A Standards-Based Open Source Application to Gather Health Assessment Data in Developing Countries

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***Abstract*—Many organizations are working in developing countries to support local health care organizations and infrastructure to provide sustainable, community-based health care. This requires not only the influx of medical staff and supplies, but also requires maintaining individual health care records and enabling the ability to collect, analyze and aggregate data in the field to customize care to the local needs of the community, and to provide continuity of care to its citizens. The recent rise of adoption of standards for electronic health records (EHR) provides an alternative to using paper forms in mobile health clinics that often serve these countries. In this paper, we describe an open-source, standards-based health assessment software application developed by the non-profit organization Health Records For Everyone (HR4E) and field tested in a mobile health clinic in rural Ethiopia in the fall of 2011. The application allows mobile health clinic staff to quickly deploy medical clinics and collect patient data electronically in the face of various environmental challenges. In addition to producing electronic patient records which are validated in-field using HL7's Clinical Document Architecture standard, the application allows medical practitioners to view and summarize patient data for in-field analysis.**

I. Introduction

Developing countries face the greatest challenges in improving health status and in eradicating extreme poverty, yet often must rely on external sources to supplement their health care services and funding [21], [7]. The key to leveraging external resources to provide *sustainable* health care requires working within the existing health care system of the country to build up local expertise and infrastructure, and to establish a connection to the global health community for information exchange and training.

Until recently, government and non-governmental aid agencies have focused on mass interventions (clean water projects, mass vaccination campaigns, mass distributions of insecticide treated bed nets, mass treatment of a prevalent disease, etc.), where typically little attention is paid to determining whether or not an individual has previously received an intervention. However, with the rise of HIV and tuberculosis (especially drug-resistant tuberculosis) in the developing world, the need to track health interventions and health status of individuals on a continuing basis has become increasingly important. This requires not only the influx of medical staff and supplies, but also the maintenance of individual health records and the collection, analysis and aggregation of data based on those records. It enables continuity and customization of care according to the needs of individuals and their communities. Electronic health record systems such as OpenMRS [16] have been used in health clinics in developing countries with some level of success. However, the system relies on a traditional 3-tier software architecture, including a web server, application server and database, and requires a sophisticated IT team to install and maintain, resources that are not typically available in many rural clinics for which electricity, Internet connectivity, and IT skills are scarce.

Until recently, the developed world has relied on paper health care records. There has been an explosion in the adoption of electronic health records (EHRs), partly due to governmental mandates such as the HITECH provisions of the American Recovery and Reinvestment Act in the United States [9]. Not surprisingly, such records are often produced from and managed by large and costly systems that require sophisticated IT infrastructure, and the resulting patient records are kept in proprietary formats. Interestingly, even in countries with widely used EHRs, these records have not been extensively leveraged to solve community health problems.

Examples from the IT world such as SQL [14] and HTML [12] demonstrate that data format and interchange standards break down barriers between proprietary systems and foster the development of more nimble alternatives. We believe that recent work to standardize formats for electronic health information interchange can play the same role for electronic health records. The Clinical Document Architecture (CDA) data interchange standard [3] is maturing under the sponsorship of HL7 [10], an international health care IT standards body. It specifies the format of building blocks to create standard health care documents, as well as the way these building blocks can be organized and interpreted. In the United States, elements of the standard are already being implemented by EHR vendors and health care institutions [5].

This paper presents a lightweight, open source software application to generate electronic health records compliant with

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the CDA standard, and designed for use in environments with limited or no resources to support an IT infrastructure. The system does not require sophisticated IT skills to install and maintain, and enables health care workers to quickly and easily design forms to collect and record the health history of patients over multiple visits, as well as to perform on-the-spot analysis and assessment of community health care needs. Furthermore, since the patient records are CDA-standard compliant, they can be uploaded to any standards-compliant reporting agency or EHR system (such as openMRS) for more broad reporting, documentation and analysis needs. The software was pilot tested in the fall of 2011 by Health Records for Everyone (HR4E) [11], a non-profit organization that supports basic health assessment services for school children in Yetebon, a rural community in Ethiopia approximately 75 miles south of Addis Ababa.

The paper is organized as follows. In section II, we describe the unique challenges to develop software for use in a mobile health clinic in a rural area of a developing country. In section III we describe the design of the HR4E application to meet these challenges, and in section IV we describe the results of the field test in which the software was used to provide health assessments for over 1100 school children over a 6 day period. Section V briefly discusses related work, and in section VI, we provide some concluding thoughts and areas of future work.

II. Requirements

Robust software for use in rural areas of developing countries faces challenges not typically seen by software engineers in developed countries. We summarize the most important of these challenges in the form of requirements below.

Skills: The mobile health clinics in which HR4E software has been used are staffed by volunteer medical professionals from the United States, and space is limited to bring IT-knowledgeable staff to the field locations. Thus, any software system to support the medical staff must be durable and easy to install, maintain and troubleshoot in the field. In addition, a streamlined work flow is critical, as the clinics serve hundreds of patients a day, working only during daylight hours. This, in turn, requires streamlined hardware and software, with as few moving parts as possible to minimize the variety of skill sets required (e.g., application programmer, DBAs, and web designers) and possible points of failure (e.g., web server, application server, database). It also requires a user interface that is easy and intuitive for medical staff to navigate and enter patient data.

Power: As is common in rural areas of developing countries, electrical power is unreliable in Yetebon. Consequently computers running health clinic software must have enough power to run with minimal breaks for the duration of the daily hours of the clinics (9 am to 6 pm).

Connectivity: As with electricity, local Internet connectivity in rural areas is generally unavailable. "Dial-up" quality Internet does exist in the larger cities that neighbor the rural areas. Thus, the software cannot rely on Internet connectivity or even a local network to function while the clinic is operating. For example, web servers must be run on local machines. Additionally, clinics are typically made of individual stations that perform different health assessment tasks. Without any connectivity between machines, there is still the need for continuity of information flow as a patient visits the individual stations. Thus, the software must be able to update a patient's record at each station without losing or requiring clinic staff to re-enter any previous data.

Extensibility: As previously noted, a mobile health clinic is an extremely dynamic environment and enabling an efficient work flow is critical. Though much preparation goes into setting up mobile health clinic visits, it is not always possible to anticipate the needs of the patients served by the clinic. At any one time, based on observed trends in the patients, it may be necessary to redesign clinic layout while it is actively serving patients. Thus, it must be possible to dynamically configure/reconfigure the software application supporting the clinic in the field as well.

III. Design and Implementation

In this section, we describe design and implementation decisions made in crafting HR4E's electronic health record software in light of the requirements described above.

Stations: A clinic is organized around stations in which staff performs specific health assessment tasks. Each station is staffed with appropriate personnel as well as a designated data entry person. These stations and associated tasks are described below:

Intake: Patients are registered with the clinic at the intake station. For each patient a paper health form and an electronic record are created and populated with basic demographic information such as name, stated age, measured height and weight.

Triage: Vital signs are gathered at the triage station for each patient. The patient is screened as well for red flags and any symptoms they might be experiencing. The result of this interaction may suggest that the patient receive additional attention at other specific stations.

Clinical: Clinical stations allow health care workers (including physicians) to examine a patient in greater depth based on observations and annotations in the patient record noted in Triage. The patient may be treated at the clinical station for parasites or trachoma. Requests for tests, longer-term therapies, and referrals are ordered and recorded in the patients record.

*Lab and Pharmacy:*The final station in the workflow serves as both a lab and a pharmacy. Prescribed medications may be dispensed and basic point-of-care tests such as hemoglobin, blood glucose, urine dipsticks, HIV testing, may be performed. This station also functions as the exit station. The paper health record is collected, and the electronic record is translated into a Continuity of Care Document [4], and copied to the pharmacy computer. The USB flash drive is then made available for reuse for a new patient.

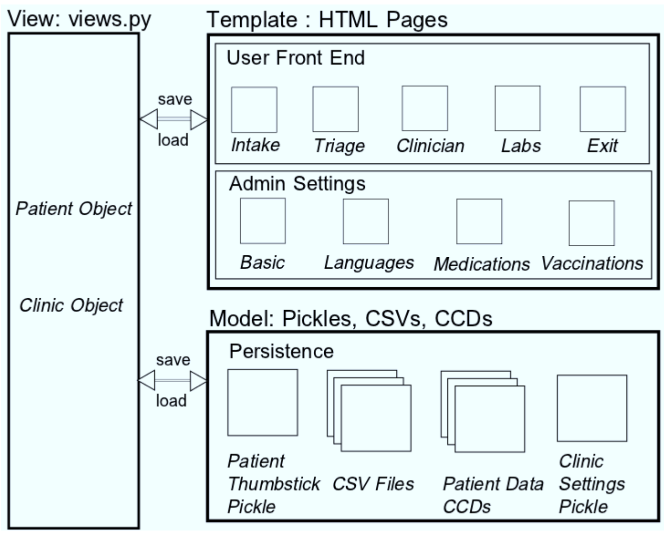

Fig. 1. HR4E Application Model Template View Architecture.

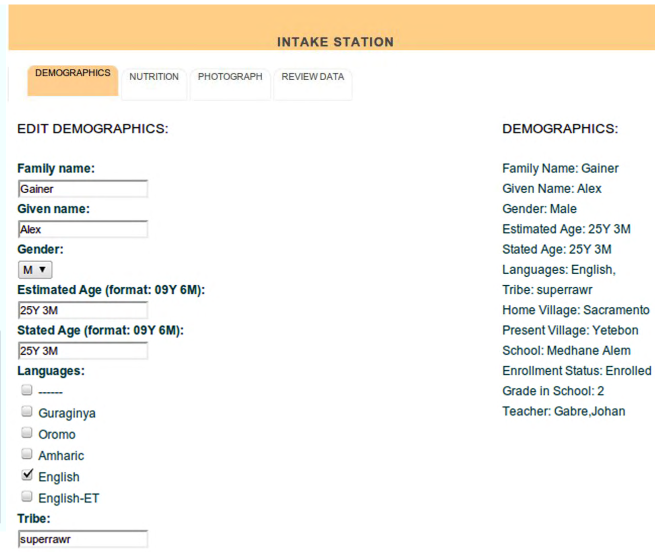

Fig. 2. Intake station page to enter demographic data.

Hardware: For durability, in the pilot test the clinic chose to use HP and Dell Netbooks with 1 GHz single-core processors pre-configured with Ubuntu Linux v11.04 [24]. The computers had 1 GB RAM and 20 GB flash storage instead of hard drives. Each computer was equipped with batteries that could provide a continuous power for twelve hours and be recharged nightly at an off-site location with a reliable electricity supply. Several team members also brought their personal MacBook Airs configured with very long continuous-duty batteries.

USB flash drives attached to a patient's wrist can reliably carry data from station to station without much difficulty. At the intake station, the flash drive is initialized with an empty patient record in the form of a serialized python object, which is then loaded and updated at each station the patient visits. At the exit station, the patient record is copied to a persistent location that contains all of the patient records associated with the clinic and can be used to generate reports for in-field data analysis.

Software: The HR4E system was developed using Django, an open source on-rails web application development framework [6]. Django is easily deployable across multiple operating systems and has a rich forms library to capture data, important features to meet HR4E's design goals. In addition, Django applications can be run in most modern web browsers, including Safari, Firefox, Chrome, Chromium and Opera.

Figure 1 shows an overview of the HR4E application, which follows Django's Model-Template-View architecture. The patient data model is defined and stored as a serialized python "pickle" [22] in interim files on USB flash drive.

Each clinic station has an associated formset to record information gathered about the patient during a task. The Django template assigns the station name and front end which uses Django's newforms library to gather patient data relevant for the station. For example, Figure 2 illustrates the intake station interface. JQuery[15] is then used to keep all of the formsets on one uniform HTML page. This feature enables patient data to be edited at a different stations without requiring the patient to physically return to the station in which the data was first entered. It also enables a clinic computer to be dynamically reconfigured to support a different station type based on the needs of a changing clinic work flow.

The view module shown in Figure 1 defines a patient and clinic object, and provides utilities to save and load patient data into the HTML forms, and to generate a Continuity of Care Document, which can be performed at the end of the patient visit, the end of the day, or the end of the multi-day clinic. The view module also provides utilities to generate .csv files from the collection of patient files that can be loaded into a spreadsheet to do further reporting and analysis.

An important feature of the HR4E application is to allow for in-field configuration of the clinic stations, including the ability to change basic clinic settings, such as the names of locations visited and staff hosting the event, as well as to add or remove medications, languages and vaccinations based on observed conditions at the clinic. This is accomplished via Admin Settings Template, and Figures 3 and 4 illustrate some of the administrative settings.

Since an HR4E clinic cannot rely on a network or a global database, the software runs on each local machine or "station" using Django development servers. One machine is designated as the exit station, and copies patient records from the USB flash drives to a common, persistent location, which can be an attached drive, another flash drive or any persistent storage. Copying the patient data is done via python scripting and without a global web server.

IV. Field Experience

In late October of 2011, HR4E teams working with the Project Mercy, a well-regarded faith-based organization with

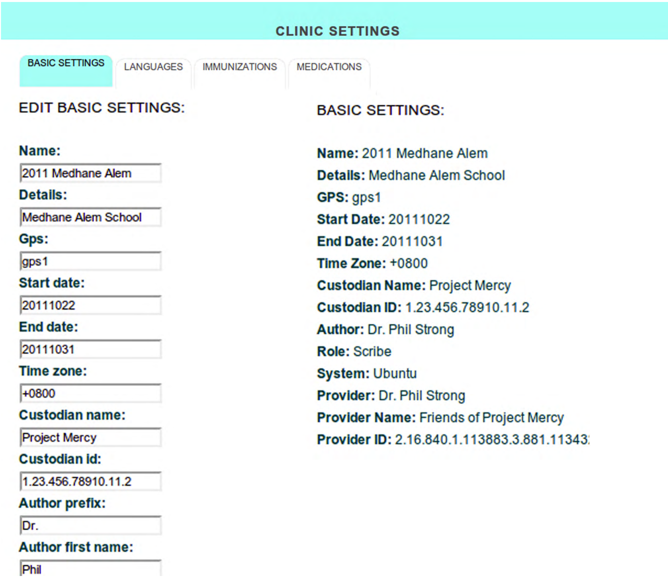

Fig. 3. Administration page to change clinic settings.

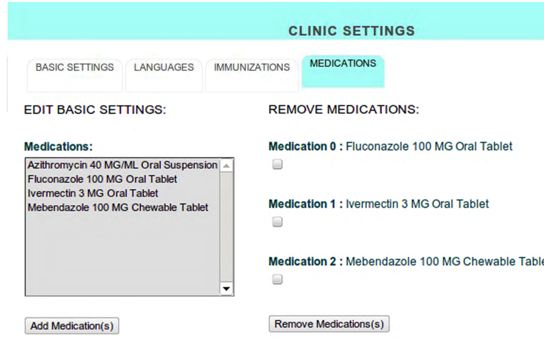

Fig. 4. Administration page to configure available medications.

operations in the United States and Ethiopia [18] spent six full working-days at two rural government-run schools in a Yetebon, a small community about 75 miles south of Addis Ababa. The team consisted of four physicians and six nurses from the United States, nine nurse-translators from Ethiopia and two IT support staff persons from the United States. Over five hundred school children visited clinics set up at each site, along with a smaller number of adults suffering from acute health problems.

Clinic workers brought five laptop computers configured as described in Section III with the HR4E pilot software, and used them to gather health assessment data. The clinic was organized according to the stations described in Section III, and appropriate clinic staff was assigned to each station. Each station had at least one computer and a dedicated translator. Because of concerns about the possible spread of infectious disease, US health workers (doctors and nurses) refrained from touching the computers, and so the translators, assisted by IT staff, performed data entry. This alleviated the need to train nurses and translators in using the software.

Patients made their way through these stations with a paper health assessment form, and a USB-drive that contained an electronic version of the paper form. Physicians typically used the paper form to see what information had been gathered so far, and to make further observations, including instructions to the pharmacy. Translators then used the HR4E software to record the physician's annotation onto the electronic health records.

Our experience in the field shows that a lightweight, standards-based software application is a viable and promising alternative for mobile health clinics. Virtually all patients made it through all stations, and at the end of six working days, 1057 paper forms and 1057 electronic health records were created (one each per patient seen). The sheer volume of patients relative to the available staff shows that patient care and throughput was not impaired due to the parallel use of both paper forms and electronic forms.

The in-field configurability of the application provided a huge benefit. Clinic settings could be set ahead of time to record the dates and location of the clinic. Available medications and available tests could be quickly and easily updated based on observed conditions at the clinic. And, at any time during the patient work flow, workstations could be quickly converted to support a different clinic station, and patient data could be easily edited at any clinic station. Finally, unlike paper forms, the electronic records could be used to generate reports to prepare supplies for the remaining days of the clinic, and for future visits. In addition, the electronic records can be brought back on future visits and enhanced with additional data when the same patients are seen again.

Field experience enabled the staff to review the clinic workflow, and dynamically make changes to improve efficiency. For example, the patient record was stored in an intermediate format on the USB flash drive, and the final external version of the patient record was generated at the pharmacy station. This step, however, is not a necessary component of a patient visit (since it is not a health assessment task and does not require the presence of the patient). It was quickly determined that performing this step en masse for all patients after the clinic was closed would speed up the throughput of the patients through the clinic. In addition, the software did not support efficient annotation by pharmacy staff of data on medications dispensed, or information on changes they had to make to medications ordered (which were frequent due primarily to limited supplies). Once it was clear to upstream users that pharmacy was recording their annotations on paper, upstream users also quickly stopped using the computer to enter pharmacy orders. The paper log generated by the pharmacy staff of all medications dispensed (and to whom) was subsequently entered into a spreadsheet to help with data analysis.

Device characteristics were reported as significant inhibitors of use. The MacBook Airs were preferred over the smaller laptops primarily because of larger screen-size (13 inches versus 10 inches). Users also found that it was more difficult to recover from data entry errors on the laptops, which was attributed to unfamiliarity with the Ubuntu user interface on unfamiliar devices.

V. Related work

As previously noted, standards-based health record systems and applications have gained significant attention in recent years. In addition to applications deployed by medical providers, several prototypes for data interchange exist [2], [13]. The Mayo Clinic [5], for example, is the largest producer of CDA documents in the world, and, spurred by HITECH meaningful use requirements, commercial EHR vendors are beginning to make investments to support HL7 standards [8], [19], [1]. However, these systems are expensive and proprietary, and require significant resources to manage and maintain. Furthermore, their support to export CDA documents is still at an early stage. While they are not viable alternatives to support health care systems in developing countries, their commitment to standards for health care data interchange provides a compelling reason for a lightweight software such as the HR4E application to produce standards-compliant patient health care documents. Ovid[23] offers a web framework to generate CDA documents and is closely related to our work. It is a solution designed to work within an established clinic setting and targeted at a dermatological care and does not address the power, connectivity challenges addressed by our implementation. However, it is further validation that a lightweight standards-based implementation of an electronic health records system is not only possible, but its flexibility provides a level of user satisfaction not always possible with proprietary systems.

Along with commercial implementations, there are a number of open source efforts for electronic health records, though they do not necessarily support standard data formats for patient information. OpenMRS, as previously noted, is an open source medical record system platform targeted for developing countries developed prior to adoption of the HL7 CDA standard, and is based on the proprietary EHR system developed by the Regenstrief Institute [16]. Open Health Tools [20] is an organization to foster open source development of tools for health care data exchange. While none of the existing projects is focused on an end-to-end application to generate EHRs, one of their projects, Model-Driven Health Tools (MDHT) [17], provides a modeling environment for the CDA framework via an Eclipse plug-in. This work is synergistic with the HR4E application, and in future work, we hope to leverage the MDHT toolkit as an internal component to create CDA-compliant documents and their respective implementation guides.

VI. Conclusions and Future Work

The HR4E application provides a small footprint, open source alternative to generate standards-compliant electronic health records. The pilot test of the application to support a mobile health clinic in rural Ethiopia demonstrates its viability as a key component of a health care information system in environments with limited IT infrastructure. Moreover, the application's commitment to open source software development and standards for patient records demonstrates that it is possible to enable low-cost solutions to promote data exchange and interoperability of existing health care systems.

In the future, we plan to address the lessons learned in the field to make it a more robust application without diverting from those commitments. During our initial field testing we saw first hand that work flow, especially in busy environments, can hamper use and adoption, and the application cannot worsen or introduce new bottlenecks in the work flow. We are working on a new version of the application with the following enhancements:

- Interim field data storage and batch CDA generation in a way that does not interfere with clinic work flow, but still permits on-the-spot field data analysis.
- A revised form that facilitates work flow changes specifically to remove work flow bottlenecks, and the ability to deploy this form within the application.
- A CDA-form-builder application that facilitates changes to forms in advance of a mobile clinic or even while the mobile clinic is active.
- We plan to tie our system into OpenMRS in order to import generated CDA-compliant electronic health records.

Finally, we plan to field-test the revised application in rural Ethiopia in the fall of 2012. In addition to evaluating work flow impact, we will likely be in a position to gather a second cycle of field data for most of the same children who visited previous clinics. This will allow us to more thoroughly investigate problems and potential solutions to identify patients, find previous records we may have generated for them, and construct longitudinal records of care. We will also continue to use paper forms, and plan to do side-by-side comparisons of total costs of using our electronic system with other methods such as field paper record scanning and microwork for data entry.

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