An EHR Platform for Realizing Precision Medicine in Emergency Care

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***Abstract*— Precision medicine has emerged as a new field that facilitates the discovery of individualized diagnostic and treatment plans for patients based on the way their unique characteristics may dictate disease response or progression. Despite its potential, there are several settings where precision medicine remains more aspiration than reality. One such setting is emergency care where physicians are called upon initiating investigations and interventions to diagnose and/or treat patients in the acute phase and making decisions regarding a patient's need for hospital admission, observation, or discharge. In this effort, emergency physicians usually have little or no information at hand. The convergence of healthcare data with multi-omics and real-world data heralds a new era where an individualized approach to emergency care seems feasible. Especially, with the latest technological innovations, physicians can be provided with patient healthcare data and tools for the analysis of these data against the various genomically and phenotypically defined patients/citizens. This paper presents a cloud-based emergency care delivery platform that incorporates an Electronic Health Record (EHR) with the aforementioned features to meet the needs of emergency care practitioners. The platform aims at bridging the translational gap between bench and bedside and moving towards a realization of personalized and stratified medicine by discovering associations between disease and genetic, environmental or process measures.**

Keywords-EHR; precision medicine; emergency care; healthcare analytics.

I. INTRODUCTION

The explosion of precision medicine and genomics research over the last decade or more is expected to herald a rapid acceleration in the identification and development of next-generation prevention and therapeutic services [1][2]. Essentially, precision medicine constitutes a holistic approach to disease treatment and prevention that considers variability in people's genes, environment, and lifestyle [3][4][5]. Under this paradigm, interventions can be tailored to individuals or groups, rather than using a one-size-fits-all approach in which everyone receives the same care. To this end, several tools need to be employed such as molecular diagnostics, imaging, and analytics [2][3]. However, there are certain challenges to clinical implementation of precision medicine which have been identified at multiple levels. This paper is concerned with the challenges related to the technologies that need to be employed in order for precision medicine goals to be met in emergency care environments.

Nowadays, research and development directors in the life sciences are working with enormous, disparate data sets, which must be stored and analyzed accurately and quickly. These data may include genomic or proteomic data (large-scale studies of organic proteins), socioeconomic data, patient medical history data, scientific texts, clinical studies and data from universities and laboratories, all in different formats and from various sources [1]. Thus, intelligent insights from that diverse, big amount of data is really hard to obtain. An Electronic Health Record (EHR) that will integrate all the above types of data and will be enhanced with decision support tools can lay the foundation for the realization of precision medicine by providing clinicians and patients with individualized information and preferences, intelligently filtered at the point of care. This is particularly useful in the emergency care where a patient's life may hinge on the instant availability and accuracy of these pieces of information. In particular, in the case of patients already genotyped in an outpatient clinic, data stored in such an EHR system could be available when they present acutely ill to the Emergency Department (ED), while in the case of patients not previously genotyped, the tools provided by such an EHR system could assist in obtaining real-time results (i.e., in fewer than several hours) when these patients present to the ED. Thus, genome-guided decision making can be supported when it is mostly needed.

This paper presents a cloud-based emergency care delivery platform that incorporates a next-generation EHR, which can serve as a supporting tool to the implementation of both population- and individual-level interventions in emergency care settings. Thus, health benefits can be maximized, harm can be minimized, and unnecessary healthcare costs can be avoided. The EHR proposed incorporates a broader data set, compared to data sets in legacy or existing EHRs, including: (a) patient information contained in Personal Health Records (PHRs), (b) health information from medical devices connected to patient such as from assistive telecare systems, (c) social care information retrieved on request from social care organizations, (d) health information extracted from various healthcare systems such as primary and hospital care Electronic Medical Records (EMRs), (e) data regarding a person's lifestyle obtained from social media like Facebook; and (f) genomics information such as genotype and sequence data extracted from biobanks and genetic databanks. The privacy concerns arisen in such an infrastructure due to its multi-owner and multi-user nature are met by a Health Insurance Portability and Accountability Act (HIPAA) compliant access control mechanism, whereby fine-grained access control is provided to users [6]. This mechanism draws from the Attribute-based Access Control (ABAC) paradigm and supports HIPAA "break the glass" access to data pulled together from all the data sources. Thus, access to the EHR of a patient is automatically granted to all physicians and nurses on duty in the ED upon patient arrival and revoked upon patient departure from the ED unless stated otherwise.

The remainder of the paper is structured as follows: Section 2 presents related work; Section 3 describes the scenario that motivated our research; Section 4 presents the architecture of the proposed EHR platform; Section 5 describes the main issues related to the implementation of the proposed platform and Section 6 concludes the paper.

II. RELATED WORK

The last few years have seen huge leaps in several research fields, such as molecular biology, genomics, and bioinformatics, which, in turn, led, among the rest, to the emergence and continued growth of precision medicine [7]. This paradigm shift in care delivery has been further expedited by converging trends of increased connectivity, through social media and mobile devices, and citizens' growing desire to be active partners in their health and wellness management [7].

A key enabling factor for the realization of precision medicine in emergency care is the Information Technology (IT) infrastructure that will support it. The infrastructure envisaged here is a cloud-based emergency care delivery platform that incorporates an EHR which is enhanced with advanced analytics tools to provide the information required for producing useful insights regarding emergency care delivery. Hence, the infrastructure is meant to be incorporated into an Emergency Medical Service (EMS). The last few years, a number of approaches have been proposed according to which health records, either EHRs or PHRs, are stored on a Cloud and can be accessed via mobile devices. In particular, in [8], an integrated EMS cloud-based architecture is proposed that allows authorized users to access emergency case information in standardized document form, as proposed by the Integrating the Healthcare Enterprise (IHE) profile, uses the Organization for the Advancement of Structured Information Standards (OASIS) standard Emergency Data Exchange Language (EDXL) Hospital Availability Exchange (HAVE) for exchanging operational data with hospitals and incorporates an intelligent module that supports triaging and selecting the most appropriate ambulances and hospitals for each case. Moreover, Watson for Genomics is a cognitive system that integrates massive amounts of new omic data with the current body of knowledge to assist physicians in analyzing and acting on patient's genomic profiles [9]. In addition, N-of-One platform assists in linking each patient's unique profile to potential treatment strategies in context, supporting targeted clinical decisions [10]. Thus, clinicians are provided with concise, accurate and clinically meaningful interpretation of molecular test results [10]. The 2bPrecise platform captures and stores genomic data from a range of sources, harmonizes clinical knowledge and genomic research to identify relevant information, and then pushes the resulting insights to the point of care to enable action [11]. Finally, several approaches to EHR integration with PHRs and other information systems have been proposed throughout the last few years [12][13][14]. Compared to these approaches, the EHR-based platform proposed in this paper facilitates the integration of a wider range of information sources into the clinical workflow, thus enabling the derivation of deeper insights into several diseases. Moreover, the tools incorporated in it enables the analysis of the EHR data against the various genomically and phenotypically defined patients/citizens thus providing the ability for individualized emergency care.

III. MOTIVATING SCENARIO

The basic motivation for this research stems from our involvement in a recent project concerned with designing and implementing an EHR-based platform for the provision of medical data access at the point of care while fully protecting privacy. This involves providing access to the appropriate people, based on patient authorizations, but also granting access to the patient's data in cases where his/her involvement in the authorization propagation process is not feasible. Moreover, it involves the analysis of these data in order to provide insights that will assist emergency physicians in diagnosing and/or treating patients in the acute

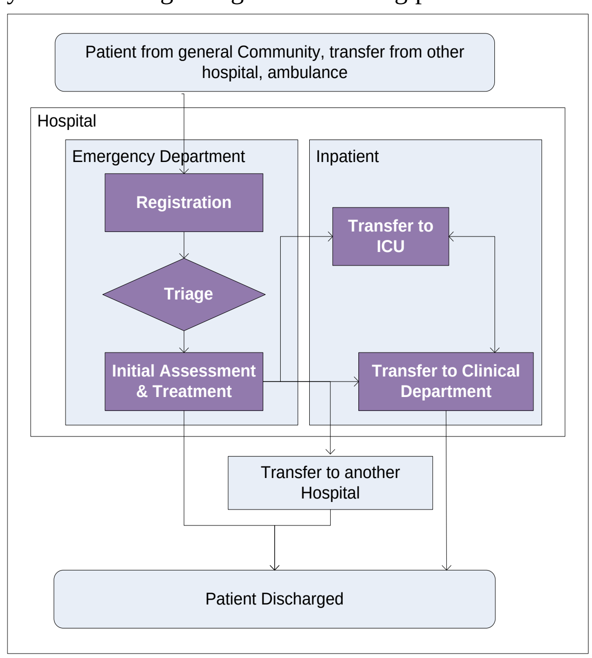

Figure 1. Patient Flow

phase.

Suppose a healthcare delivery situation that takes place within a health district where an individual is transferred to a hospital's ED (Figure 1). Upon arrival to the ED, the individual is registered as an emergency patient and undergoes a brief triage in order for the nature and severity of his/her illness to be determined. If his/her illness or injury is considered to be serious he/she is seen by a physician more rapidly than the patients with less severe symptoms or injuries. After initial assessment and treatment, the patient is either admitted to the hospital (e.g., to a clinical department or the Intensive Care Unit - ICU), stabilized and transferred to another hospital for various reasons, or discharged.

As many ED visits are unplanned and urgent, there is a need to ensure that information regarding the longitudinal patient health condition (e.g., problems, allergies, medications, diagnoses, recent procedures, recent laboratory tests) is conveyed to ED physicians automatically upon registration of a patient to an ED. Thus, inefficiencies in care, in the form of redundant testing, care delays, and less-effective treatments prescribed are eliminated and quality of care is enhanced.

IV. SYSTEM ARCHITECTURE

Figure 2 illustrates a high-level architectural view of the proposed EHR-based platform. As illustrated, the proposed platform comprises three layers, i.e., the resources layer, the services layer and the presentation layer.

The resources layer hosts the remote data resources providing the various chunks of data comprising a next-generation EHR. These resources are heterogeneous and reside at different settings. The various parts of a next-generation EHR are accessible by relevant web services, which hide away specific implementation details of each resource and provide a uniform and consistent interface to the operations in that resource. However, these resources are owned by different entities according to their specific security policy (e.g., owner of PHR and genomic data is the patient, while owner of the clinical/social data is the health/social provider where the patient has received care). Hence, each part of the EHR may be governed by different institutional or personal policies and practices with respect to confidentiality, security and release of information. However, as health and social care organizations constitute covered entities under the HIPAA Privacy Rule, they must comply with the Rule's requirements for safeguarding the privacy of protected health information.

The information stored in the proposed next-generation EHR are segregated into three categories, i.e., medical, lifestyle and genomic information.

Medical information may be obtained from:

- **EHRs:** They provide health information collected from healthcare providers where patients have received care in the past. As such, it is usually extracted from various healthcare systems such as primary and hospital care EMRs.
- **PHRs:** They provide patient health information contained in PHRs. This is mostly information from

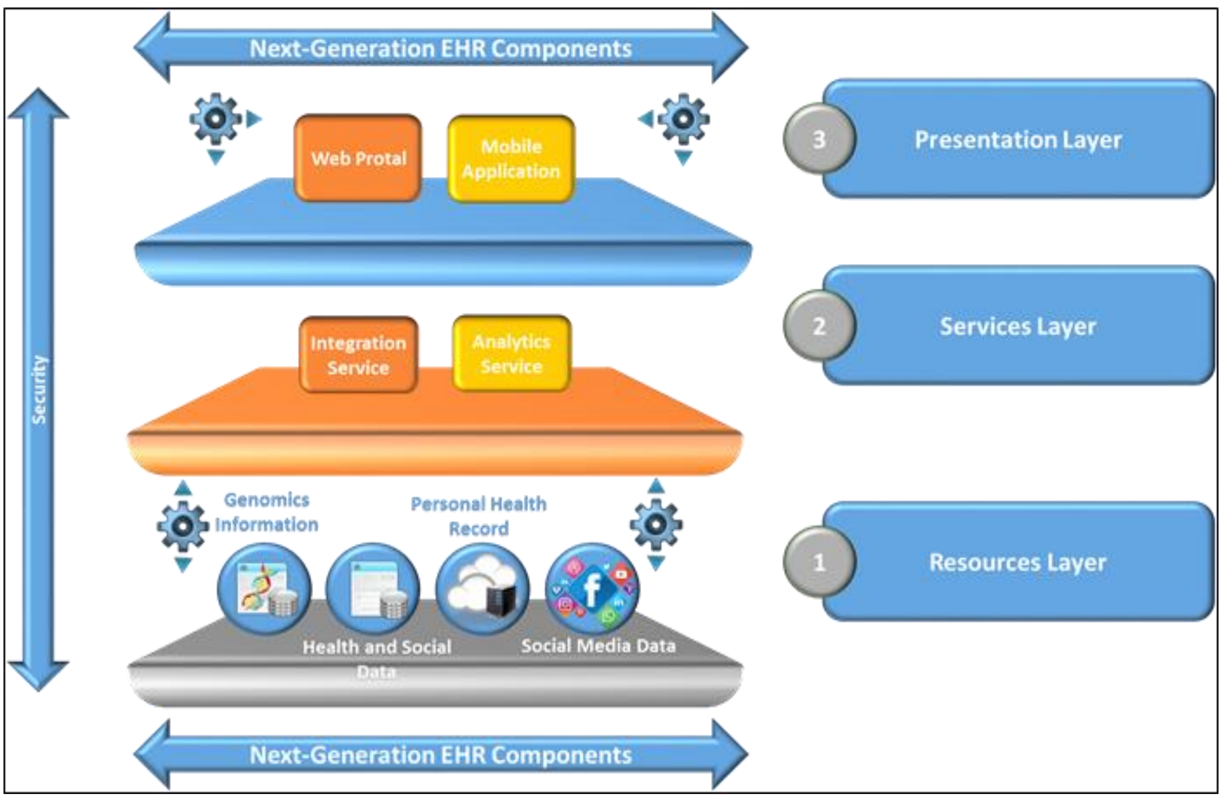

Figure 2. System Architecture

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medical devices attached to patients and it is uploaded to the PHR through a special-purpose mobile application [15].

- **Social Care Records:** They provide information collected by social care organizations which have provided their services to a patient. It is retrieved on request from social care organizations.

For the purposes of this paper, it is assumed that PHR information is stored in a cloud-based PHR while EHR and social information is stored in data repositories of geographically distributed and organizationally disparate health and social care providers, respectively. Data regarding the patient's condition are either collected by the ambulance staff or provided by the patient himself upon arrival at the ED of the hospital. These data are stored at the ED information system.

Lifestyle information is obtained from **(a)** patients' PHRs, which, apart from the health information mentioned above, may include other types of information as well (e.g., exercise and dietary habits), and **(b)** patients' activity in social media (places they have visited, sleeping hours depending on the times they become active, etc.).

Genomic information is assumed to be hosted in several research centers. It may contain genotype and sequence data extracted from biobanks and genetic databanks. As molecular phenotyping is a time-consuming procedure, it would be particularly useful if a patient has already had a complete genomic or other systematic molecular analysis performed prior to his visit at the ED of a hospital. Currently, there is a rising number of validated clinical applications for molecular phenotyping; this leads to more patients having such analyses available from their usual clinical care [3].

The services layer, as indicated by its name, hosts a number of services pertaining to information integration and analysis. This layer resides in a trusted cloud and it, currently, hosts the following two cloud-based services. Moreover, it is scalable in the sense that it can be further enhanced with additional tools as long as they are implemented in the form of cloud-based services and published in this layer so that they become instantly available.

- The **Integration Service** serves as a mediation gateway that handles interactions between users and data resource providers. Typically, it provides access to integrated patient EHR data while ensuring compliance to the relevant HIPAA and patient-defined policies by properly authorizing users of the system, i.e., medical doctors. In doing so, the Integration Service draws upon the ABAC paradigm, i.e., it mediates between requestors (e.g., healthcare professionals) and resources (EHR web services) to decide whether access of a given requestor to given resource should be permitted or denied by taking into account the attributes of the requestor, the resource, the action and the context holding at the time of the attempted access (operational, technical, or situational). However, in the case of an emergency, ED doctors gain access to a full set of a patient's information through a "break the glass" policy supported by the system.
- The **Analytics Service** constitutes a recommender system that utilizes the collaborative filtering technique in order to associate each patient arriving at the ED of a hospital with other patients who have sought emergency care in the past due to experiencing similar conditions.

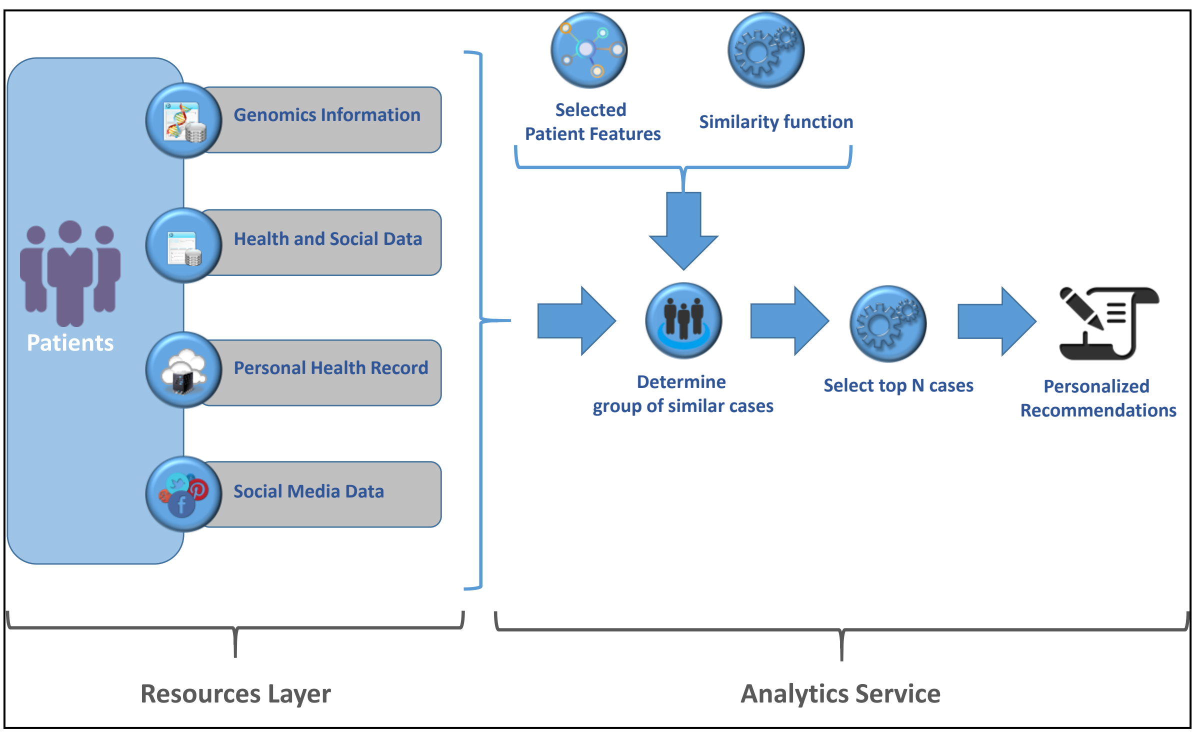

Figure 3. Analytics Service

To this end, certain features of patients are taken into consideration, which are retrieved from the next-generation EHRs (e.g., shared diseases, symptoms, family histories, lab results, urban/rural residencies, occupation, demographics, etc.). Thus, a subset of patients is identified who appear to resemble the patient currently under treatment in the ED of a hospital. Based on these cases, personalized recommendations can be extracted regarding the optimal treatment of the current patient. These recommendations are based on the outcome of treatments which have been used in similar cases in the past and are provided to ED physicians. Figure 3 illustrates a high level view of the Analytics Service incorporated in the proposed system.

The presentation layer provides the user interface whereby emergency physicians can gain full access to information included in next-generation patient EHRs. To this end, both a web portal and a mobile application have been developed.

V. IMPLEMENTATION ISSUES

To illustrate the functionality of the proposed platform, a prototype system was implemented and deployed on a laboratory cloud computing infrastructure. Prototype system implementation was based on the Oracle 11g SOA [16]. In particular, the following components of this Suite have been used: (i) Integrated Service Environment (ISE) for developing the EHR web services and (ii) an enterprise portal for healthcare professionals, collaborating healthcare organizations and researchers to access content.

The platform used for the generation of sample patient PHRs is Tolven ePHR as it has been considered sufficient for the purpose of our research [17]. With regard to health information from medical devices, weight, blood pressure and blood glucose measurements have been taken under consideration, which are uploaded in the patient's PHR automatically via a relevant Android application [15]. Due to unavailability of actual health and social data, a sample database has been created in MySQL along with the relevant web services in order to simulate healthcare and social care providers' systems [18]. The ABAC policies have been defined using eXtensible Access Control Markup Language (XACML) [19].

The implementation of the Analytics Service was based on Hadoop Mahout framework, which features various scalable machine-learning algorithms [20]. In particular, a certain part of the larger Mahout framework has been used, namely Taste, which is a Java framework for providing personalized recommendations [21]. Taste was used in order to develop a customized recommender system which comprises (a) a DataModel containing the certain patient features mentioned in the previous section and (b) a similarity function which determines the subset of patients that appear to be similar with regard to the features incorporated in the data model (Figure 3).

VI. CONCLUDING REMARKS

The emerging field of precision medicine is speeding ahead, promising a paradigm shift in care delivery, one that removes the need for guesswork, variable diagnoses and treatment strategies based on generalized demographics. A key enabling factor for the realization of the precision medicine approach is the utilization of data leveraged from direct and indirect sources to provide a more holistic view of an individual patient. Although, it is increasingly viewed as mainstream treatment, especially in cancer research and diagnostics, precision medicine is far from being integrated in several healthcare settings, including the Emergency Care settings. This paper presents a platform for enabling precision medicine in emergency care delivery which is based upon a next-generation EHR enhanced with advanced analytics tools. Thus, it is envisaged that the platform provides an appropriate infrastructure for laying the foundation for precision medicine to bring its critical benefits in emergency care. The platform's added value stems from the fact that it provides a rich set of data concerning a patient's health, lifestyle and genes and a tool for determining personalized treatments according to a set of features he is carrying. By introducing such a platform in emergency care delivery and in clinical practice in general, clinicians can mitigate many of the inefficiencies that currently encumber care optimization. These inefficiencies may be false positives, false negatives, unnecessary treatments, over- or under-medication and all have financial and quality-of-care ramifications. System evaluation is a task to be undertaken in the near future aiming at determining the system usability. Thus, its potential weaknesses may be revealed suggesting alterations in the system design and directions for future work.

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