Recording Events, Interactions, and Annotations to Communicate Reasoning in Medical Situations

Dawood Al-Masslawi
University of British Columbia
Dept. of Electrical and Computer Engineering
Vancouver, BC, Canada
masslawi@mail.ubc.ca

Rodger Lea
University of British Columbia
Dept. of Electrical and Computer Engineering
Vancouver, BC, Canada
rodgerl@ece.ubc.ca

Sidney Fels
University of British Columbia
Dept. of Electrical and Computer Engineering
Vancouver, BC, Canada
sfels@ece.ubc.ca

Leanne M. Currie
University of British Columbia
School of Nursing
Vancouver, BC, Canada
leanne.currie@nursing.ubc.ca

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Abstract
In recent years data collection and communication has become increasingly *ubiquitous*, to the extent where it is possible to capture and communicate many parts of live experiences. In a novel approach, we propose recording of events, interaction, and annotations in order to access characteristics that communicate the reasoning behind the decision-making of care providers. Recording is done with free-form and implicit data collection, and communication of spatio-chronological characteristics of events, interactions, and annotations are done with augmented interfaces. This enables care providers, who make decisions, to identify what factors have played the most significant role in the decision-making. In the context of chronic care, this research is aiming at, better understanding how to capture and communicate the medical decision-making process. Our preliminary experiments show success in communicating the reasoning processes of the document analysis sessions in a lab environment. We have started to look at how this improves reliability and practice outcomes of the decision-making in real-life medical environment.

Author Keywords
Capture and access; ubiquitous computing; decision support; healthcare; chronic diseases.

ACM Classification Keywords
H.1.2. Human factors, H.1.2. Human information processing, H.3.4. Current awareness systems, H.3.5. Web-based services

Introduction and Motivation

Chronic care is a long-term process in which high costs and multiple health implications are very common [1]. The large numbers of stakeholders involved, who have diverse expertise, adds further complexities to chronic care [1]–[3]. Namely, this requires medical workflows to be loosely defined. During this process, care providers might change frequently and medical data is subjected to passing of time [3]. For this reason, care providers often have difficulties in communicating the decision-making process that a patient's case undergoes [2]. The collected data about the patient's history accumulates over time, which becomes a problem since care providers cannot retrieve a substantial amount of the relevant data [1]. In addition, it is a challenging task to synthesize and make sense of this data for the purpose of decision-making [4]. Hence, questions such as the following remain unanswered, once time has passed and memories have faded. How and why care providers have made the decisions that they made? What factors have played into the made decisions, and to what extent? Why care providers decided those factors are significant? [5]. It might not be clear how the data was collected and used. For example, why medical evidence was ignored, while it could have influenced the treatment. Was the reason that care providers did not notice that evidence, or they perceived it as insignificant? Research shows that data collection and communication are fundamental issues relevant to these questions in medical decision making [1]–[4]. Data collection and communication can change the reliability of the discovered and communicated medical evidence, and consequently the practice outcomes in decision-making [1].

In this work, we investigate what principles in study, design, and evaluation of data collection and communication can support decision-making in chronic care. We are specifically focusing on knowledge acquisition points, with identifying events, interactions, and annotations that capture data elements in medical decision-making. For data collection we emphasize on, free-form and implicit collection of data, that is, loosely defined capture of web, mobile and sensory data. A set of novel principles referred to as ubiquitous capture, are defined to enable implicit and free-form data collection. As for data communication, interactively communicating the spatio-chronological characteristics of data is emphasized. The set of principles defined for data communication are referred to as augmented access. These principles are set and refined by analysis of the decision-making in chronic care, synthesizing related work, and iterations of experiments using prototypes. Further experiments and evaluations in real-life medical environments are in planning and preparation stages, to find out how the captured data elements affect reliability and practice outcomes.

The reminder of this paper is organized as follows; the next section provides a review and synthesis of the research done on decision-making in medicine and technology. Then we discuss the proposed method for data collection and communication. The following section will describe the built technology. Field studies and future work are discussed next. The last section presents our concluding remarks.

Related work

Authors in [6] define Capture and Access (C&A) as "to augment an individual's memory and provide implicit information sharing between groups". In this regard, work such as [2] notes that interactions in a medical environment can be used to augment data that is relevant to collaboration activities. These interactions are verbal and spontaneous, which means they could be lost otherwise, if not captured. Their proposed application captures interactions between users based on co-location of heterogeneous devices. This free-form collection of data has allowed to support collaboration of medical workers in decision-making. During their study the authors also observed that most of the interactions are not documented. This brings a question to mind: even if these interactions were documented, which is not a trivial task itself, how much the resulting documentation would be useful to the user, given the immense amount of recorded data? Authors in [1] investigated this issue by capturing interactions during autism therapy sessions, to provide highly indexed videos that communicate the therapy process, and support the team decision-making. The highly indexed videos were embedded in an interactive timeline that visualizes spatio-temporal characteristics of data. As well as work done in [7] for education of children with special needs where authors used selective archiving, which utilizes implicit capture of data. This was similarly done in [4], to classify activities of infants and toddlers (e.g. assemble, non-play, drinking, jumping, tossing, etc.) based on interactions with smart toys. This helps communication and decision-making of the therapy teams in identifying behaviors that are of potential significance. For instance, indicators to risk of autism, for early diagnosis.

A common perspective among the aforementioned work is the collection of data to augment a process, and provide access to that data later on. We argue that in a long-term process, such as chronic care, the increased volume of the collected data does not necessarily mean increased access. We see the reliability of data as a central issue, to increase access and step closer to augmenting the reasoning processes. Work such as [1], have set path in this direction.

Capture and Communication of Reasoning

Capturing easy to access information in complex social situations is a challenging task, especially when subject matter of the situation is of professional or scientific nature [5]. For this reason, there is a need for proactive measures to ensure the comprehensive capture of data and easy access for retrieval by the users [8]. C&A techniques are capable of providing such capabilities to enable the users to record and communicate data they need for decision-making [1].

For example, we have observed the following in chronic wounds' home care, when a nurse takes over a patient's home visits from another nurse. It is unclear which data elements in the past wound assessments were relied on, to make decisions about changing a wound care product in the care plan. It could be specific patient data, guidelines, or other data elements. In our proposed approach, we provide access to indicators to the reliability of decision-making data elements (e.g. number of people reviewing a medical document, time spent for reviewing) during the care process. The decision-making data elements are seen as constant stream of data (e.g. medical documents, care guidelines), which feed the interaction and drive the process. Given this, a nurse can see that a care guideline document was interacted with by more

stakeholders, and in longer times, compared to other data elements in the same period. Consequently, the nurse gets access to the reasoning process involving the guideline documents (or other documents) and the decision to change the care plan. Otherwise, the nurse has to either go through data that others already looked at before, or contact all those who had made the decision. In the latter case, people might not remember much of their reasoning process. Similarly, even the same nurse might not remember some of her own reasoning processes, given the long time span of care and large numbers of patients. Therefore, the nurse will have to redo some of the work she, or others, did to come to previous decisions.

We have set the following principles that characterize the developed tools in our framework, to record events, interactions, annotations, and communicate the reasoning. The Ubiquitous Capture and Augmented Access (UbiCA) principles are as follows,

- Capture factors that play into decision-making (i.e. decision elements), to provide insight into decision-making processes.
- Ensures free-form and implicit capture of interactions, events, and annotations, to support loosely defined workflows.
- Record spatio-chronological characteristics of decision elements in situations, to give indicators to the reliability of decision elements in reasoning.
- Communicate data through visual augmentations accessible parallel to work material, to associate subject matter of work with captured data.
- Use interactive visualizations, to build augmentations.

Free-form and implicit collection of data such as gestures, and measuring time spent, number of people or locations, frequencies, or order of interactions, events, and annotations are done using mobile prototypes (discussed in the next section). This supports loosely defined workflows, since use of web, mobile, and sensor technology can be done with minimum assumptions on place, time, and the people involved. Similar perspective is adopted in [2] and [7].

Using visual augmentations accessible in parallel to work material (e.g. digital documents), supports synthesis and sense-making. These augmentations visualize spatio-chronological characteristics of data elements. They enable an aligned access to the work material and the captured reasoning process. The interactivity of the visual augmentations supports synthesis of work material and different scales and layers of spatio-chronological characteristics of data. These concepts are extended from work done in [1] This is the main difference between our work and other studies such as [1] or [7].

These principles allow collection and communication of data that captures the experience of decision-making based on medical evidence. These experiences can be reestablished by communicating their context. That is, a context of spatio-chronological nature. Data such as how many people, in how many places, for how long, how many times, and in what order, as opposed to the who, where, and when (spatio-temporal characteristics) researched by others [2], [4]. Based on our observations in real-life chronic care, we have found that the long time span of the chronic care, and other aforementioned characteristics, puts care providers in situations where the spatio-chronological data elements have more impact on their decision-making. People

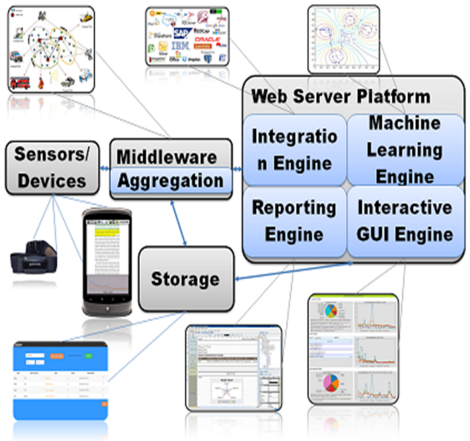

Figure 1. UbiCA back-end infrastructure. The middleware aggregates data in real-time, and after analysis the data is visualized using the GUI engine. The integration engine integrates data from the middleware and the storage (and other data sources). The machine learning engine the data it gets from the integration engine. The storage stores the aggregated and the analyzed data, in addition to storing multimedia data such as documents.

involved in chronic care perform variety of activities almost as if they have interchangeable roles, without assumptions on time, place, and type of activities [2]. A nurse does not keep track of everyone, and all the places, or all the times that pertain to the treatment of a patient.

Our work aims at improving the perception of how data is used in decision-making of chronic care. Since the users would know for example, which evidence invoked more events and interactions, or had more annotations, comparing to other available evidence.

Considering the aforementioned UbiCA is defined as, *augmenting work material with freeform and implicitly aggregated sensory data, events, interactions and annotations, to communicate spatio-chronological characteristics of situations*.

Back-end Infrastructure and Prototypes

To build prototypes that would comply with the UbiCA principles for data collection and communication (discussed in the previous section), we have developed a back-end infrastructure using open source and in-house made software. Figure 1 is a schema of the UbiCA back-end infrastructure. The middleware, brokers data between other components. The integration engine, channels and transforms data from variety of sources. The machine learning engine is used to analyze data. This engine is not used in the prototype discussed in this paper; however, it is used for another prototype that is under development, to classify verbal behaviors by sampling audio from mobile devices. We use the reporting engine and the interactive Graphical User Interface engine to build interactive visualizations. The storage is used as a central repository for data. On the front-end we developed prototypes leveraging web, mobile, and sensor technology.

Using this infrastructure, a number of preliminary prototypes were developed. However, the more recent prototypes were developed based on research done on C&A. The developed prototype discussed here, named UbiCADocs (figure 2), runs on the Android operating system, and it is used to access digital documents. Its dashboard, accessible in the same interface as the reader, was developed using the infrastructure described above. Indicators in the dashboard provide augmented access to the reasoning process during decision-making. Indicators such as, how many people, how long, and how many times, have interacted with different parts of a document. The motivation for developing this prototype is that medical documents play an essential role in discovery, as well in communicating medical evidence for the purpose of decision-making [3]. Specifically we have observed that in chronic wounds' home care medical guideline documents are used frequently in decision-making. However, due to large amounts of medical documents accumulated over time in chronic care, and loss of the reasoning process, it is a challenge to establish the reliability of these documents [3], [1].

Using this prototype, we can capture indicators to user review and user input behaviors. User review behaviors indicate what the user has looked at, and interacted with, more frequently and in longer periods. These indicators include interactions such as, zooming, scrolling and swiping, searching, copying, and printing. User input behaviors indicate users' priorities and emphasis, relevant to time and frequency of user input to medical documents. These indicators include user input methods such as, annotating, highlighting,

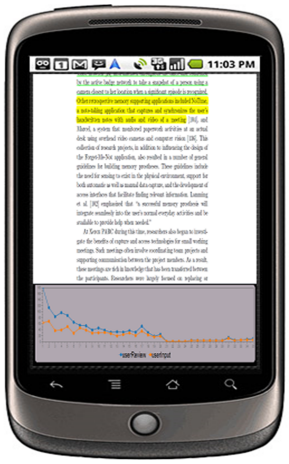

Figure 2. UbiCADocs's graphical user interface. The dashboard at the bottom indicates the spatio-chronological characteristics of events, interactions, and annotations. It is interactive and allows for zooming in/out to change the scope of data. The blue line (darker) indicates the user review index, and the orange line (brighter) indicates the user input index for each page of the document. It can be seen in this sample that the pages in the beginning of the document invoked more interaction.

underlining, striking out, and pen strokes. Based on these interactions a user review index and a user input index are calculated for each page of the document, which captures spatio-chronologic characteristics of user review and input behaviors. Each item of the user interaction, and their weights, are normalized between 0 and 1. As shown in equation 1 and 2 the sum of these items are weighted by frequency (ω_c) and time spent (ω_t) on reviewing or adding input to the document. Normalization will smooth out the effect of large numerical values. The weights represent the importance of the page relevant to time and frequency of the interaction. That is, user interactions at earlier times and at earlier page counts (i.e. frequencies) have an exploratory nature, but interactions that happen later, and in higher frequencies, demonstrate their value to the synthesis and sense-making of medical documents and medical decision-making. As interactions persist with higher frequencies and in longer periods, their value will increase comparing to other interactions.

$$\textbf{User\_Review\_Index} = \omega_c \omega_t \sum_{i=0}^{n} \text{User Review Indicator}, \text{n} = \text{No. of Indicators} \quad (1)$$

User_Review_Indicators=

$$\{\text{Scroll}, \text{Zoom}, \text{Search}, \text{Copy}, \text{Print}\}$$

$$\textbf{User\_Input\_Index} = \omega_c \omega_t \sum_{i=0}^{n} \text{User Input Indicator}, \text{n} = \text{No. of Indicators} \quad (2)$$

User_Input_Indicator=

$$\{\text{Highlight}, \text{Annotate}, \text{Underline}, \text{Strikeout}, \text{Stroke}\}$$

$$\textbf{Normalized\_Indicator} = \frac{1 - e^{-x/m}}{1 + e^{-x/m}}, \text{m} = \text{Avg Interaction}, \text{Min} = 0, \text{Max} = 1 \quad (3)$$

In equation 1 and 2, the assigned value for *n* is 5, since we have 5 indicators for each index. In equation 3, *m* represents the average number of interactions, which signifies a point where the exponential increase of the Normalized Indicator decreases in slope, and *x* represents the captured value of the interaction indicator to be normalized. The indicators are calculated by counting the interactions for each page, and the indices are calculated, or updated, when a user turns the page. Then the indices are sent to the back-end infrastructure, where it is visualized centrally (using the web) on all devices opening the document.

Field Investigations and Future Work

We have focused our field investigations on chronic wounds' home care, and conducted observational studies, initially in an uncontrolled setting. We attended four full-day training sessions for nurses in a local medical facility. We shadowed the trainee nurses while they perform specific tasks, such as wound documentation, for a fictitious patient visit, using an application for chronic wounds' home care documentation. We were able to identify some of the data elements that they use in their reasoning. These included, medical guideline documents, patient progress notes, and patient's wound photos. In addition, we were able to identify some of the common decision-making and communication practices and issues in chronic wounds' home care nursing. These findings have helped to set the UbiCA principles, which were used in design of the UbiCADocs prototype (figure 2).

This prototype was evaluated in the lab environment, in paper reading group discussions. Primarily to observe its functionality in discussions that make heavy use of documents, and require users to reason and

	Paper 1(20 p)	Paper 2 (19 p)	Paper 3 (19 p)	Paper 4 (20 p)
No. of users	3	2	2	8
No. of intr	53	168	296	710
Mean of p intr	2.65	8.84	15.57	35.5
Variance of p intr	3.12	38.86	203.19	66.25
P with max intr Indices	1, 4	10, 11	1	5, 8, 17
P with min intr indices	5, 9, 11-19	17-19	7, 10, 14-15	11, 19

Table 2. Collected data using the UbiCADocs prototype, intr=interactions, p=page(s). Number of users=no. of users, number of interactions=no. of intr, mean of page interactions=mean of p intr, variance of page interactions=Variance of p intr, pages with maximum values of interaction indices=P with max intr Indices, pages with minimum values of interaction indices=P with min intr indices.

communicate based on documents. The UbiCADocs prototype (figure 2) was used in four one-hour long group paper-reading discussions in our research lab. The discussed papers were of similar length. We had eight participants, of which seven were not stakeholders in this study, and they were briefed about the prototype. Different numbers of them used the prototype at each session. Table 1 summarizes the collected data using the prototype. With more participants (No. of users) we recorded more interactions (No. of intr) using the UbiCADocs prototype. The mean of page interactions (mean of p intr) show on average how many times a page invoked interactions. The variance of interactions (Variance of p intr) shows how widespread the interaction counts were in a session. For example, in page 3 it can be concluded that users have interacted very differently with the pages, and the same pages were used differently in the reasoning of the users. Pages with maximum values of user input and review indices (P with max intr Indices) were interacted with more, and pages with minimum values of user input and review indices (P with min intr indices) were interacted with less comparing to other pages. These indicate how much the users relied on different parts of the documents in the discussion.

Based on the results it was found that the parts of papers that were discussed more, and evoked more events, interactions, and annotations were identified correctly. For instance, these included parts such as, the abstract, results presentation, and diagrams. Furthermore, the spacio-chronological characteristics of the captured data reflected the reasoning processes that took place in the discussions. The prototype supported the loosely defined flow of the discussion, since data was collected implicitly and in free-form from mobile devices. The augmented interface provided a parallel, and an interactive access to the spatio-chronological characteristics and the documents. This allowed to associate between the parts of the documents and the captured data from the users. This evaluation gained us preliminary results in communicating the reasoning process that is based on documents. However, it should be noted that this evaluation has limitations in terms of replication in a real-life chronic care environment. The main purpose here was to evaluate a proof-of-concept prototype, and we will investigate this further in our future work. Specifically, in the context of chronic care, this approach is relatively unexplored. However, it is similar to approaches that provide support for medical decision-making using highly indexed work material such as annotated video or audio records [1], [2].

Following to our earlier studies, we are in the process of ethics approval to start two studies in real life medical environments, in wounds' home care nursing, and both in local health authorities. In the first study, our goal is to better understand how nurses use different data elements in their decision-making. Especially the progress notes, wound photos, and medical guideline documents that are used in the existing wound care documentation software, and how it affects reliability and practice outcomes. In the second study, as an initial evaluation in a real life medical environment we will deploy a customized version of the UbiCADocs prototype. This is to study how the prototype changes confidence, as well as time and effort related outcomes in decision-making that is based on (wound care) guideline documents. Then we can compare use of data, reliability, and practice outcomes in both studies. The Think Aloud [9] method

will be used to collect real-time thought verbalizations as subjects perform specific care activities. The Situational Awareness[10] method will be used to code and interpret the collected data. This method has shown success in similar contexts [11].

Conclusion

In this study, we have realized that in long-term processes, such as chronic care, the large numbers of people involved, the accumulated data, and the loosely defined workflows complicate the reasoning. We have found that freeform and implicit collection of sensory data, events, interactions and annotations, to communicate spatio-chronological characteristics of situations, can provide access to the reasoning processes. These processes were based on data used for synthesis and sense-making. This can affect reliability of medical evidence, by increasing level of confidence in decision-making. As a result, care providers need less time and effort to make decisions. Our future studies in two real life medical environments will gain us a better understanding of the impact of UbiCA on reliability and practice outcomes in chronic care.

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