Using Timeline Displays to Improve Medication Reconciliation

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Abstract -- **Objective: To explore approaches for integrating and visualizing time-oriented medication data in narrative and structured formats and to address related issues on handling temporal abstraction, granularity, and uncertainty. The ultimate goal is to improve medication reconciliation by providing clinicians with more accurate medication information in patient care. Methods: An event taxonomy was generated to capture different combinations of clinical and temporal uncertainties. A prototype of a temporal visualization system was implemented using an open source software package called Timeline. Medications were parsed and mapped to the event taxonomy, and then represented in Timelines. Seventy-five medications from narrative discharge summary reports and seventy-nine medications from structured orders were used as data input for temporal visualization. Five physicians served as domain experts and answered ten proof-of-concept survey questions. Results: Overall positive feedback from experts suggested the potential value of the proposed timeline visualization method. Challenges were also identified, and future work will include reconciliation of medications from various sources based on temporal attributes and medication classification.**

Keywords – medication; reconciliation; timeline; structured; narrative; display

I. INTRODUCTION

The process of creating an accurate list of a patient's medications, for the purposes of resolving discrepancies and supporting accurate medication ordering, is referred to as medication reconciliation—a task in which the continuity of a patient's medications is addressed when the patient is admitted to, transferred within, or discharged from a clinical facility [1]. Accurate medication reconciliation is important for patient care, since errors could cause significant adverse events [2-4].

Various studies [5-7] have been conducted over the past few years to address key organizational and research issues related to medication reconciliation. Among the most recent efforts, Poon and colleagues developed a preadmission medication list (PAML) for medication reconciliation [6]. PAML extracts structured medication information from four electronic sources, and presents it to clinicians, who then create the PAML by consolidating and reconciling the information from the various sources into a single coherent list. However, the PAML only used coded mediation data; it did not use narrative text sources. Time-oriented medication information was displayed in a table format.

Despite little attention was paid to an automated medication reconciliation process, less was done to advance it using temporal visualization techniques. Temporal visualization involves tasks of collecting, navigating and visualizing time-oriented information [8]. Early work included a formal system developed by Cousins and colleagues [9] that represented temporal data as events on a timeline, with a set of operators to support temporal manipulation. A general visualization environment for personal histories, developed by Plaisant and colleagues [10], presented a one-screen overview of a computerized patient record using timelines. Shahar et al. [11-14] developed methods and systems for interactive computation and visualization of domain specific temporal abstractions. Other methods also include integration of 2D and 3D visualization [15], and various statistical and graphical methodologies. Among recent efforts, an open-source MIT project called Timeline [16] is an ongoing Web-based development effort to model complex time-based events.

In this paper, we describe a timeline method that involves processing, merging, and displaying time-oriented medication data retrieved from a mixture of coded and narrative text sources. The timeline display is intended to improve the creation of medication lists by showing clinicians when and what medications

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from pharmacy orders and discharge summary reports have been overlapped by, concurrent with, or contiguous to each other over time. We describe the prototype application of our method to a set of patient records and discuss results of a proof-of-concept evaluation conducted to assess the usefulness of such medication timeline visualization.

II. METHODS

Our approach involves the collection of patient medication data from both coded and narrative text sources, mapping these data to event taxonomy, and then visualizing these data in a prototype implemented using open source Timeline technologies [16]. Patient medications can then be viewed over time and grouped by data sources. Each medication entry is linked to its original patient record for reference.

Sources of patient medication information: New York Presbyterian Hospital (NYPH) makes use of two major clinical information systems: the commercial product Eclipsys XA order entry system [17] and the internally developed WebCIS documentation and data repository system [18]. Eclipsys allows clinicians to order medications that are initiated and discontinued at various points during a hospitalization. Clinicians also enter medication information in narrative text, as part of the patient's discharge instructions. WebCIS provides narrative medication lists as parts of clinic notes, admission notes and discharge summaries. Medication orders from Eclipsys are transmitted to the pharmacy system, converted into dispensing orders and transmitted to WebCIS; therefore, WebCIS has coded medications from the outpatient medication order entry system and inpatient pharmacy system.

Medication data used for this study were from three major WebCIS components: discharge summary reports, ambulatory and inpatient pharmacy orders. Discharge summaries normally consisted of admission/discharge diagnoses, chief complaint, history of present illness, allergies, past medical/surgical history, medications, social history, physical examination, laboratory data, hospital course, and medications from discharge summaries were in narrative texts.

Parsing narrative medications: The authors of this paper have previously built a medication parser to perform this task with sufficient accuracy [19]. The parser relied on parsing rules written as a set of regular expressions and on a user-configurable drug lexicon, where a broader definition of medication information was used, including drug names appearing with and without dosage information, misspelled drug names, and contextual information. Medication information in narrative text was parsed into basic medication information (Drug Name, Dose, Route, Frequency, and "PRN" ("as needed") flag) and additional context (section of the discharge summary report).

Drug names was identified and confirmed with the drug lexicon derived from RxNorm, a standardized nomenclature for clinical drugs that has been included in the Unified Medical Language System (UMLS) [20]. Drug name identification used a multi-word lookup from the input text to the drug lexicon. The drug lexicon may contain meta-data about the drug name, which would then be connected to the drug in the parser output.

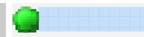
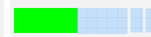
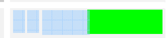
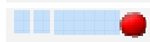
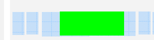
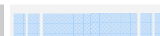
Experts reviewed the original discharge summary reports and the completed data mapping to correct any omissions and mismatches. Their feedback was collected to help improve the performance of the medication parser.

Mapping narrative and coded medications to an event taxonomy: Based on the nature of a medication event, parsed narrative medications and structured medication orders were further mapped into three different categories. Each category and its sub-categories were assigned graphical symbols to illustrate corresponding concepts in timeline visualization. Different shapes and colors represent: 1) the length of the event. For example, a solid dot represents an event happened at a point of time, whereas a sold bar represents an event happened over a period of time; 2) the degree of the uncertainty. For example, a green bar represents certain duration of an active medication, whereas a faded blue bar represents uncertain duration of an uncertain medication usage; and 3) the nature of the event, for example, a red dot represents a stop point, and a yellow dot represents a warning or fact that need careful attention. The following taxonomy table illustrates the mapping with clinical examples.

Table 1. Taxonomy for medication event duration. represents continuation

Event Category 1: Medication event happened at a point of time.	
Example: The patient received 2/3 benzathine penicillin shots, 2.4 million units IM, given 5/8/99.	
Event Category 2: An event that may not involve direct medication usage at certain point.	
Example: The patient has an allergy to sulfa drugs.	

Event Category 3: Medication event happened over a period of time.

Taxonomy Group	Start Time	Stop Time	Active Usage	Examples from patient records	Illustration
1	Known	Known	Active	Hospital course 04/03/1999 - 05/11/1999: Her diabetes was brought under control with Glyburide 20 mg q day	
2	Known	Known	Uncertain	Ambulatory order 01/01/1997 - 01/24/1997: Tolinase 500 mg, p.o. (Specimen received)	
3	Known	Unknown	Active	She was diagnosed with chronic HTN after her last delivery which was complicated by PEC. She has been maintained on a variety of medications, and started regimen of Enalapril (10mg BID), Spironolactone (25mg qd) and lasix (40mg qd) on 10/04.	
4	Known	Unknown	Uncertain	Hospital course 01/31/2005 - 02/03/2005: patient was discharged home on Calcium, Magnesium, Vicodin and probably Ceftin for antibiosis.	
5	Unknown	Known	Active	In ER, 160/78 89 24 96% RA. She was given Prednisone 60 mg po qd, Albuterol, Atrovent and admitted.	
6	Unknown	Known	Uncertain	Pre-admission medications: Dilantin, Neurontin, Prednisone, multivitamin and Ibuprofen.	
7	Unknown	Unknown	Active	The patient has a history of hypertension in the past, previously on Lisinopril and Hydrochlorothiazide, recently diet-controlled, history of increased cholesterol on Mevacor.	
8	Unknown	Unknown	Uncertain	Patient previous medications may include Methotrexate and Fosamax.	

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Handling temporal granularity: Four different representations were implemented using inherent Timeline software features, as elaborated in the following figures:

a. Time interval: depending on different records, it varies from day or month, to year or decade.

Figure 1. Time interval (by days)

b. Counting bar: given a particular time point, time intervals before and after the anchor point were counted in positive and negative numbers.

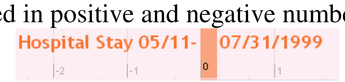

Figure 2. Time counting bar

c. Bird's-eye-view time map: in a large scale, this shows when major medication events happened and prolonged.

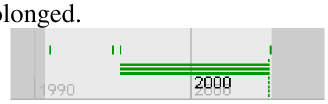

Figure 3. Bird's-eye-view time map

d. Text description: each medication entry links to a pop-up window where start time and stop time were written in text.

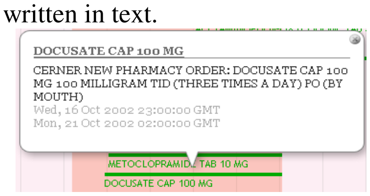

Figure 4. Text description

Proof-of-concept survey on pilot study: Five physicians with biomedical informatics training reviewed the prototype of the temporal visualization application using both narrative and structured medication data. Ten survey questions were asked to assess the usefulness of the visualization method. Comments on design concepts, graphic user interface, handling temporal granularity and uncertainty, and mapping and merging data from multiple clinical sources were collected during the survey.

III. RESULTS

Data sources: Each medication entry was linked to a pop-up window, which included its data source and the portion of the original patient record where the medication was mentioned (see Figure 4). Furthermore, users could filter and highlight certain medications based on different data sources using inherent Timeline software features. Figure 5 illustrates how a user could highlight discharge medications from the complete medication list. In this example, blue was selected as the highlighting color. As "discharge medication" was typed in the text box, the highlight function was automatically triggered, and all discharged medications were highlighted with blue squares.

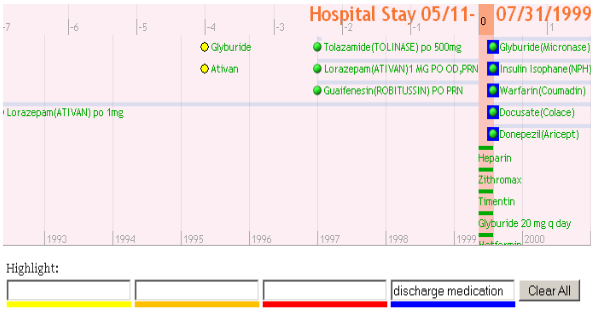

Figure 5. Highlighted discharge medications

Parsing narrative medications: Among the 75 medications retrieved from narrative discharge summary reports, 21 were determined to be pre-admission medications, 28 were in-hospital medications, 23 were discharge medications, and 3 were mentioned as noncompliant and allergy medications.

Mapping narrative and coded medications to event taxonomy: All 154 medications were mapped to one of the three event categories. One one-time inpatient medication (Penicillin shot) was mapped to category one. Three allergy medications retrieved from narrative summary reports were mapped to category two. The rest of the 150 medications were mapped to category three. Among them, medications administered before hospital stay fell under event taxonomy group 1, 3, 5 or 7 (see table 2). Structured inpatient pharmacy orders and narrative medications administered during hospital stay were combined and mapped to event taxonomy group 1. Structured ambulatory orders with definite duration time were mapped to group 2. Structured ambulatory orders with indefinite discontinuation time and discharge medications from narrative discharge summaries were mapped to event taxonomy group 4. Medications with unknown prescription time, uncertain usage or PRN status fell under either group 6 or 8.

Handling temporal granularity: For each patient record, a main panel with time intervals at the bottom and the time counting bar on top was implemented as the default display. The middle point of a given hospital stay was used to be the anchor for the time counting bar. A user could click on the main panel and drag it horizontally to view medication events happened before and after the anchor point. A bird's-eye time map was added to the bottom of the main panel for records with medications used over decades. Time period displayed by the main panel appeared as a highlighted area in the larger-scaled bird's-eye time map. The main panel synchronized with the bird's-eye time map to provide a zoom-in and zoom-out look and feel. Most granular time information on each medication could be viewed in the pop-up text box after clicking on the medication name.

Proof-of-concept survey on pilot study: Overall feedback from five physicians on the concept of using timelines for more accurate medication lists was positive (rated 4.8 out of 5 on a Likert scale, with 1 being strongly disagree and 5 strongly agree). It was agreed that timelines provided a clear presentation of prescription, discontinuation, and duration times to help users decide the status of certain medications. Another identified advantage of timelines over a frequently-used medication table was its ability to visualize relationships among medications; for example, it would be easier to identify overlapping and neighboring medications in timelines. Survey participants all commented that simplicity and ease of use are of paramount importance in terms of application design. Given clinicians' often lack of time and experience with computers, over-complicated design would only make the application time-consuming or confusing, resulting in diminution of use. Comments on future work included suggestions on grouping medications based on data sources or therapeutic classes, and within the same group, ordering them by time or medication risk level. One physician pointed out that Coumadin (warfarin sodium) and Colace (docusate) could be prescribed at the same time but should not be treated at the same risk level. Another physician expressed his need to view medication dosage change over time, and recommended the use of a trend chart similar to a stock monitor.

IV. DISCUSSION

We have extracted medications from narrative discharge summaries, combined them with data from structured medication records, and represented the union in timelines based on the event taxonomy mapping. Some issues related to data sources and temporal representation will be discussed, along with potential solutions.

A major task of medication reconciliation is to resolve discrepancies exist among heterogeneous data sources. Discrepancies are present not only in basic medication information, such as drug names and classes, but also in temporal information with different levels of granularities. Temporal granularities from multiple data sources may vary from hours to decades. It is as important to consolidate the difference in time as to provide clinicians a flexible presentation that allows them to switch easily between viewing a medication synopsis and scrutinizing a drill down. In this study, the authors attempted to address this issue by combining several graphical user interface approaches to render a zoom effect. Ultimately, more advanced web technologies, such as a real-time "magnifier" driven by context or cursor movement, could be more convenient and efficient for busy clinicians to use.

Another key task in reconciling medications is to know at what point of time, or during which period of time, what medications were in active use. In an ideal situation, both the medication start and end times would be clearly recorded, but in reality, either one of those time points can be uncertain. In some cases, even with known start and end points, one is uncertain about the actual usage of a particular medication, which poses a major research challenge: reconciling medication discrepancies involves handling both temporal uncertainty and clinical uncertainty. Usually a patient record has the two types of uncertainties mixed at various levels. For example, the following admission notes state: "Patient was previously seen in consultation by Ear/Nose/Throat after trials of Sudafed were tried without success to help with the problem". Clinically, it is certain that the patient took Sudafed before, but temporally, there lacks enough information for one to identify when Sudafed was given to the patient and for how long. In this case, if there is no more additional information available, one need to find some anchor time point, such as the date when the note was taken, to be the event end point and conclude that Sudafed was given at some point prior to the notes taking. This way, although still not completely certain, one can narrow down the estimated range of time interval and reduce the level of temporal uncertainty to some extent. In another example, the following discharge summary dictates: "on hospital day #3, patient was discharged home with antibiotics, probably Ceftin". The temporal information is certain and clear in this case, but clinically, there are several uncertain factors – what antibiotics the patient was given; whether the patient took it; if the medication was taken, it was used for a while or stopped right away. Because of the clinical uncertainty, the end point of temporal event becomes uncertain, and so does the corresponding time interval. It is not unusual to see the two types of uncertainties entwined with and affect each other in a patient record. In this case, the level of clinical uncertainty or the nature of the clinical event changed the level of temporal uncertain. Had the patient been given a penicillin shot at discharge instead, the temporal information would be a certain point – the discharge time. As complex as the clinical scenarios can be, the uncertainty issue can be one of the most complicated and challenging research problems. Different from conventional methods of dealing with uncertainty, the event taxonomy classifies various combinations of clinical and temporal uncertainties encountered in patient records, and lays a good foundation for a clinician-friendly timeline representation.

Besides discharge summaries and orders, medication information can be found in many other data sources, such as admission notes and pharmacy benefit management (PBM)-based claims data. In addition to common data sources, a new perspective is to focus on patient-centered personal medication records. Clinicians and pharmacy dispensing systems provide and handle prescriptions, but it is the patients or family members who know how the medication regimen is followed. Given personal health records have gained increasing attention, it is promising for a personal medication record to become a contributing component to medication reconciliation. As more data sources are added, it is critical and exigent to determine the comprehensiveness and reliability of those data sources. A significant amount of research is needed to merge and represent heterogeneous data from various sources. Furthermore, to integrate the representation into practice, we are challenged to take into consideration not only clinicians' work flow and information load, but also the health information network infrastructure that supports data integration and exchange.

Nevertheless, progress in medication reconciliation, as many other issues in the field, may depend less on the advances of technologies than on how the structure and management of our current care delivery systems can be improved. Rather than one or few research groups' endeavor, the success of medication reconciliation demands a multidisciplinary effort from the entire organization continuously and collaboratively.

V. CONCLUSION

The implementation of a timeline visualization that presents and represents medication data from narrative and structured sources is feasible, and has the potential to help clinicians with more accurate medication lists, which promises added value to current medication reconciliation process.

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