Combining personal diaries with territorial intelligence to empower diabetic patients

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Abstract—Information is today recognized as a major source of benefit, for those who are able to properly create and manage it. With the advent of new computing, storing and networking technologies, transforming data into useful, ‘marketable’ information has become a major goal for companies, organizations and governments. The healthcare domain makes no exception. Governments and healthcare companies are paying increasing attention to patient-centered care and to its positive effects on business metrics, such as finances, quality, safety, satisfaction and market share. Appropriate information sharing and communication is then recognized to be one of the key factors for patient-centered care. In this paper, we propose an infrastructure for the development of special-purpose applications meant to improve care experience of diabetic patients while creating public value for services. This is achieved by a profitable combination of territorial knowledge with personal data and events available and processed on smartphones.

Keywords spatio-temporal metadata collection; mobile application development; empowering patient-centered services.

I. INTRODUCTION

A. Premise

The myriads of data available today may be profitably aggregated into information, and the resulting effective usage is critical to gain competitive advantage and address societal needs. In particular, information is today recognized as a major source of benefit, for those who are able to properly create and manage it by new computing, storing and networking technologies. Transforming data into useful, ‘marketable’ information has then become a major goal for companies, organizations and governments, which devote their investments towards the design of advanced solutions in several and significant domains, such as environment, healthcare, and renewable energies. In those domains, the user-centered approach to the development of tools exploiting shared information is becoming a focus of each initiative meant to better the quality of life. The healthcare domain is in particular, one of the fields that are greatly taking advantages of appropriate information sharing and communication which is then recognized to be one of the key factors for patient-centered care. The term ‘patient-centered care’ is used to indicate healthcare that respects and satisfies the preferences, needs and values of patients. Governments and healthcare companies are paying increasing attention to patient-centered care and to its positive effects on business metrics, such as finances, quality, safety, satisfaction and market share. In this context, a well investigated field concerns the development of mobile solutions explicitly addressed to assist people who suffer from diseases that require a continuous monitoring during everyday activities, such as diabetes. In fact, with the continuous worldwide increase of diabetes spread, the need to massively include IT support and telemedicine systems during all the phases of diabetic care has become a compelling priority, both to improve self-management activities and to reduce the global healthcare costs.

A great support for the development of innovative solutions derives from the combination of unique features of mobile devices and the operating systems, such as the pervasiveness of smartphones, the growing number of sensors with which they can interact, and the availability of shared and produced multimedia data. These represent distinctive features that are usually not available on traditional personal computers. A concrete example of the use of sensors-related information is represented by the context aware applications that provide users with new types of services and interfaces capable to adapt themselves to the ongoing situations. Some statistics about the increasing number of mobile applications that take advantage of the data coming from such sensors to accomplish their main tasks can be found in [1].

B. Motivation

According to Dey, "context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." [2]. The increasing number of
sensors available on a mobile device facilitates the development of context-aware, user-adaptive solutions. By combining user-entered data with the information generated by the myriad of sensors available on a modern smartphone, it is currently possible to develop useful solutions on behalf of diabetic patients. However, so far, although almost every type of data that can be retrieved from current mobile devices has a geographic reference, such a characteristic is not being properly exploited by the majority of the proposed solutions. As a matter of fact, existing systems do not yet consider the surrounding context as an active source of information, that is, they keep the capability of a spatially enabled territory within elementary and autonomous functions. Then, probing or making sense of all the information that could be potentially in hand to users is a challenging task [3].

The awareness of such a limitation has stimulated researchers to investigate how territorial communities could be involved in the design of information systems for obtaining a better understanding of data they produce and use. The collective intelligence of a community, indeed, can play a primary role in the development of new strategies that can dramatically improve several aspects (social, economic, etc.) of a given territory and offer mutually related new services. By this mind-changing, also the environment neighboring a local community of diabetic patients becomes a valuable source of additional information through the creation of new types of connections among patients and among patients, physicians and medical facilities, thus improving healthcare coordination, simplifying access to resources and reducing barriers to services. However, in order to realize such a transformation, a supporting infrastructure is necessary that acts as an underlying common layer for new types of applications. In order to design and develop such a platform, the factors of primary importance that should be taken into account are the need of a shared communication protocol among all the involved entities, extensibility i.e., the ability to add new features without affecting the existing components, and the opportunity to hide the format differences of data coming from heterogeneous data sources.

C. Contribution

The goal of the research we are carrying out is to define methods and techniques for handling the multidisciplinary complexity of data coming from a spatially enabled territory. In particular, in this paper we describe the initial results of our research targeted to provide users with personalized services based on a less invasive technology through the experimentation of new process models meant to share information and integrate software components. Moreover, we aim to obtain a significant relapse in the social sphere through the awareness that associating the territory actors and community and insuring the mutualisation and cooperative exploitation of information may contribute to meet the challenges of territory sustainable development.

This goal can be achieved by a profitable combination of territorial knowledge with personal data and events. We propose a software infrastructure for the development of special-purpose applications meant to improve care experience of diabetic patients while creating public value for services. Moreover, a spatio-temporal database has been designed to collect, aggregate and manage both the metadata generated by user-performed activities and those captured through the sensors available on a smartphone device. On the basis of this infrastructure diabetic patients are provided with innovative functionalities and may also automate several recurring operations. Moreover, metadata collected from individual patients can be aggregated and managed to support public healthcare services, allowing for, e.g., planning, management and research activity. The final goal is to enrich collective knowledge and territorial intelligence (see Fig. 1).

The paper is organized as follows. Section 2 discusses some related work. In Section 3 the domain of diabetes healthcare is introduced and the open issues related to the adoption of the information technology are discussed. The proposed e-health system is described in detail in Section 4. Future steps of this research work are advanced in Section 5.

Figure 1. Metadata collected from individual patients are aggregated and managed to support public healthcare services.

II. RELATED WORK

Worldwide scientific and the industrial communities recognize that contextual information and related metadata play crucial roles in the proper management and use of growing types of data. In this section we review some work which show how metadata content may be exploited in software systems that support everyday activities. The description of papers that analyze in detail actual metadata standards or describe how to efficiently structure a context-aware middleware is outside the purposes of our discussion.

All the papers discussed here share some underlying ideas on the need to classify user-generated information reducing as much as possible tedious, error-prone and time-consuming operations like the manual insertion of labels. In particular, for what concerns the user generated contents (particularly multimedia files) there is a general agreement that, besides the acquisition of the actual multimedia object, also the greatest amount of contextual related metadata should be acquired. Such type of additional information can then be analyzed and used, e.g., to automatically add cataloging labels to the multimedia objects.

In [4] authors recognize the importance of exploiting time information to automatically generate collection and summaries from a set of photos. They propose two photo browsers for collections with thousands of time-stamped digital images, which exploit the timing information to structure the collections and to automatically generate meaningful summaries. Users are provided with multiple ways to navigate and view the structured collections. Having structured the set of images into clusters, various summarization schemas can be created. In addition, such schemas can be specialized whenever additional metadata information become available (such as the location or in presence of a face recognition algorithm).

Davis and Sarvas [5] insist on the need to manage the growing number of media files produced by final users and address the use of metadata as a feasible solution. Moreover they recognize the need to exploit the spatio-temporal context
and social community of media capture to deduce media content. They propose a client-server system that combines the features of a traditional camera phone with a remote web server. It gathers all the available information at the point of capture, and uses such metadata to find similar media previously annotated.

In [6] the importance of using metadata to describe the content of mobile data is recognized. Authors’ proposal consists of a search engine that is able to analyze image and audio content and supports two types of search methods. Both methods rely on an automatic metadata extraction done for new files.

A detailed analysis of the importance of annotating personal multimedia files with context-related information was also performed by Viana et al. [7]. They categorize research about multimedia annotations into context-based and content-based approaches. They propose a two-step method which leverages the collection of the largest amount of available information about user’s context when a multimedia document is created. It then enriches that information through ontologies and semantic reasoning.

Also Kim et al. [8] deal with the problem of effectively managing the photo libraries stored on mobile devices. Even in this case it is recognized that the manual annotation of all the information needed for an efficient retrieval and management, is unfeasible mainly due to the huge amount of time required. They proposed to automatically gather such information from the metadata directly stored on the mobile device. Therefore, they designed a mobile Android application, Photo Cube, which extracts several metadata from photos, combines them with mobile device metadata and uses them to improve their management and searching. The application provides also hierarchical search and browsing facilities using parameters such as address or date/time.

Lee et al. propose a mobile prototype which recommends 3 applications that best match user’s context [9]. An adaptive mobile interface is created, based on five parameters characterizing user’s context of use, namely time, location, weather, emotion and activities. The state of such variables and the history of past context information are input to a machine learning and inference algorithm, which derives the 3 recommended applications.

In [10], the metadata management issues are analyzed from a different point of view. The authors observe that usually different mobile applications operate on the same aspects of the whole user context and manage the same types of data but they store information in private databases. As a direct result, this lack of interoperability represents a common source of information redundancy. Therefore they argue that on mobile platform there is the need of a greater interoperability at data management level. Moreover, they observe that on modern mobile devices a large amount of data usually owns also a spatial component. A greater interoperability could result in a join criterion for several resources. Exploiting interoperability of data management is useful not only on the single device but also across devices. For example, suppose that a group of users shares information about a meeting; when a certain user adds information about the meeting location, such data could be easily exchanged among the other participants. In order to address the interoperability issue, the authors present and discuss an architecture for interoperability between installed application, co-located devices and web application. Their approach is based on a central data repository on mobile devices that all applications use cooperatively.

An important field that, during time, has greatly taken advantage from the technical development in the aggregation, management and exploitation of the wide amount of heterogeneous data is represented by Medicine. In this context, the above mentioned mobile revolution is playing a central role in the emerging field of e-health, a broad term that encompasses methods for electronically transmitting medical information to sustain and/or improve a patient’s health status [11].

A recent report by ITU-T Technology Watch [12] mentions the interoperability among the 5 prerequisites for transforming healthcare into e-health services:

- Emphasizing Greater Interoperability
- Increasing Coordination over e-health Standardization
- Ensuring Privacy, Security and Safety
- Reducing the Standardization Gap in the Developing World
- Leveraging existing ICTs like Mobile Devices and Social Media

The last prerequisite again emphasizes the role of mobile devices to collect community and clinical health data, delivery of health care information to practitioners, researchers, and patients, real-time monitoring of patient vital signs, and direct provision of care.

Mobile applications are, in fact, gradually gaining consensus as a valuable means to improve healthcare services. A detailed review of 42 controlled trials that investigate the use and limitations of mobile-based systems in the context of healthcare services can be found in [13].

III. THE DOMAIN OF DIABETES CARE

A detailed analysis about the present support level of existing mobile applications designed to help patients with the self-management of their diabetes can be found in [14]. The majority of reviewed applications support the basic tasks needed by a diabetic patient such as diet, physical exercise, insulin dosage or blood glucose level and, according to the authors, can represent a suitable solution for diabetes self-management. However, the study shows also how, although mobile applications are usually preferred to traditional computer or Web-based solutions, several usability issues and limitations still exist, related, e.g., to data entry difficulty, lack of personalized feedback and missing integration with existing health records.

The focus of the research we describe in this paper is to find a proper combination of mobile devices pervasiveness and capability with an infrastructure supporting a well-established
distributed information system to automate as much as possible the self-management activities of diabetic patients, and transform the deriving informative heritage into a valuable information for the territorial communities.

The initial step of our investigation concerned the state of the art analysis about the existing mobile solutions and the open issues to face in order to achieve the real consensus by users, which still remains the major obstacle for an actual success of a solution.

A growing body of evidence shows that self-monitoring of blood glucose (SMBG), by persons living with diabetes, along with improved understanding of insulin-carbohydrate-meal matching, prevents or delays progression of diabetes complications, and allows patients to lead healthy and productive lives. Since 2006 the adoption of modern “real-time” continuous glucose monitoring (CGM) has enhanced patients’ ability to monitor and improve glucose awareness. Diabetes care today provides real-time CGM for clinical and personal use, which is increasingly accepted by both patients and clinicians as an important component in managing their disease process [15]. Another beneficial effect of CGM on insulin-dependent patients is recognized to be an increased sense of safety, provided that they will be alerted to high or low glucose levels as these changes occur, potentially before they become symptomatic, thus allowing for corrective action to be taken promptly. However, tools able to support patients’ self-management skill should provide a holistic view of the different critical components of diabetes therapy, i.e., nutrition, physical activity, emotional/physical stress and medications. To achieve that, a mobile application capable to dynamically capture relevant aspects of patients’ context may enable them to monitor the interplay of those components.

The establishment of an infrastructure where methods and techniques are conveyed for the specification of IT diabetic healthcare management solutions implies to face several issues, related e.g., to the amount of data daily generated (big data) in the presence of heterogeneous sources (data fusion) in space and time variable (spatio-temporal data), to the need to present those variations in a visual form on advanced devices, in order to gain an immediate and significant synthesis, and to perform complex geo-processing analyses (data visualization, advanced interfaces, geoprocessing).

Since the initial phases of our analysis we kept in mind those general issues while conceiving an e-health system for diabetes care that could improve care experience of patients while supporting public healthcare services.

IV. EMPOWERING PATIENTS THROUGH A METADATA AGGREGATION FRAMEWORK

From a high level point of view, the system is characterized by a traditional client-server architecture. As shown in Fig. 2, it is made up of four main interacting components where the backend is designed around the principles of Service Oriented Computing (SOC) while the client is entirely deployed as a mobile solution.

Figure 2. The client-server architecture

A. The System Backend

From a functionality perspective, the initial role of the backend is to retrieve all data sent from each mobile client, analyze and provide feedback to the user and warn medical personnel, in case some measurements exceed established limits (e.g., send an alert to the intended physician when the glucose value is over a fixed threshold). The most innovative feature of the proposed system is that the backend also acts as a computational platform to exploit the considerable amount of aggregated information and enable the development of new types of data-oriented applications or functionality. As an example, let us consider the following complex query that could be formulated by a physician: "show the insulin level variations among men older than 65 during summer in the Campania region." To solve such a query, data coming from different sources, possibly stored in different formats, must be seamlessly integrated and processed. In order to face the inner complexity of those tasks, the SOC principles have been used when designing the backend modules. Accordingly, format differences are overcome by the XML-based approach, each functionality is offered as a set of interacting Web services, and distributed datasets are embedded within a unique computation platform, hence hiding the heterogeneity of data and architectures involved. Moreover, considering that each service that contributes to the composition can provide the functionality of an existing software system, in a platform-independent way, the SOC paradigm is an appropriate choice for reuse of software components and represents one of the "de facto" options for the fulfillment of interoperability among heterogeneous technologies, architectures and data representations. Results for Web services composition of heterogeneous data can be found in [16, 17].

B. The Client Side

The Communication Module deals with all the issues concerning the efficient information exchange with the backend (e.g., coding, compression and encryption of information, sending of big amount of data such as high-resolution images through the wi-fi module).

The second module of the client side is the Metadata Collection Framework that is responsible to aggregate and manage metadata either directly generated by user-performed activities or coming from the various sensors usually available on an Android device. In addition, it offers a high level API that simplifies the development of mobile applications addressed to exploit such metadata. As shown in Fig. 3, the framework main components are the Metadata Collection and Aggregation Background modules and the High Level Library that lets developers make use of such metadata.

The first task performed is metadata retrieval. It is carried out by the Background Module, namely an Android service that scans (at regular or user-defined intervals) all metadata sources available on a mobile device. A list of the most important traceable metadata sources freely accessible on the Android platform can be found in Table 1. Every single metadata is
subsequently stored in the internal database of the framework. It is worth noting that every time the service is launched it performs the operations and then stops until the next iteration. In that way the impact on other user's activities and on the device battery life is reduced. The only significant exception happens when tracking user's physical activity (walking, running, driving or still), by means of the built-in functions provided by the recent versions of the Android platform.

Figure 3. The Metadata Collection Framework

To enhance the query performance and avoid privacy and security violation issues, we chose to store only metadata, while the real referred content, such as pictures and documents, is retrieved by the High Level Library according to parameters chosen by the developer. In particular, the stored metadata are grouped into several classes of objects, such as images, videos, phone calls, and browser history, and for each class, we have designed a table which stores all relevant metadata. Moreover, in order to facilitate spatio-temporal queries we decided to add information about time and space for each type of metadata collected. In fact, some of them are not automatically acquired by the Android platform. As an example, when the users receive a phone call only the temporal information, namely the date, time and duration, is automatically inserted.

The algorithm we defined to add spatial information to any type of data sources, is informally described in Table 2.

In order to use the database content, we have created a supporting library to allow filter and display of information on the basis of specific combinations of space and time. Such a library is in charge of translating complex queries which involve, as parameters, non-trivial time series and/or spatial information, into appropriate invocations to the standard component of the Android platform, namely the Content Provider, which allows to share information by means of simple methods to retrieve and store data.

From a high level point of view, the library methods query the database adopting the traditional SELECT/FROM/WHERE structure. According to the specific application needs, the WHERE parameters can be automatically fulfilled by the library or provided by the developer in order to obtain fine grained results. In particular, developers can choose to simply retrieve the desired metadata according to traditional SQL-like query (e.g., give me all the phone calls received from Bob) or filter them according to combination of time and space parameters. As for time parameters, exact values (e.g., a certain day) or intervals can be inserted. When dealing with spatial data, instead, the parameters can be inserted with the desired level of accuracy using either a specific coordinate or a simple textual string. For example, the library method findPhotoByPosition when invoked with the two parameters "Salerno", "10" will search all the photos that have been taken within 10 kilometers around the city of Salerno while when invoked with the parameters "Salerno, via dei Principati", "7" will search all the photos that have been taken within 7 kilometers around the specific address in Salerno. The result of a method invocation will be a composed object made up of the element (or the list of elements) that matches the desired query. It is also possible to combine together two or more methods in order to obtain more complex results or better refine the obtained output (for example we may want to get information on all our multimedia files recorded in August when we were far away from Salerno).

C. The Mobile Application myDDiary

The functionalities provided by myDDiary application can be analyzed under two main points of view.

First of all, myDDiary, has been designed to be a complete solution for the self-management of several aspects of diabetes care. The list of the main features offered by the application can be found in Table 3. Moreover, for each type of data that can be inserted, a "Note" field is also provided which offers patients the opportunity to add additional unstructured information. As mentioned earlier, due to the extensive amount of information that a diabetic user may need to insert every day, a desirable requirement is the automation of repetitive tasks. As an example, the proposed application uses the Bluetooth protocol to communicate directly with external devices and perform traditional text oriented tasks, such as the insertion of blood pressure level. The goal of our research is to extend the set of automated tasks by embedding also those tasks that currently require a more invasive technology and a repetitive actions, such as the survey of physical activity and the discrimination between food-related and personal pictures. By properly exploiting the functionalities offered by the Metadata Collection Framework, we are testing some feasible solutions to automate as much as possible and without the use of CPU-intensive methods both the picture discrimination problem and the need to record the daily physical activity.

As for the latter task, let's consider the following scenario: a user has set on the calendar of his mobile device a recurring fitness plan: Gym from 19.00 to 20.00 from Monday to Wednesday and running on Thursday and Friday. Let's suppose also that on the corresponding calendar entry such activities are marked as "Gym" and "Run". The user decides to use myDDiary to compute the number of times he missed the physical activity during the last two months.

The application checks that the gym activity has been actually performed verifying whether user's position and the gym location were inside a reasonable convex hull for a certain amount of time. The run activity is instead checked by calculating the speed value within a time range of a calendar entry taken from the personal planning, on the basis of the user's position stored as metadata.

The other functionality of myDDiary allows to control patient’s nutrition behavior, starting from the pictures of his/her meals taken while the application is running. myDDiary distinguishes such pictures from other available multimedia files on the smartphone, by adding special codes to the EXIF metadata available for every JPEG image in Android.

Fig. 4 shows one of the various logging options available on myDDiary. In particular, through it the user can easily check the details and the weekly trend of his physical activity, and compare them with the corresponding blood glucose variations.

Dealing with highly sensitive information, in the context of our system, privacy issues represent a factor of the utmost importance. In particular, not all the user activities (e.g., a personal call) have to be transmitted to the back-end module.
Therefore, the other important task performed by myDDiary is to provide users with a fine-grained control over the data that can be actually sent and shared. For example, the user can choose to send his current location only when she is at the hospital; for phone calls, she can choose to share only the metadata that match some fixed keywords such as "Doctor's phone number" or, as for the multimedia files, only those directly taken with the myDDiary application.

Figure 4. One of the logging options of myDDiary

<table>
<thead>
<tr>
<th>TABLE I. TRACEABLE METADATA SOURCES ACCESSIBLE THROUGH ANDROID</th>
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<tr>
<td>1. Hospital emergency phone number ( \rightarrow ) hospital</td>
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<tr>
<td>2. Phone number ( \rightarrow ) doctor</td>
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<tr>
<td>3. Email address ( \rightarrow ) nurse</td>
</tr>
<tr>
<td>4. Social media profile ( \rightarrow ) personal data</td>
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<tr>
<th>TABLE II. THE ALGORITHM TO ADD SPATIAL INFORMATION TO DATA SOURCES</th>
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<tbody>
<tr>
<td>1. Geolocation service</td>
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<td>2. Map service</td>
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<tr>
<td>3. Location tracking service</td>
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<tr>
<th>TABLE III. A LIST OF SOME FEATURES OFFERED BY THE APPLICATION</th>
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<tr>
<td>1. Real-time monitoring of blood glucose levels</td>
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<tr>
<td>2. Notification about emergency situations</td>
</tr>
<tr>
<td>3. Personalized reminders for medication</td>
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</table>

V. CONCLUSION

In the present paper we have illustrated the initial results of our research aiming to provide users with personalized services on the basis of the experimentation of new process models meant to share information and integrate software components. The first issue we have faced is represented by the multidisciplinary complexity of data coming from a spatially enabled territory. As a matter of fact, the awareness that associating the territory actors and community and insuring the mutualisation and cooperative exploitation of information may contribute to meet the challenges of territory sustainable development has represented the leitmotiv of our experimentation. The initial results have been based on a combination of territorial knowledge with personal data and events exposed through Web services. The resulting aggregated information has produced benefits at different extent, from the local to the surrounding context, up to the national coverage.

The second issue we have faced refers to the development of special-purpose applications that may benefit of complex data coming from a given spatially enabled territory. To this aim, we have proposed a software infrastructure capable to empower mobile users by innovative functionalities that better support their daily activities and also automate several recurring operations on the basis of information captured from the surrounding context as well as triggered by the users themselves.

A special-purpose application, named myDDiary, has been experimented to improve care experience of diabetic patients while creating public value for services. On the basis of the proposed infrastructure, diabetic patients are provided with an application for the self-management, which includes the monitoring of several parameters, such as the blood glucose level and the amount of carbohydrate ingested. Moreover, metadata collected from individual patients can be aggregated and managed to support public healthcare services.

In the future, we plan to enrich the relationship between collective knowledge and territorial intelligence by adding new types of data sources, such as the emergent intelligent sensors. To achieve this goal, we will take into account interoperability requirements and investigate new strategies for information storage.

REFERENCES


<table>
<thead>
<tr>
<th>Metadata sources</th>
<th>Android Telephony framework</th>
<th>Android media store framework</th>
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<tbody>
<tr>
<td><strong>Basics</strong></td>
<td>Calls log and details</td>
<td>Images</td>
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<tr>
<td>Alarm clock</td>
<td></td>
<td>Service state</td>
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<td>Browser history</td>
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<td>Browser Bookmarks</td>
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<td>Calendar</td>
<td>SMS details</td>
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<td>Contacts</td>
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<td><strong>Android Location Framework</strong></td>
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<td>Pressure sensor</td>
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<td>Proximity</td>
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</table>
For each event that does not have spatial information:

Retrieve its date and time.

Extract a time interval which starts 2.5 minutes before and ends 2.5 minutes after.

Look for another event with Global Position System (GPS) data happened during the established interval.

If some GPS data are found:

Use the Android Reverse Geocoding functionalities to translate such GPS data into an Address object.

If the Address object is valid:

Update the appropriate fields in the corresponding element table.

else:

Mark the fields related to Spatial Information as Null.
<table>
<thead>
<tr>
<th>Blood glucose level</th>
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<tr>
<td>Estimated amount of carbohydrate in the meal</td>
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<tr>
<td>Physical activity log</td>
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<tr>
<td>Periodic notifications</td>
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<tr>
<td>Alerts in case user missed a certain activity (e.g., pressure measurement at 18.00)</td>
</tr>
</tbody>
</table>
Figure 1

Metadata from patients' devices

Information linked to individual patients

Territorial intelligence and collective knowledge