A Software System for Predicting Patient Flow at the Emergency Department of Aalborg University Hospital

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Abstract

This paper presents a software system for predicting patient flow at the emergency department of Aalborg University Hospital. The system uses Bayesian networks as the underlying technology for the predictions. A Bayesian network model has been developed for predicting the hourly rate of patients arriving at the emergency department at Aalborg University Hospital. One advantage of using Bayesian networks is that domain knowledge and historical data can easily be combined into an intuitive graphical model. The aim of this paper is to describe the software system delivering the predictions of the Bayesian network model as a decision-support system for employee shift scheduling at the emergency department.

Keywords: Bayesian network; learning from data; real-world application; software.

1. Introduction

Over the last three decades, Bayesian networks, see e.g., Kjærulff and Madsen (2013), have been applied in a range of different domains due to their ability to represent and manage uncertainty in an intuitive graphical model. Two key features of Bayesian networks are the capability of combining information from both domain expert knowledge and historical data into a single knowledge representation and their explainability.

We describe a software system for predicting patient flow at the emergency department of Aalborg University Hospital. The purpose of predicting patient flow is to support the employee shift planning at the emergency department. The employee (or nurse) shift planning is currently a manual process based on domain knowledge and experience of the planners.

The software system is developed using HUGIN software. HUGIN software is a suite of tools for developing and deploying Bayesian network models (Andersen et al., 1989; Madsen et al., 2005). This paper describes the software system developed with a focus on the technical implementation and functionality.

2. Methods and Materials

A Bayesian network $N = (\mathcal{X}, \mathcal{P})$ over a set of discrete variable $\mathcal{X} = \{X_1, \ldots, X_n\}$ is a efficient factorization of the joint probability distribution when its directed, acyclic graph G is sparse. The joint distribution $P(\mathcal{X})$ decomposes into a product of conditional probability distributions (CPDs) $P(X \,|\, \mathrm{pa}(X)) \in \mathcal{P}$ as specified by G such that $P(\mathcal{X}) = \prod_i P(X_i \,|\, \mathrm{pa}(X_i))$, where $\mathrm{pa}(X_i)$ are the parents of X_i in G. The Conditional Linear Gaussian (CLG) Bayesian network, see e.g., Lauritzen and Jensen (2001), is a hybrid model with discrete and continuous variables where the latter follows a CLG distribution, i.e., $Y \sim N(\alpha(i) + \sum_j \beta_j(i) z_j, \sigma(i)^2)$, where i is a configuration of the discrete parents of Y and z_j is the value of the jth continuous parent of Y, respectively. We use a CLG Bayesian network as the prediction model.

3. Patient Flow

The software system is developed for the emergency department at Aalborg University Hospital. Aalborg University Hospital is the largest hospital in the region of North Jutland (one of five regions in Denmark) with 538 beds located in Aalborg (as of July 2020) and 244 beds at other local hospitals in the region. In total the hospital had 6646 full time positions in 2018. The emergency department covers more than half of the activities in the region.

Employee shift scheduling at the emergency department is a challenge, especially if the flow of patients must be taken into consideration. According to Danish legislation the employees must know their working schedule four to six weeks in advance typically for a four weeks period. The actual planning includes different employee profiles to make sure that all functions of the emergency department are covered.

Patients arrive at the emergency from three main sources, i.e., 1-1-2 (emergency telephone number), emergency medical center and own family doctor. The aim of the system is to support the employee shift planning by identifying periods where an increased (or decreased) number of patients should be expected given a horizon of four weeks.

The key performance indicators (KPIs) for the emergency department include ratio of patients waiting more than four hours for a completed treatment plan and triage within 30 minutes after arrival. The system targets the KPIs through improved scheduling support aiming to achieve, e.g., a reduced use of temporary workers.

The CLG Bayesian network model for predicting patient flow is constructed from a combination of domain expert knowledge and historical data using the learning capabilities of HUGIN software (Madsen et al., 2003, 2017). The prediction model is estimated off-line and a number of indicator variables are included in the model to adjust for specific (and returning) events such as, e.g., national holidays, vacation, social events and sport events.

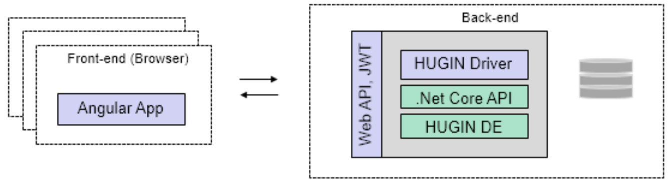

Figure 1: System Software stack.

4. Web Application Software Architecture

Figure 1 shows the software technology stack. At the bottom is the HUGIN Decision Engine (HDE) implemented in ISO C for efficiency and portability. The HDE has a set of Application Programming Interface (API) wrappers. The system is implemented using ASP.NET Core on top of the HDE using the HUGIN .NET Core API. ASP.NET Core is a free and open-source web application framework developed by Microsoft. The client side is developed using Angular while the server side is developed as a Web API using JSON web token authentication and authorization. The web API back-end (referred to as HUGINDriver) provides a set of web end points for, e.g., authentication and inference (i.e., predicting the number of patients for a certain period).

Figure 2 shows a simple example of the calendar part of the web front-end. On the left, May 2019 is shown where the selected day, Friday 17th, is marked as a bank holiday (General Prayer Day) and Saturday 25th is also marked (only two events are included for the example - the red dots specify the number of events on a day). On the right, we see the last week of August, 2019 where DHL Stafet is marked to take place between 10am and 9pm (a running event over three afternoons).

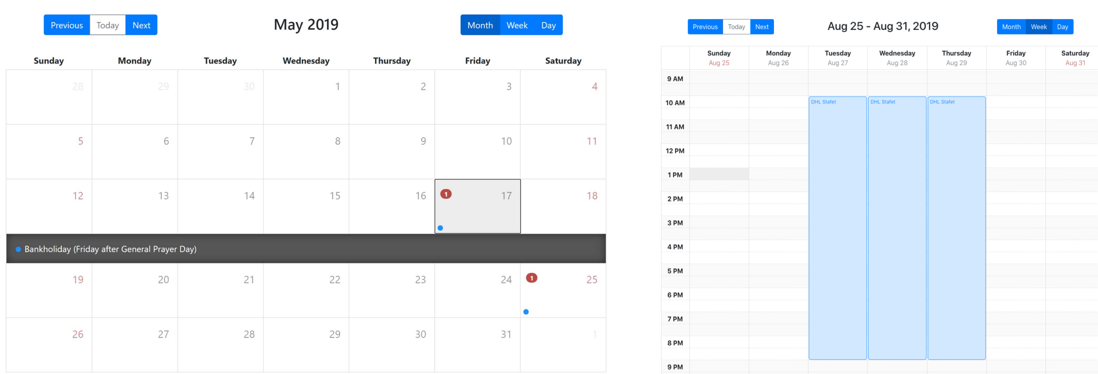

Figure 2: Calender view (left) month and (right) week.

Figure 3 shows the predicted patient flow for a period of May 2020. The figure shows the total number of patients at an hourly rate. It is possible to make predictions for specific types of patients and at different rates. The prediction for the entire period is shown in the lower part of the figure while the upper and larger part shows the selected part of the period (Friday 22nd to Sunday 24th). The blue curve is the prediction without adjustment for events while the green curve shows the prediction with adjustment for events. On Saturday, May 23rd, 2020 the yearly carnival (the largest in Northern Europe) was planned to take place in Aalborg. It is clear from the figure that the carnival is expected to produce a much higher number of patients in the afternoon than a regular Saturday.

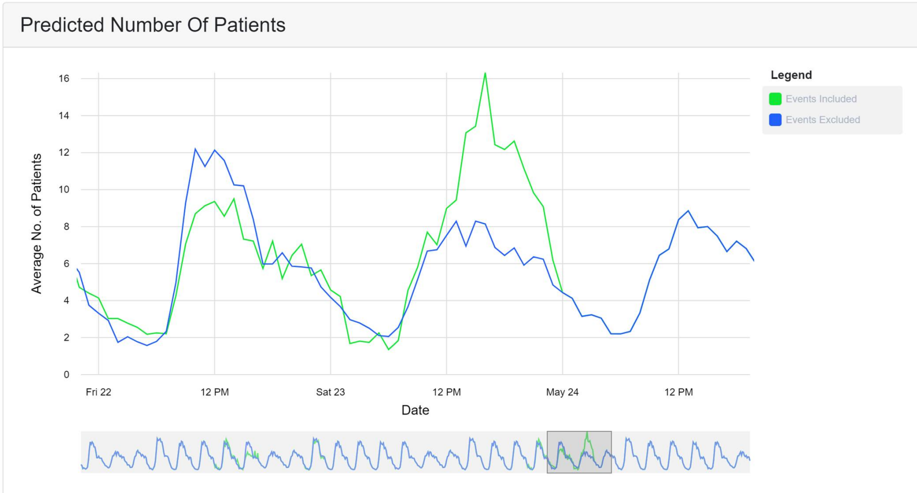

Figure 3: Prediction of patient flow at an hourly rate.

5. Conclusion and Future Work

A software system for predicting patient flow at the emergency department of Aalborg University Hospital has been described. It is developed as a web application with a front-end developed in Angular and a back-end web API using the HDE for model representation and inference. Future plans include on-site deployment of the system at the emergency department as a decision support system for nurse shift planning. The evaluation on-site has been delayed due to the COVID-19 situation, and is currently planned for fall 2020.

Acknowledgments

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