plaisant et al., 1998] (as discussed in Section 3.2.3) can mark the dates of medication dispensations on the timeline of the respective prescription. For the medication visualization for emergency care by Ozturk et al. (see Section 3.1.2) dispensations are actually the fundamental data-entities. Thus, dispensations and the calculated duration of the dispensed quantity of medicine are visualized

rather than the underlying prescriptions. Plaisant et al. claim that dispensation information can reveal over- and under-usage of medications [Plaisant et al., 1998, p. 79].

- **Costs**
  LifeLines [Plaisant et al., 1998] (see Section 3.2.3) enables mapping a medication's price to the color of its timeline. However, no other visualization project mentioned medication costs.

List of Figures

3.1 Timeline ([Zhu et al., 2009]) 10
3.2 Prescription history visualization for emergency care ([Ozturk et al., 2014]) 12
3.3 Medicine Prescription Visualization ([van der Corput, 2013]) 14
3.4 MyNYP ([Wilcox et al., 2016]) 16
3.5 Integrated Viewer ([An et al., 2008]) 18
3.6 VisuExplore ([Rind et al., 2010]) 20
3.7 LifeLines ([Plaisant et al., 1998]) 22
3.8 Midgaard ([Bade et al., 2004]) 24
3.9 KNAVE II ([Combi et al., 2010]) 26
3.10 VIE-VISU ([Horn et al., 2001]) 27
3.11 TimeLine ([Bui et al., 2007]) 28
3.12 Chittaro's mobile Visualization ([Chittaro, 2006]) 30
3.13 CPDV ([Faiola and Hillier, 2006]) 31

4.1 Rough sketch of Daniel's medication visualization 41

5.1 Data model 52
5.2 The hierarchy-structure 56
5.3 The flattened hierarchy-structure 57
5.4 The basic interface of our medication history visualization 59
5.5 The context-area 61
5.6 The focus-area 62
5.7 Hierarchy-column of the prescription-table 64
5.8 The Prescription-Timeline-View 67
5.9 How instructions are merged 69
5.10 Weekly intake-pattern in the timeline-view 69
5.11 Indication icons - examples 70
5.12 Tooltips 72

6.1 Scenario A - basic interface 80
6.2 Scenario A - zooming & tooltip 81
6.3 Scenario B - zoomed to 5 days 85
6.4 Scenario B - displaying the last year 85
6.5 Scenario B - displaying all antibiotics-prescriptions 86

6.6 Scenario B - the tooltip reveals the indication 86

List of Tables

4.1 Our interviewees 35

5.1 The columns of the prescription-table 66
5.2 Indication keywords and icons 71

Glossary

ACM Digital Library ACM (Association for Computing Machinery); ACM Digital Library (`https://dl.acm.org/`) an online library for scientific publications from numerous publishers.. 5

CatalogPlus CatalogPlus (`http://catalogplus.tuwien.ac.at/`) is the online catalog of the library of the technical university of Vienna.. 5

CSS "Cascading Style Sheets" is a language that described how HTML elements should be displayed.. 7, 55, 74

ELGA Elektronische Gesundheits Akte - A electronic health record-system for the entire nation.. 43, 47

Google-Scholar Google-Scholar (`https://scholar.google.at/` is an online search-engine focused on scientific publications.. 5

HTML Hypertext Markup Language. 7, 55

IEEE-Xplore IEEE-Xplore (`http://ieeexplore.ieee.org/Xplore/home.jsp`) is a digital library for scientific publications.. 5

PubMed PubMed (`https://www.ncbi.nlm.nih.gov/pubmed/`) is a digital library for scientific publications in the field of biomedicine.. 5

RIM HL7 is a group of international standards focused on computer-based data-transfer in the healthcare sector. The Reference Information Model is the basic root-model for all data-messages .. 17

Acronyms

DDD Defined Daily Dose. 14

EHR Electronic Health Record. 1–3, 5, 9–11, 13–15, 17–22, 25–29, 32, 39–41, 48

HIS Hospital Information System. 1, 2, 40

InfoVis Information Visualization. 2

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