Visualizing the Overview of Temporal Patterns of Patients' Activities

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Abstract

It is necessary to determine patients' activities for effective management in hospitals and affiliated regional medical institutions. The purpose of this study is to support the identification of features from temporal patterns of patients' activities using information visualization. This paper introduces a technique called "ChronoView" for visualizing temporal patterns. ChronoView provides an overview of many temporal patterns and enables us to easily determine the similarity and anomaly of temporal patterns. In order to illustrate a use case, temporal patterns of patients' activities were extracted from an actual data set of patients of the University of Tsukuba Hospital. This paper reports some features of the temporal patterns identified using ChronoView.

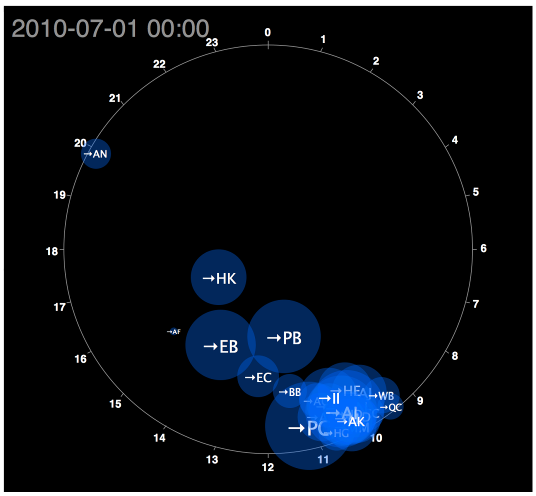

Figure 1. Daily temporal patterns of admission visualized using ChronoView. Each blue circle represents a clinical group. Admission time of most clinical groups is concentrated between 10:00 and 11:00. Admission time for Group HK (Emergency group) and a few other groups is independent of the time of day.

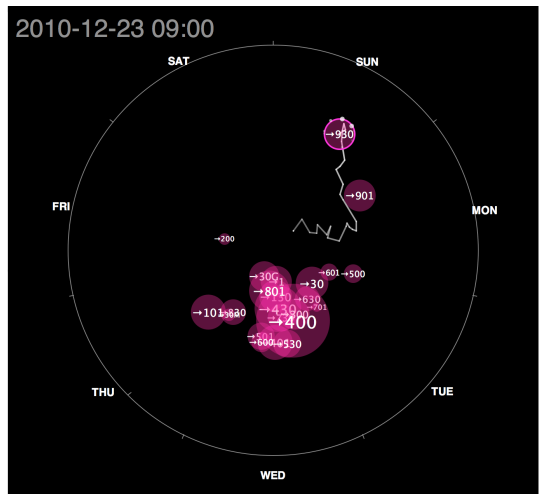

Figure 2. Weekly temporal patterns of transition into wards. Each red circle represents a ward. Transition into most wards is independent of the day of the week. Transition into Ward 930 changed and was concentrated on the weekend. The gray polyline represents the moving history of Ward 930.

1 Introduction

It is necessary to determine activity patterns of patients for effective management in hospitals and affiliated regional medical institutions. Activity patterns need to be determined from various viewpoints. It is important to determine the temporal patterns of patients' activities. What type of features does each clinical group have in temporal patterns of admission? What kinds of differences exist among wards in temporal patterns of moving in? Are temporal patterns of admission changing? Determining patients' activities and their changes with respect to the previously mentioned viewpoints is necessary to manage clinical groups that are accepted and to allocate beds in wards.

Date and time can be expressed as simple numerical data. However, understanding the significance of date and time converts the analysis of temporal patterns into a complex process. Time is a linear as well as periodic entity. Thus, we cannot disregard the periodicities of date and time in the temporal patterns of human activities. Therefore, even for a single pattern, we have to observe the pattern from several viewpoints such as a day-period, week-period, and month-period. Moreover, it is difficult to observe many temporal patterns simultaneously. Consequently, the analysis of temporal patterns can be very complicated and problematic. To solve these problems, we need certain techniques to visualize the overview of many temporal patterns.

The purpose of this study is to support the analysis of patients' activities. In particular, we aim to improve the efficiency of identifying features from many temporal patterns by focusing on the temporal aspects of activities.

We have already proposed a technique called "ChronoView" for visualizing many temporal patterns[1]. This technique represents a temporal pattern, i.e., a set of time-stamps, using a position on a two-dimensional plane. Therefore, it provides high space efficiency and contributes toward determining the similarity between temporal patterns. We have developed an analysis tool that provides ChronoView. Using this analysis tool, we have been able to visualize a data set of patients.

2 Related Work

Powsner and Tufte proposed a graphical summary of patient status[2]. They used small repeated graphs with identical formats to show the time-oriented status of a patient. Plaisant et al. proposed LifeLines, which provides a general visualization environment for personal patient histories[3]. These seminal works focus on offering information about an individual patient. There are certain studies that focus on patients' activities. For example, Brodbeck et al. presented a case study using Masterplan, which provides several different views of patients' flows[4]. In this study, we aim to determine the features of temporal patterns of patients' activities such as admission, transition, discharge, and other clinical events.

For visualizing temporal patterns, various visualization techniques have been developed. One of the most common techniques is plotting each event on a time axis[5]. LifeLines adopted this technique. A time axis can be drawn as a circle or a spiral to reveal the periodicity of temporal patterns[6]. Another technique adopted a representation similar to a river to express the time-oriented quantitative data[7]. There are various techniques similar to those mentioned above; however, it is difficult to represent many temporal patterns together using these techniques. The scalability of visual representations for a large number of temporal patterns is an important issue.

3 Temporal Patterns and Their Overview

This section presents a formal definition of a temporal pattern, and describes an issue of visualizing the patterns.

3.1 Formalization of Temporal Pattern

Events or activities related to inpatients are accompanied by date and time, i.e., time-stamps. Every event is recorded using a time-stamp. Assume that a patient p of Group PB (obstetric group) is admitted to Ward 300 at time t. This is considered as an event and is accompanied by a time-stamp t and other attributes such as *patient* p, *admission*, *PB*, and *Ward 300*. Events that satisfy certain conditions are considered as an *event group*. For example, events of all admissions into Ward 300 comprise an event group. A *temporal pattern* is a set of time-stamps that accompany an event group. We define a temporal pattern as follows: Let E be a set of events. Each event $e \in E$ has a time-stamp $t(e)$. Each event may also have certain other attributes: a patient, one or two ward(s), action (admission, transition between wards, discharge, and so on), and a clinical group. Let, $a(e)$ and $g(e)$ denote an action and a clinical group related to an event e, respectively. For example $E_{PB,Adm} = \{e \in E | g(e) = PB \text{ and } a(e) = Adm.\}$ denotes a set of events that represent admissions to Group PB. Moreover, $T_{PB,Adm} = \{t(e) | e \in E_{PB,Ad}\}$ denotes a temporal pattern that accompanies events in $E_{PB,Ad}$. By analyzing the set, we determine a pattern of admission related to the obstetric group.

3.2 Overview of Many Temporal Patterns

If we focus on a single temporal pattern, plotting every time-stamp in the pattern on a time axis allows us to easily determine the pattern. A histogram is also useful to understand the frequency distribution of events. For example, when we want to identify the monthly distribution of admission to the obstetric group, such methods work well. However, we want to identify not only the distribution of an event group but also the remarkable features in many event groups. There are many sets of events to be observed and the temporal patterns of these sets should be observed with respect to various periodicities. One naive method for our requirement is to draw all possible histograms and to compare them. This impractical method fills the computer display with many histograms for large groups. We require a more practical method to observe an overview of all event groups efficiently.

4 ChronoView

ChronoView is a technique for visualizing many event groups with time-stamps. This technique represents each event group as a position on a two-dimensional plane. Event groups are placed on a plane similar to the clock face of an analog clock. First, we give the twelve o'clock position on the clock face to the time-stamp t_0. Then, moving clockwise, we then place all time-stamps on the circumference according to the time elapsed from t_0. If we suppose that U is the set of all time-stamps, the position of the time-stamps is expressed by the function $f_0: U \to \mathbb{R}^2$ given by

$$f_0(t) = (r \cdot \cos\theta, r \cdot \sin\theta)$$

where r denotes the radius of the clock face circle, and

$$\theta = \frac{\pi}{2} - 2\pi \frac{t - t_0}{c}.$$

Suppose that T is a finite set of time-stamps, i.e., $T = \{t_1, t_2, \ldots, t_n\}$. We assign the barycenter of the positions of t_i ($i = 1, \ldots, n$) to the set T. The positions of a set of time-stamps can be represented by the function $f: 2^U \setminus \{\emptyset\} \to \mathbb{R}^2$.

$$f(T) = \frac{1}{T} \sum_{t \in T} f_0(t).$$

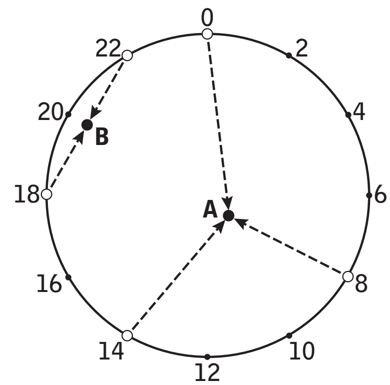

Figure 3. Basic idea of ChronoView.

For example, let us consider the case where $c = 24$h. Figure 3 illustrates the basic idea of ChronoView and shows two event groups: A and B. If events in Group A occurred at 00:00, 08:00, and 14:00, the group is placed near the center of the clock face. If events in Group B occurred at 18:00 and 22:00, then the group is placed close to 20:00 on the chord between 18:00 and 22:00. It is easy to observe whether events in the group have occurred in a wide range of time-periods, or only during certain times, by representing an event group using such positions. In Figure 3, a period c is set to 24h and t_0 is 00:00 (midnight). When c is seven days, it represents a diagram of a one-week period. In a similar way, ChronoView can represent a one-month or one-year period.

5 Visual Tool for Temporal Patterns

We have implemented ChronoView in a visual tool. The tool provides some functions as follows.

- A time-period can be selected from one-hour, one-day, one-week, and one-month.
- Individual time-stamps are plotted. ChronoView has some ambiguity in representation, because it represents a set of time-stamps by a position on a two-dimensional plane. To eliminate this ambiguity, bullets that represent individual time-stamps are drawn on the circumference of a circle expressing an event group (see Figure 4).
- Moving averages of event groups are shown. ChronoView shows the barycenter, i.e., the average of time-stamps. The length of the range to compute the average can be selected using a slider. The range can also be changed. Movement of the barycenter according to the movement of the range can be presented as an animation.
- The moving history of an event group can be drawn. Moving averages are presented as an animation. However, the animation is not helpful in determining an exact route of a moving average. The tool draws the trajectory of the moving average of a selected group explicitly (see Figure 5).

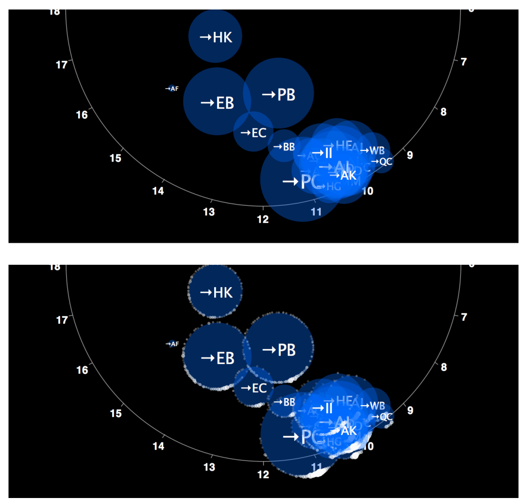

Figure 4. (Above) Normal view, without individual time-stamps. (Below) Individual time-stamps are plotted on the circumference of each blue circle.

6 Use Case

UTH is affiliated to the University of Tsukuba, and is located about 40 miles northeast of Tokyo, Japan. It has approximately 30 clinical groups and 23 wards consisting of 800 beds[8]. A complete data set of all inpatients' activities (with encrypted id's), ranging over a two-year period from April 2010 to March 2012, was provided by UTH. The Ethics Committee of UTH has approved the statistical treatment of this data and the resulting publication of research findings in our project. We extracted various event groups from the data set and visualized temporal patterns of the groups using the analysis tool.

6.1 Remarkable Features of Event Groups

We consider admission to each clinical group as an event group. Figure 1 shows temporal patterns of all event groups represented as a ChronoView. The time range is three months from April 1, 2010 to June 30, 2010. Each blue circle represents a clinical group. As is shown, most circles are concentrated from 10:00 to 11:00 on the circumference of the clock face. We can infer that the admission time of most clinical groups is concentrated between 10:00 and 11:00. This shows that admissions of planned hospitalization are performed in the morning.

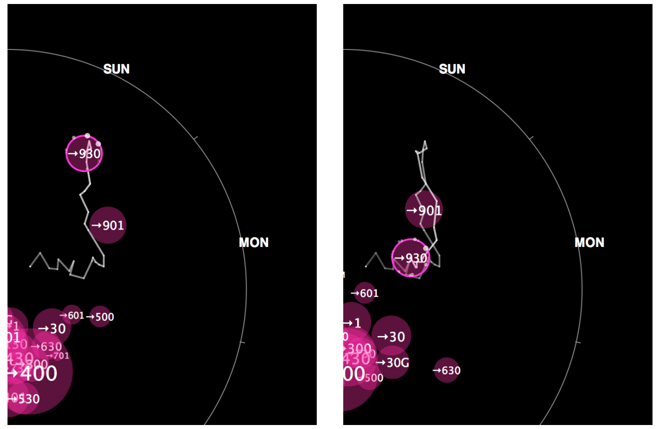

Figure 5. Moving history of Ward 930. (Left) Ward 930 moved to Sunday in late December 2010 and (Right) Ward 930 returned to the center of the clock face.

In contrast, Group AN (Sleep Disordered Breathing group) was placed close to 20:00. This suggests that all the patients of Group AN were hospitalized for tests. Group HK (Emergency group) was placed close to the center of the clock face. This suggests that the admission of Group HK occurred independent of the time of day. This feature is in the nature of the role of Group HK. Group PB (Obstetric group) and Group EB (Child Health group) were also placed near the center of the clock face. We can say that the admission of these groups also occurred independently of the time of day.

6.2 Change of Features of Event Groups

Here, we consider transitions to each ward as an event group. Figure 2 presents the temporal patterns of all event groups represented in a one-week period. Each red circle denotes the moving average of a ward for three months. In addition, the moving history of Ward 930 is drawn with gray lines. We see that Ward 930 moved to Sunday and then returned to the center of the clock face (see Figure 5). This suggests that in late December 2010, the transition to Ward 930 was concentrated on the weekend.

7 Conclusion

We have shown that we can understand the overview of features of patients' activities by visualizing temporal pattern data extracted from the data set of movement of patients. The results of the study shown so far are based only on the temporal patterns extracted from the data set. We did not use the expertise of the hospital for our conjecture. We have two objectives for future work. The first is the improvement of visual representation to efficiently express the information required by medical professionals. The second is to design a smooth connection between ChronoView and other visual representation methods for detailed information because ChronoView can only show the overview of temporal patterns.

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