Augmenting EHR Interfaces for Enhanced Nurse Communication and Decision Making

Alessandro Chetta
University of Illinois at Chicago
Dept. of Computer Science
achett3@uic.edu

Jane M. Carrington
University of Arizona
College of Nursing
janec@email.arizona.edu

Angus Graeme Forbes
University of Illinois at Chicago
Dept. of Computer Science
aforbes@uic.edu

ABSTRACT

The use of electronic health records (EHRs) in clinical environments provides new opportunities for nurses to integrate data analyses into their practice. While having access to these records has many benefits, the act of recording, retrieving, and analyzing this data can nonetheless introduce communication issues, as navigating and interpreting large amounts of heterogeneous data can be difficult, and conclusions can be hard to validate. In this paper, we describe a series of integrated visual interfaces to help nurses document and reason about patient data and about clinicians' understanding of patient data. The interfaces present the output of a predictive algorithm that makes use of historical EHR data, patient vital signs, and nurse handoff reports in order to classify a patient in terms of their likelihood of experiencing clinical events. Furthermore, the interfaces enable the nurses to quickly explore the original data and to examine other nurses' interpretation of patient activity during previous shifts. We present a series of usage scenarios that introduce our interactive visualization tools in the context of real-world healthcare situations.

CCS Concepts

•**Applied computing** → *Health care information systems; Health informatics;* •**Human-centered computing** → *Visual analytics; Information visualization;*

1. INTRODUCTION

Research by Carrington and Tiase [7] has explored how a range of issues have mitigated the effectiveness of the electronic health record (hereafter, EHR) in clinical situations. Nurses are often unable to effectively sift through the large amount of data available via the EHR in order to find pertinent information [18]. Studies of nurse behavior has found that many nurses make an effort, when possible, to talk to each other face-to-face as they change shifts precisely because current implementations of EHRs make it difficult to accurately transcribe a summary of patient behavior during a period of observation [5]. Even when nurses are able to provide verbal or textual summarizations, or handoff reports, of patient health during a shift-change, these summarizations can themselves be misinterpreted or ignored [6]. Ineffective communication between health care professionals may account for an alarming number of miscommunications that have lead to catastrophic events in patient health [19]. For instance, a report by the Institute of Medicine [14] finds that up to 98,000 patients die per year as a result of complications of therapy due to ineffective communication and, moreover, that errors in communication cost US hospitals an estimated $12 billion annually [10].

In this paper we describe an implementation of an interactive system, based on ideas proposed by Forbes et al. [12] for augmenting EHRs to better serve nurses' day-to-day workflow. Forbes et al. discuss a system for determining the probability of particular patient outcomes given a patient's vital sign, verbal handoff reports, and historical EHR data. Here, we present three integrated visualizations that facilitate nurse communication and nurse decision making. These interfaces are available online[1] and are currently being evaluated by nursing students at the University of Arizona and nurses at Banner University Medical Center in Tucson, Arizona. The first interface presents an overview of potentially high risk outcomes for a particular patient. The second interface enables the nurse to investigate the clinical events that are likely to be associated with any of the high risk outcomes, as well as an overview of why these clinical events are indicated for the patient. The third interface allows the nurse to scroll through a timeline of relevant data recorded automatically (i.e., vital signs) or by a nurse (i.e., through spoken or written text).

An important consideration that motivates the design of our interactive visualization tools is that errors are unavoidable: a nurse may at some point make an incorrect annotation or miscommunicate their understanding of patient data; computational models that incorporate historical data will necessarily be imperfect as new advances in medicine and healthcare are made. That is, we assume that data presented by our visualization tools may be untrustworthy in some cases. However, the design of our interfaces encourages a nurse to investigate both human-annotated and machine-generated data precisely to facilitate the discussion of differing opinions about the meaning of patient data. Enabling these discussions, rather than ignoring, or never noticing, conflicting interpretations could lead to more effective pa-

VAHC '15 October 25, 2015, Chicago, IL, USA
© 2015 ACM. ISBN 978-1-4503-3671-0…$15.00
DOI: 10.475/123_4

[1] The online version of our visualization application is available at: http://alessandrochetta.github.io/ACT.

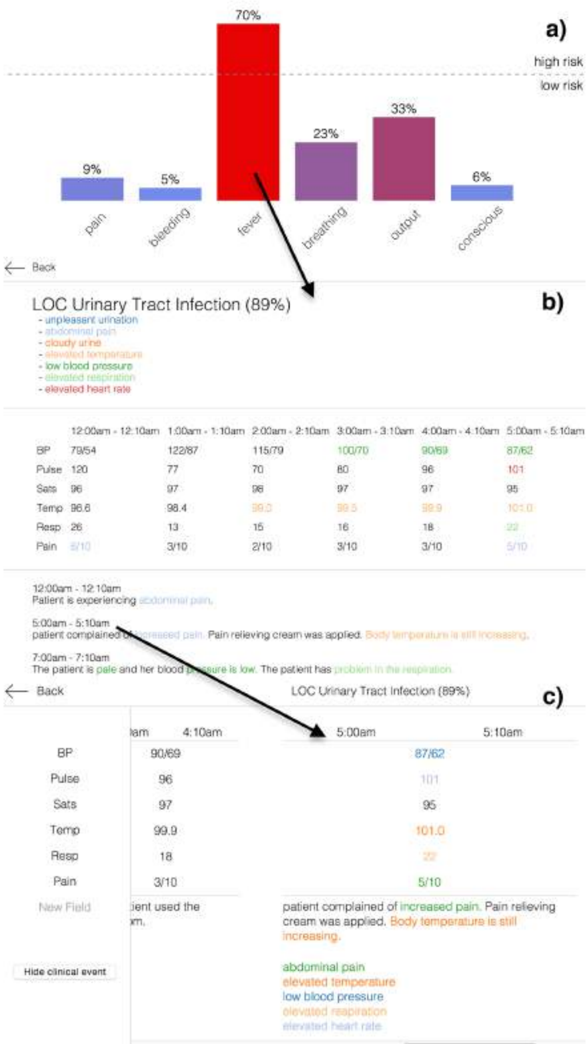

Figure 1: This figure represent a typical workflow of a nurse using our tool. a) The *outcomes chart* interface here shows that there is a lower risk of major outcomes related to pain, bleeding, breathing, changes in output, or a loss of consciousness. However, a high risk of fever (70%) is indicated. By clicking on the third bar, shown in red to indicate a high risk of its occurrence, the nurse automatically navigates to the clinical events list. b) The *clinical events list* interface here shows clinical events related to fever. Color coding is used to associate symptoms to the supporting evidence found in the EHRs. The nurse can click on the second snippet to navigate to the more detailed report provided in the timeline interface. c) The *augmented flow sheet timeline* visualizes detailed data report via a timeline interface. The color coding helps the nurse to understand the relations between symptoms and the EHR fragments (as recorded by a nurse in previous shifts). In this mode, the nurse can both view and edit or annotate the EHR history related to the patient.

tient care. We describe details of each of the three interfaces below.

2. RELATED WORK

Research on nurse communication has explored both benefits and potential issues with incorporating EHRs into clinical workflows. Likourezos et al. [15] examine nurse satisfaction with effective use of EHRs, and explore how EHRs can improve hospital efficiency. Our work specifically attempts to utilize visual interfaces to facilitate effective nurse communication about individual patients. Work by Abraham et al. [1, 2] investigates issues surrounding transformation of information and responsibility, or *handoffs*, between clinicians. Cohen et al. [8] and Wayne et al. [20] focus on the importance of finding a standardized handoff procedure to guarantee effective communication of patient health status during a nurse shift. Also, as noted by Denmer-Fushman et al., clinical observations of a patient are often in large part recorded as narrative text [9]. Our tools enable nurses to collect short reports using natural language regarding the patient health status. Nurses can insert new information in the system, without following strict standards or constraints, whenever they recognize a significant event that should be recorded for a future consultation. This approach minimizes the time it takes for data entry, and the textual, interpretative data is directly coupled with the vital signs measured during a visit with a patient. A nurse can easily integrate the information gathered from a handoff with the reports previously stored in the timeline. Furthermore, as Hyun et al. [13] discuss, nurse narratives can be effectively analyzed by automated natural language processing algorithms. Our visual interface currently makes use of a predictive system based on a statistical machine translation algorithm, as described by Forbes et al. [12], but could potentially be integrated into other predictive systems as well. Both the temporally synchronized textual snippets and the end-of-shift summaries are used to better predict potential patient outcomes.

Our visual interface is inspired by previous investigations into how visualization can be used to effectively represent health data. Rind et al. [18] provide a comprehensive overview of the use of interactive information visualization approaches to query and explore EHRs, identifying a number of features important to describing a single patient's data. These include the effective presentation of clinical events and numerical data over time, and being able to view heterogeneous data on the same timeline in order to facilitate the interrelation of events and data for providing an overall understanding of patient health. Our *clinical events list* interface, described in Section 3.2, implements a table to represent measurement values across multiple time periods, as is illustrated in the Fig. 1b. As noted by Aigner et al. [3], "it is enormously difficult to consider all aspects involved when visualizing time-oriented data." During the design and implementation of the *augmented flow sheet timeline*, described in Section 3.3 and represented in Figs. 3 and 1c. Our time axis is characterized by time intervals, because of the nature of nurse reporting in clinical environments. Each period of the flow sheet in the EHR has a particular duration; they never overlap because they refer to a nurse report and, in our domain, only one nurse reports the patient status in a given interval of time. Our system is also inspired by the work of Monroe et al. [16], who use a query based approach to find event patterns of interest in a complex timeline. Our system does not attempt to display complex temporal patterns, however we use an interactive timeline interface to track nurse interpretation alongside vital sign collection within an EHR flow sheet. Another important feature that our tool provides is the ability to find and edit errors in the handoff reports made in earlier shifts (discussed in the usage scenario below).

3. AUGMENTING ELECTRONIC HEALTH RECORDS

Nurses can use our tools both to communicate detailed information to each other and also to understand the automated decision making process which alerts them when there is a high risk of a major outcome, such as pain, bleeding, fever, problems with breathing, changes in output, or a loss of consciousness. The tool has three main views, the *outcomes chart*, the *clinical events list*, and the *augmented flow sheet timeline*, each of which are implemented as web interfaces that can run on a desktop browser or on a tablet computer. The client code for the interface is written in HTML5 using Javascript and the D3.js visualization toolkit.

3.1 Outcomes Chart

The *outcomes chart* shows an overview of the predicted likelihoods of major negative outcomes, as determined by a decision making algorithm. Each of the six outcomes are displayed as a bar of great or lesser height in a bar chart, as illustrated in Fig. 1a. Each outcome bar's color ranges from pale blue to red, based on the likelihood of the related outcome. By default we use a palette that is safe for users with colorblindness [17], but we also allow users to switch to other palettes as desired. The outcomes are currently generated by a machine learning algorithm that takes in input collected via our timeline interface, described below, but they could potentially also be generated by other means. The outcome is considered high risk when the likelihood is greater or equal than 50%. This interface can be consulted at a glance by the nurse in charge in order to get a quick view of the overall health status of a patient. In addition to providing a very high level overview of the patient, the nurse can use this outcome chart to investigate the reasons *why* the algorithm classified a patient as high or low risk for a particular outcome. Each outcome bar is a clickable link to another view that lists details about the clinical events related to the patient, as determined by an analysis of the flow sheet data, the textual annotations, and historical EHR data. Fig. 1a shows an example of an outcomes chart for a patient that has a high risk of a negative outcome related to fever.

3.2 Clinical Events List

The generated *clinical events list* interface (Fig. 2 and also Fig. 1b) shows the set of potential clinical events, as determined by an algorithm that classifies the heterogeneous inputs in terms of a database of thousands of diagnoses. First it retrieves a set of patient symptoms selected through an analysis of nurses' text over the course of the patient's stay. These symptoms are the input to a classifier that associates each of them to a set of potential clinical events with a certain probability. These probabilities are displayed and each clinical event can then be further expanded interactively to

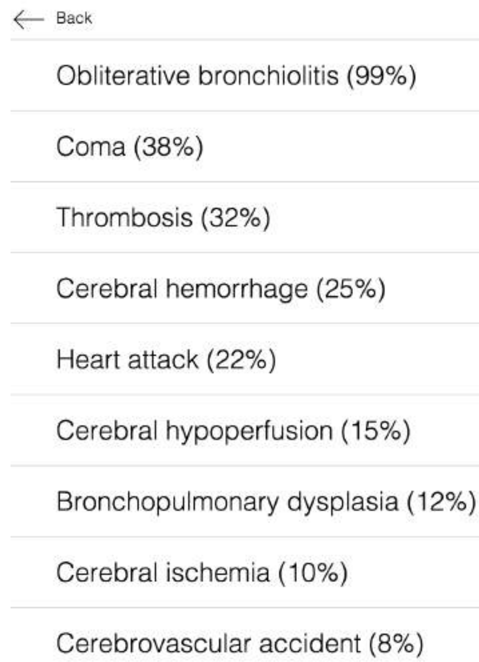

Figure 2: Example of clinical events related to a specific major outcome. Each clinical event has its probability on the right hand side. The user can expand a clinical event to get further information. The user can choose to go back to the outcomes chart interface clicking the back top bar.

provide more information explaining the correlation between the clinical event and the patient's symptoms. In this way, a nurse can investigate the reasoning mechanism that led the decision making algorithm to predict a particular clinical event. The information is represented in three parts: a list of symptoms, a set of vital sign measurements, and textual descriptions made by nurses, collected via the augmented *flow sheet timeline* interface described below. The list of symptoms are those that the patient experienced of the course of his or her current stay. Here we apply simple color coding; each symptom is assigned a unique color, and then the EHR fragments that are associated with a symptom also use the same color. This way the nurse can at-a-glance recognize which of the EHR fragments are correlated with each symptom. The set of measurements could include, for example, blood pressure, temperature, heart rate, or any other measurement normally recorded on a flow sheet. Measurements are reported in an m by n table, where m is the set of measurement labels needed to monitor the patient and n is the number of time periods in which the nurse visits the patient to record events and take notes. For instance, if the symptom "fever" is colored red, then the value related to the measurement "temperature" would be also red if it determined that this value indicates fever.

The textual snippets list all the text related to handoff or nurse annotations that are relevant for the predicted clinical event. Colors are also used to indicate when a sentence within the handoff triggered a the classification algorithm to correlate it with a particular symptom. This interface is linked to the *flow sheet timeline* in order to enable the

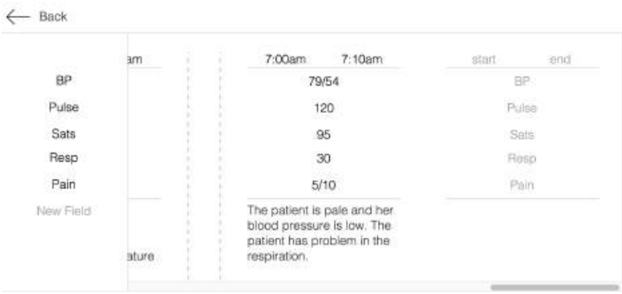

Figure 3: Screenshot of the augmented flow sheet timeline. On the left there are the measurement labels; the user can add more labels by clicking on "New field." The scroll area on the right displays earlier reports, a collapsed block of time (where no events where annotated by a nurse), and a space to input new data. The nurse can scroll to the left or right to see early or later events.

user to retrieve the specific textual data and/or measurements involved in the automated reasoning process. The user can see the retrieved nurse commentary in the context of the timeline by clicking any EHR fragment in this interface. When a report is retrieved, the *flow sheet timeline* interface scrolls automatically to the requested report. Furthermore, the color coding is retained across the different views so that the user can associate the EHR fragments to the symptoms displayed in the *clinical event list.* The user can also manually scroll the timeline back and forth to see what happened to the patient before and after the retrieved report time.

3.3 Augmented Flow Sheet Timeline

The *augmented flow sheet timeline* facilitates meaningful textual input from the nurse, providing interpretive clues that contextualize the meaning of the numerical flow sheet data. Nurses can insert an arbitrary number of measurements and textual annotations related to a patient's health status at any given moment during his or her shift. This interface is the primary location used in our visualization tool to enhance communication between nurses. The interface has a vertical fixed bar on the left hand side and a horizontal scroll area in the center. The vertical bar contains the measurement labels indicating the subset of measurements that the nurse wants to monitor in order to take care of the patient most effectively, without being overwhelmed by irrelevant data. These measurements include blood pressure, pulse, temperature, and other empirically monitored vital signs, as well as qualitative assessments made by the nurse or by the nurse in conjunction with the patient, such as level of pain using the pain index. The user can add further measurement labels at any moment, and moreover can choose to view any numerical data as a line chart in order to more easily see trends over the current shift or over multiple shifts. By sliding the scroll area to the left, the user is able to view previous annotations and patient measurements. In this way, a user can quickly see all the patient history since the initial intake report. The user can also edit or annotate the comments made during earlier shifts from previous handoffs.

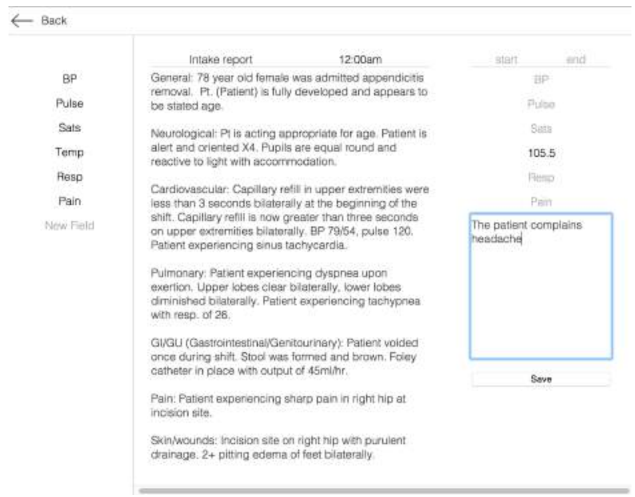

Figure 4: Usage scenario: Patient admission, first EHR inserted in the system. The nurse added the "Temp" label in the measurement label bar. From now on the patient temperature can be stored in each future report. The nurse wrote a short description of the event and he or she can save it by pressing the save button at the end of the form.

To reduce cognitive overload, in cases where a portion of the report does not contain any text the report is automatically collapsed, hiding numerical data that is less relevant in order to simplify the visual display. The "hidden" data is indicated by a collapsed block delimited by two vertical dashed borders. In this way the reports initially only display times that contain textual snippets, which are assumed to be more significant since they were worthy of commentary. However, the collapsed reports can be viewed and edited simply by clicking on the collapsed block. Fig. 3 shows a nurse adding a textual description in natural language during a patient visit.

4. USAGE SCENARIOS

This section describes example usage scenarios, as provided by nursing students at the University of Arizona. These usage scenarios, and many others like them, help us to understand the day-to-day workflow of nurses and how the nurses interact with the interfaces in a clinical environment.

4.1 Patient admission; intake report

A new patient, 78 year old female, is admitted with chest pain. The nurse in charge creates an intake report related to the current patient health status. The intake report is inserted quickly in the flow sheet timeline, creating the first record related to the patient in the system. After this first step, the intake nurse adds all the measurement labels needed to monitor the patient with chest pain. In the morning, at 8:35am, the patient complains of a headache, thus the nurse in charge at that moment decides to measure the body temperature and to collect it in a report adding also a textual description of the patient complain. Fig. 4 shows how the nurse can insert a new text field in the timeline; only relevant measurements are displayed by default, though additional data can be displayed on demand.

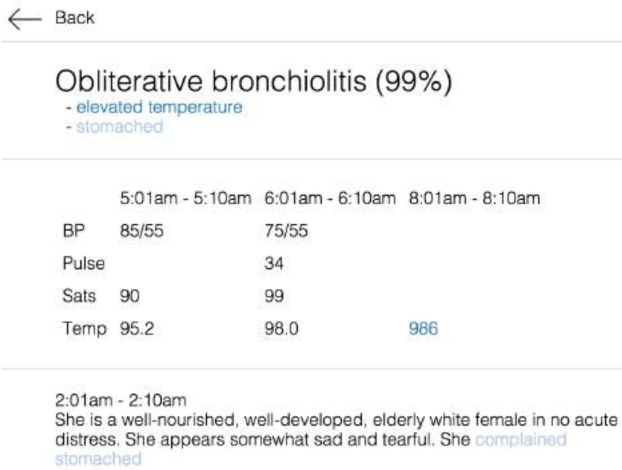

Figure 5: Usage scenario: Error recognition. The temperature value of 986 is clearly an error. The nurse clicks on it to edit the related report.

4.2 Fever outcome; EHR browsing

The nurse examines the outcomes chart and sees that the most likely outcome suggested by the system is "Fever" (Fig. 1 a). The nurse wants to understand why the system is predicting a risk of negative outcome related to fever with a probability of 75%. The nurse uses the interface to explore the data indicated in the automated reasoning process by clicking the bar related to "fever." The system visualizes the clinical events list interface, which shows the nurse all of the most likely clinical events that are related to the patient, based on the current patient health status. The clinical events are ordered by their likelihood index. At this point the nurse can get more information by clicking on one of the clinical events listed. The nurse chooses "LOC-Urinary Tract Infection," which is predicted by the system with a probability of 89%. The interface expands the clinical event (Fig. 1b); now the nurse can see more details about the symptoms that the algorithm recognized from the nurse comments and measurements of vital signs, which in this case include the following significant symptoms: unpleasant urination, abdominal pain, cloudy urine, elevated temperature, low blood pressure, elevated respiration, and elevated heart rate. Finally the nurse can see snippets of reports that contain significant sentences related to the recognized symptoms. For instance, one of the snippets contains the sentence "patient complained of increased pain around the abdomen." The system is able to recognize the symptom "abdominal pain" from this sentence. At this point, the nurse wants to know the recent history of the patient's health status. In particular, the nurse wants to know what happened some hours before that the patient complained about the abdominal pain. To do so, the nurse clicks on the snippet that contains that information, and the system visualizes the handoff using the *flow sheet timeline* (Fig. 1c). The nurse scrolls left on the timeline and the earlier annotations appear. Having verified that the system accurately made sense of the annotations left by the previous shift's nurse, the nurse can return to the clinical events list to see if any of the other generated events help to reason more effectively about patient care.

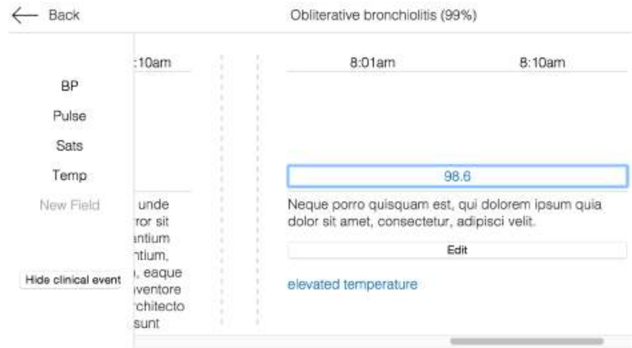

Figure 6: Usage scenario: Error recognition. The nurse can correct the error. The temperature will be stored correctly with a value of 98.6 rather than 986.

4.3 Error recognition; timeline editing

A nurse just starting his or her shift wants to gather a general idea of the current patient's health status, and so looks at the outcomes chart and notices with surprise that the system suggest an issue related to fever with a probability of 99%. The nurse then measures the patient's body temperature, noting that the patient has a nearly normal body temperature. The nurse clicks the bar related to the outcome fever in the chart and the system lists all the likely clinical event that the patient could experience given the high risk of fever (as in Fig. 2). The system predicts Obliterative bronchiolitis with a likelihood of 99%, which again seems unusual. The nurse expands the clinical event to see more information. In this view the nurse spots a measurement that is clearly wrong. The patient temperature, in a report taken at 8:01am by a previous nurse, is equal to 986 (Fig. 5). Clearly the previous nurses meant 98.6, but by mistake the nurse inserted 986 in the report, causing the algorithm to predict the high risk of fever as likely outcome. The nurse in charge wants to correct this mistake. To do so, the nurse clicks on the erroneous measurement from the *clinical events list* interface and the system visualizes the report that contains that measurement in the timeline. The nurse edits the report replacing the "Temp" measurement with 98.6 rather than 986 (Fig. 6), which reruns the algorithm and produces a more meaningful overview of the patient's health.

5. CONCLUSION AND FUTURE WORK

As discussed in the usage scenarios above, our interactive visualization tools are effective at enabling nurses to communicate and to reason more clearly about a patient's health. Further work is required to evaluate the interface design and visual encoding of our tool; we expect to add additional visualizations as well as to enhance the current ones, especially the *augmented flow sheet timeline*, by continuing to explore effective temporal visualization techniques [4]. We will also identify specific areas in a nurse's workflow that could be improved by effective visual analysis tools. For instance, we plan to investigate the interplay between physicians and nurses when incorporating these interactive visualization interfaces into healthcare scenarios. However, we are already encouraged by the nursing students and nurse practitioners who have given us initial positive feedback. The use of natural language snippets coupled with empirical data, both recorded at specific intervals throughout a patient's stay, encourages a more thorough analysis of patient health, as both data types are presented along a single time axis. At the same time, the danger of misreading a patient's data is mitigated by the ease of use of exploring the data in order to verify both the automated analyses [11] and other clinicians' interpretations of the patient's health.

6. ACKNOWLEDGMENTS

This work is funded in part by the National Institutes of Health, award #R01EB020395 (part of the NSF/NIH Smart and Connected Health Program).

7. REFERENCES

[1] J. Abraham, T. Kannampallil, and V. L. Patel. A systematic review of the literature on the evaluation of handoff tools: Implications for research and practice. *Journal of the American Medical Informatics Association*, 21(1):154–162, 2014.

[2] J. Abraham, T. G. Kannampallil, and V. L. Patel. Bridging gaps in handoffs: A continuity of care based approach. *Journal of Biomedical Informatics*, 45(2):240–254, 2012.

[3] W. Aigner, S. Miksch, W. Müller, H. Schumann, and C. Tominski. Visualizing time-oriented data—A systematic view. *Computers & Graphics*, 31(3):401–409, 2007.

[4] R. Bade, S. Schlechtweg, and S. Miksch. Connecting time-oriented data and information to a coherent interactive visualization. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*, pages 105–112, 2004.

[5] J. M. Carrington. Development of a conceptual framework to guide a program of research exploring nurse-to-nurse communication. *CIN: Computers, Informatics, Nursing*, 30(6):293–299, 2012.

[6] J. M. Carrington. The usefulness of nursing languages to communicate a clinical event. *CIN: Computers, Informatics, Nursing*, 30(2):82–88, 2012.

[7] J. M. Carrington and V. L. Tiase. Nursing informatics year in review. *Nursing Administration Quarterly*, 37(2):136–143, 2013.

[8] M. D. Cohen and P. B. Hilligoss. The published literature on handoffs in hospitals: Deficiencies identified in an extensive review. *Quality and Safety in Health Care*, 19(6):493–497, 2010.

[9] D. Demner-Fushman, W. W. Chapman, and C. J. McDonald. What can natural language processing do for clinical decision support? *Journal of Biomedical Informatics*, 42(5): 760–772, 2009.

[10] J. Effken and J. Carrington. Communication and the electronic health record: Challenges to achieving the meaningful use standard. *Online Journal of Nursing Informatics (OJNI)*, 15(2), 2011.

[11] A. G. Forbes, S. Savage, and T. Hollerer. Visualizing and verifying directed social queries. In *Proceedings of the IEEE Workshop on Interactive Visual Text Analytics (TextVis)*, October 2012.

[12] A. G. Forbes, M. Surdeanu, P. Jansen, and J. M. Carrington. Transmitting narrative: An interactive shift-summarization tool for improving nurse communication. In *Proceedings of the IEEE Workshop on Interactive Visual Text Analytics (TextVis)*, October 2013.

[13] S. Hyun, S. B. Johnson, and S. Bakken. Exploring the ability of natural language processing to extract data from nursing narratives. *CIN: Computers, Informatics, Nursing*, 27(4):215, 2009.

[14] L. T. Kohn, J. M. Corrigan, and M. S. Donaldson, editors. *To Err is Human: Building a Safer Health System*. National Academies Press, 2000.

[15] A. Likourezos, D. B. Chalfin, D. G. Murphy, B. Sommer, K. Darcy, and S. J. Davidson. Physician and nurse satisfaction with an electronic medical record system. *The Journal of Emergency Medicine*, 27(4):419–424, 2004.

[16] M. Monroe, R. Lan, H. Lee, C. Plaisant, and B. Shneiderman. Temporal event sequence simplification. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2227–2236, 2013.

[17] C. Rigden. 'The Eye of the Beholder'—Designing for colour-blind users. *British Telecommunications Engineering*, 17:291–295, 1999.

[18] A. Rind, T. D. Wang, A. Wolfgang, S. Miksch, K. Wongsuphasawat, C. Plaisant, and B. Shneiderman. Interactive information visualization to explore and query electronic health records. *Foundations and Trends in Human-Computer Interaction*, 5(3):207–298, 2011.

[19] J. E. Stevenson, G. C. Nilsson, G. I. Petersson, and P. E. Johansson. Nurses' experience of using electronic patient records in everyday practice in acute/inpatient ward settings: A literature review. *Health Informatics Journal*, 16(1):63–72, 2010.

[20] J. D. Wayne, R. Tyagi, G. Reinhardt, D. Rooney, G. Makoul, S. Chopra, and D. A. DaRosa. Simple standardized patient handoff system that increases accuracy and completeness. *Journal of Surgical Education*, 65(6):476–485, 2008.