Published in Journal on Visual Languages and Computing.

This version of the article has been accepted for publication, after peer review and is subject to Elsevier terms of use.

The Version of Record is available online at: http://dx.doi.org/10.1016/j.jvlc.2015.03.002

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 defining new processes to support a fruitful exchange of strategic information at the local level, which could encourage local dynamics and improve the relationships between ultimate users and the territory and vice versa. This is particularly relevant in the healthcare domain, so we have developed a mobile application to provide diabetic patients with personalized services based on a technology with a low level invasive impact, through the experimentation of new process models meant to share information and integrate software components. Such a special-purpose application is 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: healthcare domain, territorial intelligence, 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 advantages 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 the focus of each initiative meant to better the quality of life. The healthcare domain is one of the fields that are greatly taking advantage of an appropriate information sharing and communication, recognized as 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 the so called *mobile health* solutions (*m-health*, for short) 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.
The unique features of mobile devices and their operating systems may greatly support the development of innovative solutions. These represent distinctive features, usually not available on traditional personal computers, including the pervasiveness of smartphones, the growing number of sensors with which they can interact, and the capability of shared multimedia data. A concrete example of 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 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 [17].

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." [8]. 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 ultimate users. However, so far, the geographic reference of data has not been properly exploited by the majority of existing solutions, although that is a characteristic available in almost any type of data retrieved from a modern mobile device. As a matter of fact, existing systems do not yet consider the surrounding context as an active source of information, that is, they limit the capability of a spatially enabled territory to elementary and autonomous functions. On the contrary, it is widely recognized that acquiring information from a territory and integrating it with data produced by users and public organizations may significantly enhance the strategic planning and the involved processes. Then, probing or making sense of all the information that could be potentially in hand to users is a challenging task [6].
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 targeted users becomes a valuable source of additional information through the creation of new types of connections among users and among users, domain experts, and provided facilities, thus improving the organization of services, 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.

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, we investigate new ways to exchange strategic information at the local level, through processes that encourage local dynamics and improve the relationships between ultimate users and the territory.

The results presented here fall in the healthcare domain, and are meant to provide patients with personalized services based on a technology with a low level invasive impact, through the experimentation of new process models meant to share information and integrate software components. We also aim to extend the impact of those results in order to address the challenges of territory sustainable development, encouraging mutualisation and cooperative exploitation of information between individuals and communities. This goal can be achieved by a profitable combination of territorial knowledge with personal data and events organized through a software infrastructure conceived for the development of special-purpose applications meant to improve users' experience while creating public value for services. 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.

The experimentation we are conducting concerns an environment neighboring a local community of diabetic patients. We are developing new types of connections among patients and among patients, physicians and medical facilities, in order to improve the healthcare coordination. 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 activities. The final goal is to enrich collective knowledge and produce territorial intelligence addressed to improve the decision making by healthcare experts and organizations.

The paper is organized as follows. In Section 2 some related work is discussed. Section 3 introduces the concept of territorial intelligence. It also discusses how it can profitably support the diabetes healthcare domain. Section 4 analyses the requirements and the open issues related to the adoption of the information technology within the healthcare domain. In Section 5 the architecture of a service-based framework is specified for data-oriented applications. Details about the mobile application conceived to support patients' self-management of several aspects of diabetes care are given in Section 6. Future steps of this research work are advanced in Section 7.

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 [15] authors recognize the importance of exploiting time information to automatically generate collections 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 [7] 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 [19] 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. [24]. 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. [18] 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 [20]. 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 [4], 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 share 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 has greatly taken advantage from the technical development in the aggregation, management and exploitation of the wide amount of heterogeneous data is represented by Healthcare. 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 [16].
A recent report by ITU-T Technology Watch [25] 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. Collective Knowledge and Territorial Intelligence for the Healthcare Domain

Generally speaking, Territorial Intelligence (TI) is a system of models, methods, processes, people and tools that allows for a regular and organized collection of data heritage generated by a territory. In particular, it consists in the availability and exchange of know-how among local actors of different cultures [2]. Through data processing, analyses and aggregations, TI allows data transformation into information, its preservation and availability, and its presentation into a simple, flexible and effective form so that to constitute a support for strategic, tactical and operating decisions.
Currently, TI is gaining an important role for organizations and companies belonging to the same geographic area because it works as a collector of diverse knowledge and contributes to improve the exchange of strategic information at the local level [26], [10]. As an example, the goal of a territory homogeneous in terms of population, environmental resources and economic activities requires an analytical design approach that takes into account several aspects, ranging from communication lines to public work, from social policies to services for citizens. In this context, the interrelationship among territorial actors is strongly beneficial because it can play a significant role within the participatory city planning with the involvement of local stakeholders and citizens who can express their needs and share their knowledge.
A relevant contribution to these new forms of governance could be guaranteed by exploiting ICT as fundamental support to the collaborative work and to the transformation of information into knowledge. In particular, making the collective knowledge accessible and deployable by decision makers represents the first step towards the automation of a transparent federation process addressed to build networks and clusters to which specific actions can be linked.
The healthcare domain represents a field where TI and ICT can be profitably combined to strengthen the skills of a territory, to understand its phenomena, to interpret local dynamics concerning the ordinary arrangement as well as extraordinary phenomena involving patients, institutions and organizations. As a matter of fact, as shown in Figure 1, raw data generated by users through devices and sensors, can be properly processed, aggregated and shared. In order to perform those tasks, datasets from patients have to be associated with appropriate metadata thus guaranteeing their interoperability. Moreover, once shared and enriched by personal sense making, they can contribute

to the collective meaning making. On this basis, the territory can finally take advantage of collective knowledge, produce innovation in the healthcare management, and create cross-fertilization in terms of added value for different domains.

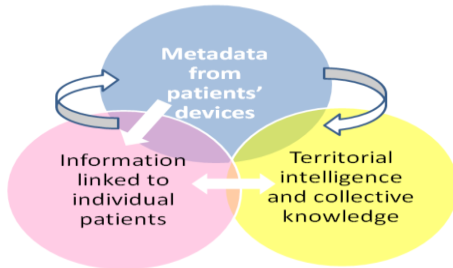


Figure 1. Metadata collected from individual patients are aggregated and managed to support public healthcare services.

An example of such a progressing is illustrated in Figure 2, where the expected interrelationships among territory actors are depicted and supported by the underlying technology. Each diabetic patient is able to use specific (mobile) applications that collect data (and metadata) about some of his relevant parameters, such as blood, physical condition, food, and physical exercise. The goal for this collection is wide. Those parameters can be collected and shared with the physician in charge of monitoring his health condition, with the local healthcare institutions to take part to campaigns for monitoring global trends and tuning existing protocols, with other patients to build a collective awareness as well as social artifacts (social constructivism). As for the ICT support, it is paramount for both improving patients' life and contributing to a sustainable development by extending the impact of TI processes to a broader context. In the example depicted in the figure, if a patient has a positive experience with a restaurant where a gluten-free cooking for diabetics is available, the value of this information is multifaceted[1]. It can be shared with the diabetes community (collective knowledge), it can be properly managed by caregivers and healthcare institutions (healthcare management), and it can eventually represent a peculiarity of that territory to be promoted by institutional web sites for tourism (territorial intelligence).

[1] There exists a strong relationship between diabetes and celiac disease. They are both autoimmune diseases and it is rather frequent that people suffering from an autoimmune disease have a particular predisposition to develop other ones.

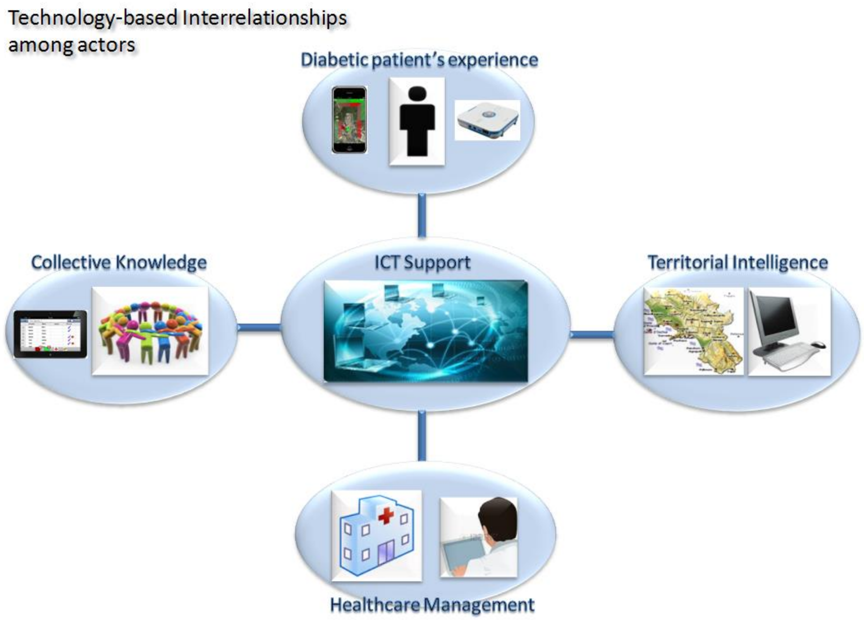


Figure 2. ICT support for collective knowledge and territorial intelligence

IV. Requirements Analysis

The very initial step of our investigation has 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 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 [11]. 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.

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 [14]. 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. Two recent surveys on mobile applications for diabetes care report that few integrated health applications have been designed so far. In [5] the authors review existing mobile applications, analyzing features related to important aspects of diabetes care, including self-monitoring, education, integration of social media functions, disease related data sharing, and synchronization with personal health record. Their survey reveals that the importance of the latter features is still underestimated and, although some form of lightweight integration with social media does exist, the goal to enhance patients' social engagement is far from being achieved. Similarly, limited forms of integration with social media integration were observed in the apps analyzed in [23]. The authors describe, in particular two apps emphasizing that feature. One integrates Facebook and Twitter to keep user informed on updates to the app, while providing an online forum where user may share his/her care experience and get feedback on topics like insulin pumps and gestational diabetes. Another versatile app they mention in their survey, is able to store patient's personal data locally, to log comprehensive medical examinations, and to visualize average blood glucose over 1 week, 1 month or 3 months.

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, fitness activity, emotional/physical stress and medications. The complete integration of those components would also entail the expected impact on collective knowledge and Territorial Intelligence, so as to close the loop depicted in Figure 1. 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, while being an active contributor for the whole community.

We started the design of our prototype system adopting a process inspired by Rosson and Carrol's scenario-based design method [22]. Scenarios of usage were in fact chosen as our primary design objects, because of their simultaneous ability to guide design and to facilitate usability evaluation and assessment during the iterative development process. To better understand the extent to which technology is supporting people involved in the world of diabetic cares (primarily patients, physicians, and families), we conducted a field study to build scenarios of established healthcare practices which could be used to derive user requirements. The design process entailed participation of a wide range of users and stakeholders, including physicians, nurses, social workers, patients, and informal caregivers (usually patients' relatives). We then exploited HCI usability principles, as well as appropriate interactive design patterns, to extract a set of generic system requirements. Based on those requirements we then developed a new set of scenarios which overcame many of the issues envisaged in the original scenarios and could be implemented with the support of mobile technology.

IV. THE FIELD STUDY

An initial inquiry carried out at the Diabetes Care Center of Salerno, allowed us to set up the right investigation thread for the field study and observation that followed. Physicians at the center helped us to identify representative groups of possible stakeholders (including elderly and young patients, families and care providers) and select from them 40 people as interesting subjects for further observation. In particular, 6 specialized physicians 24 patients and 10 informal caregivers (family members) were selected. Among the patients, 8 were young people aged between 14 and 23, 6 were working adults and 10 were retired.

As explained above, the goal of this fieldwork was to depict scenarios of established patient pathways, of existing training programmes for the care workforce and of adopted organizational models, from which user's requirements could be derived for an effective m-health system. The observation and the informal interviews performed allowed us to gain a comprehension of the care processes and management activities as they occur in real healthcare settings, including those that benefit from information technology support.

From clinicians' viewpoint, we were able to gain insight into the complex protocols for integrated diabetes care they usually adopt, sometimes in the presence of co-morbidities. The flaws in existing procedures were generally related to *low level of interoperability among actors* (e.g., support to communication between the diabetologist and other specialists in case of co-morbidities, or real-time access to patient's anamnesis in case of first aid interventions).

From patients' point of view, we perceived that their expectation from mobile technology as a means to improve quality of life is high. Some of the interviewees use existing mobile applications but most report on inadequate support to *personalization of care management programme* to specific characteristic of patient's profile and to specific geographical contexts or timeframes. This would allow them to easily adapt their care management programme when travelling or when certain circumstances force them to change their life habits (e.g., moving to a new place or starting some gym activity).

The informal caregivers claim that *training support* should be much improved as well as communication with the physicians and with the healthcare organization, in charge of patient's care programme. Parents also feel that local public institutions like schools should be assigned an active role in training activities so as to increase motivation in young patients and to allow early auto-diagnosis and nutrition education. In general, they believe that any such initiative should not be left in charge of a few valuable volunteering physicians and that *the territory should be rather engaged in the care workforce*, devising special services that patients and their relatives could benefit through their mobile phones inside an integrated m-health system.

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 m-health system for diabetes care that could improve care experience of patients while supporting public healthcare services.

In summary the main requirements emerged from the field study were:

- Personalisation of care management programmes to specific characteristics of patients' profiles and spatial/temporal conditions
- Fusion, analysis and interpretation of patient and care provider data, to improve decision making among formal and informal caregivers and patients;
- Multi-channel and multi-actor interaction and exchange of knowledge in territory-integrated care settings, through some digital collaborative platforms, which strongly relies on mobile technology;
- Development of new patient pathways, new training programmes for the care workforce and new organisational models to improve the coordination of care services as well as the skills and collaboration of health professionals, social carers and informal caregivers;
- The creation of new knowledge for the management of co-morbidities and for addressing poly-pharmacy.

The design activity that originated from the above requirements was aimed at exploiting the potentials of mobile technology 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.

V. 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 Figure 3, 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 [21].

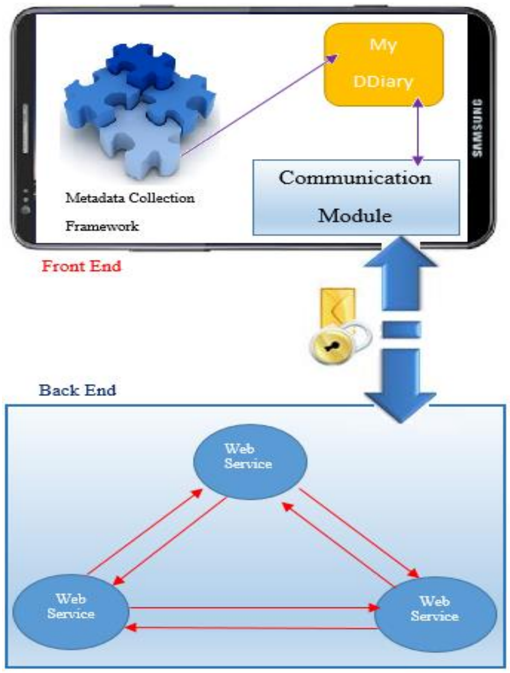


Figure 3. The client-server architecture

A. *The System Backend*

From a functionality perspective, the initial role of the backend was 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). Besides such a traditional software system that collects and parses data coming from the single mobile devices, we have decided to develop a more advanced computational platform able to manage, aggregate and process information coming from different and heterogeneous data sources, thus providing a solid framework for the development of data-oriented applications. To achieve this goal, some requirements of primary importance have been taken into account, such as the platform independence, the architecture flexibility, and the ability to seamlessly add additional data sources. Moreover, the design efforts have been targeted to satisfy the need to provide final users and developers with both a high-level mechanism to extend the platform functionality, a shared communication protocol, and finally a unified data format to facilitate the information exchange.

To satisfy such complex requirements, we have decided to develop the core backend functionality according to the SOC principles that, during last years has become a well-accepted methodology to design distributed systems and achieve interoperability among heterogeneous technologies, architectures and data representations. The basic notion behind such a computational approach is the idea of service, namely, an independent software module able to perform a defined set of operations. A service exposes its capabilities through its public interface that is usually described using public standards and technologies accessible by anyone in a platform independent way. Therefore its functionality can be invoked by any type of software system, such as desktop and mobile applications and other services.

Figure 4 shows a high-level overview of the entire backend architecture.

The design was mainly influenced by two requirements concerning the seamless integration of heterogeneous data sources into the overall computational process, and the ability to dynamically extend the list of available functionality. To achieve the required flexibility, we further categorized each candidate service according to different layers of abstractions, as specified in [12]:

- the data services layer,

- the application services layer,
- the orchestration services layer.

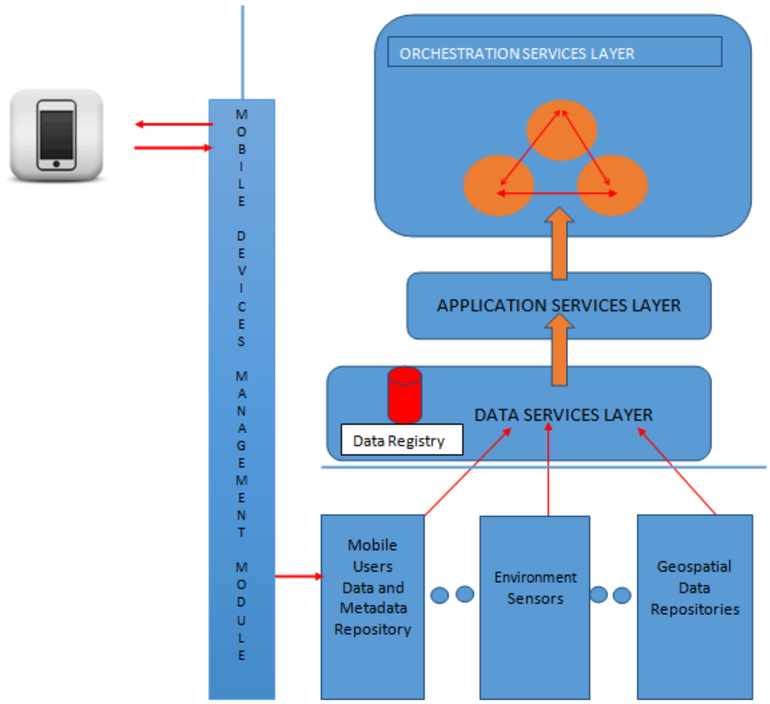


Figure 4. The backend architecture

The data services layer represents the lowest level of abstraction. Its main role is to encapsulate the different data formats and encodings of the various information sources into a unique representation, and provide the higher levels with a standardized interface for their retrieval and exploitation. In addition, the data services layer offers support for the extension of the available data sources. When a new data source is available or needed, a service that exposes the functionality and access policies of the original software system is added to the data layer. Moreover, the definition of the service public interface along with all the relevant metadata are added to the Data Registry, a service directory that allows other services or applications to discover the type of information offered by every module available in the data layer. The main drawback of such an approach is represented by the time-consuming task of mapping the original data to the format used throughout the system. However, the ability to deal with a single data representation simplifies both the process of managing and exposing the characteristics of additional data sources, and the development of higher level services necessary to perform data integration operations to support the execution of complex user queries. This feature reveals to be fruitful in domains where the inner data complexity impacts on the whole development process, such as the Geographic Information System (GIS). Here, the various data formats (e.g., shapefiles, GML) used to store and describe geospatial information dramatically increase the complexity of services [3], [9].
The intermediate level of the proposed architecture is represented by the application services layer. It collects the diverse software applications that make up the building blocks of the entire system functionality, ranging from basic reporting to geoprocessing functions. The functionality and business logic of such applications can be easily exposed by using one or more services available in this layer. Finally, the orchestration services layer represents the architecture level that supports the definition of user queries and complex business processes, realized by properly combining both the functionality offered by lower layers services and the functionality provided by previously defined services composition. Actually, the composition is implemented by using a high level scripting language,

namely the Business Processes Execution Language (BPEL) [1] that can be used both to answer a specific user query and build more complex workflow. It is clear how such a loose coupled approach greatly increases the overall flexibility of our software infrastructure since the same information source or functionality can be exploited, at the same time, by different entities, in different contexts and according to different needs.

As a concrete use case of services composition, let us recall the example described in Figure 2. The “simple” addition to an institutional portal of the user-provided information concerning a restaurant with gluten-free meals for diabetics, can be seen as the aggregation of several modules output, potentially distributed in different locations. The Web service managing the user-provided information can be exploited by a data validation module that may need to check its validity against a set of information quality requirements. The validated information constitutes, in turn, the input of another service that deals with all the geospatial details of the surrounding environment .

As shown in Figure 4, the bidirectional information exchange between the backend and the mobile devices of final users is guaranteed by the Mobile Devices Management Module. The two main roles of such a module are the format translation of the input and output messages and the storage of the information generated from the mobile device. In particular, in order to simplify the exchange of data we have chosen to abstract from the specific internal representation of the single mobile operating system and adopt a common intermediate data representation. For such a data format, an important aspect to take into account is the right trade-off between flexibility, size of exchanged data and processing time required for the encoding and decoding operations. The latter two aspects are particularly important in a mobile context due to the reduced computation capabilities of most devices. To this aim we have adopted the JavaScript Object Notation (JSON) as underlying data representation language [27].

B. *The Client Side*

The first 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 Figure 5, 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 fitness activity (walking, running, driving or still), by means of the built-in functions provided by the recent versions of the Android platform.

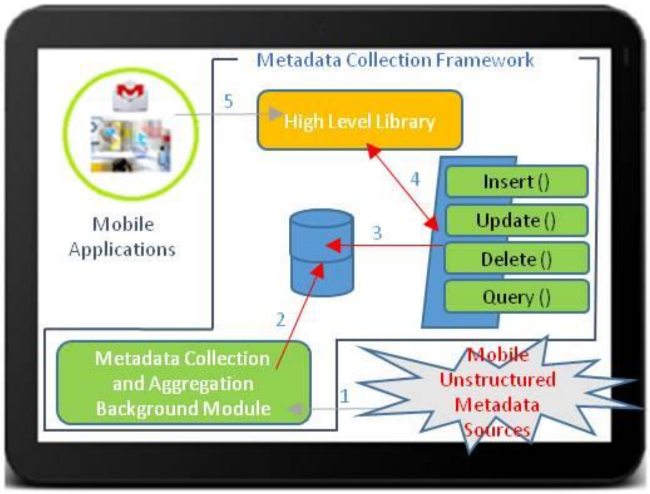


Figure 5. The Metadata Collection Framework

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).

VI. THE MOBILE APPLICATION *MYDDIARY*

In this Section we describe the mobile application *MyDDiary* which has been developed to address the requirements given in Section 4.

MyDDiary has been designed to be a comprehensive solution for the self-management of several aspects of diabetes care. Moreover, it embeds empowerment and context functionalities within a more general environment where their interrelationships can be exploited in a transparent manner. Figure 6(a) shows *MyDDiary* home screen displaying three sets of functionalities, related to selfcare, empowerment and context, respectively. In Appendix I the complete list of *MyDDiary* functionalities is given.

(a) (b) (c)

Figure 6. (a) MyDDiary Home (b) the trend of the glycemic index and (c) the insertion of a new georeferenced value

The first set covers the basic self-care treatments, namely the glycemic index, the insulin dosage and ingestion, and the calorie count. Due to the extensive amount of information that a diabetic user may need to input every day, a desirable requirement is the automation of repetitive tasks. To this aim, for each functionality *MyDDiary* offers an immediate overview of the last week trend through a graphic, then it allows the user to add new values and update his/her diary. Figure 6(b) displays the graphic of the glycemic index over the last week and Figure 6(c) shows the interface for the insertion of a new glycaemia value, automatically associated with its geolocalization. This last feature can be relevant for medical studies, considering that for instance a scientific relationship has been discovered between the blood glucose level and the elevation of the place where a patient lives.

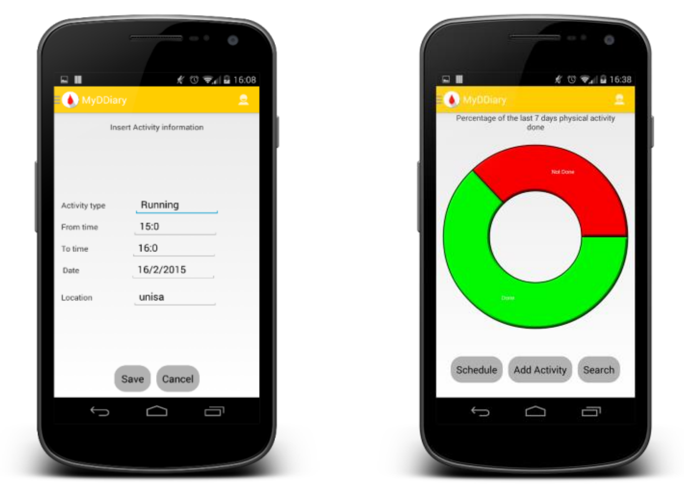
An additional function, *Meals* allows to control patient's nutrition behavior, starting from the pictures of his meals taken while the application is running. *MyDDiary* distinguishes such pictures from other available multimedia files on the smartphone, by adding special codes to the EXIF metadata available for every JPEG image in Android. Once an image is captured, it is sent to the server for the calorie count. The resulting value is also added to the local database. In Figure 7, the result of the whole path to obtain the calorie count of a meal is illustrated.

Figure 7. The calorie count of a meal

As for the Empowerment set of functionalities, the goal of our research is to extend the set of automated tasks by embedding also those that currently require a more invasive technology and repetitive actions, such as the survey of fitness activity. By properly exploiting the functionality 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, most of those daily activities.

Let us consider the following scenario. A diabetic 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 us also suppose that on the corresponding calendar entry such activities are marked as "Gym" and "Run". The user decides to use *MyDDiary* to monitor his fitness activity and compute the number of times he missed the scheduled training during the last two months. Moreover, he/she needs to obtain an immediate overview that compares the fitness activity, calorie counts and glycemic values of the last week.

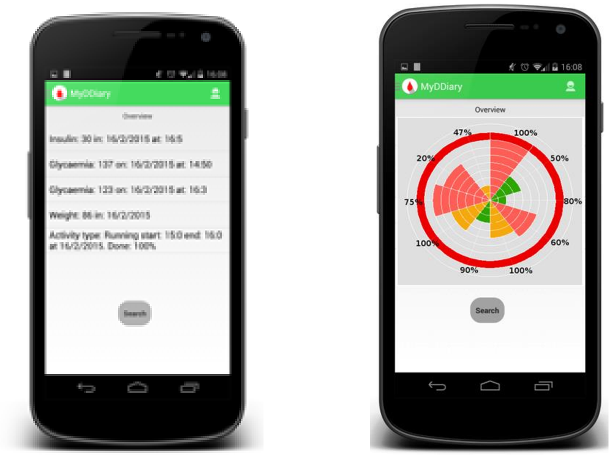
The application checks that the gym activity has been actually performed by verifying whether user's position and the gym location were inside a reasonable convex hull for a certain temporal range. The run activity is instead checked by calculating the speed value within a time range of a calendar entry taken from the personal planning, on the basis of user's position stored as metadata. Figure 8(a) illustrates the planning of a fitness activity while Figure 8(b) visually represents the percentage of activity really performed in a given temporal range.



(a) (b)

Figure 8. (a) Planning a new fitness activity and (b) the visual representation of the performed fitness activity

As for the Overview function, we have defined a visual metaphor capable to integrate three different parameters within a unique view, namely the glycemic index (a raw data), the calorie count (an aggregated value) and the percentage of fitness activity (a calculated value) done in a given temporal range. Figure 9(a) shows the list of such parameters where each entry can be selected for a subsequent detailed access. In Figure 9(b) the summarizing metaphor is illustrated that represents respectively the glycemic index as the length of a slice, the calorie count as the slice color based on the semaphore metaphor, and the percentage of fitness activity done. Besides the hint that the patient himself can obtain from such a view, this function allows different stakeholders to gain an immediate overview of the current health state of a diabetic user. As an example, the physician could profitably receive the image and make decisions about the trend of a specific treatment or detect alert situations.



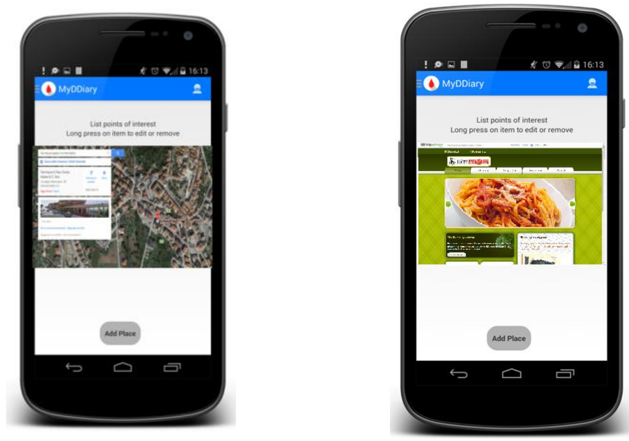
(a) (b)

Figure 9. (a) The textual synthesis of user's activities and (b) the corresponding visual representation. The red ring corresponds to the warning customized threshold for the glycemic index.

The last set of functionalities concerns some relevant context information. Besides personal and health data accessible through the Profile function, the user can manage the POI geolocalization which can be useful also in a wider domain, such as the acquisition of location-based services. As an example, when reaching a new area, it can be classified and described in terms of relevance for the diabetic patient. This classification is also stored within the local database, thus every subsequent access to that area will invoke and filter the POIs advisory on the basis of the user's needs.

Finally, the T(erritorial) I(ntelligence) function is useful to establish some relationships among patients, territorial communities and services. Indeed, the local database stores information about patient's customized parameters as well as events and activities planned within the personal diary. A portion of that information can be properly exchanged by the patient on a dedicated social network where new patterns can be discovered and additional facts built. The derived collective knowledge could be in turn convenient for the patient himself/herself when it is offered through location based services. Thus, diverse scenarios customized on the patient's needs have been experimented during prototype testing, as follows. Once a diabetic patient reaches a new place, he automatically receives (1) some relevant information, such as the location of the closest center for therapy of diabetes, where emergency medications and insulin can be prescribed and obtained, (2) recommendations about restaurants offering breakfast and meals customized for diabetic patients' diet (with the calorie count), and finally (3) information on the presence of fruit and vegetables biological markets. Moreover, based on the fitness activity planned for that day, (4) he/she can be informed about the sport facility available in that area with the corresponding opening times.

Figures 10(a) and 10(b) show the information the diabetic patient receives when visiting a new city. In particular, Figure 10(a) illustrates the notification of a pharmacy satisfying his treatment needs, it is displayed through GoogleMaps. Analogously, Figure 10(b) shows the information that the user receives at dinner time about a restaurant nearby, where food intolerances are properly handled .



(a) (b)

Figure 10. (a) the information about the closest pharmacy and (b) the information about a restaurant with the calorie count facility

When designing the application we also took into account the privacy issue, especially important when dealing with highly sensitive information. In fact, not all the information caught by patient's smartphone (e.g., personal calls) should be transmitted to the backend module. Therefore, *MyDDiary* has been designed to provide users with a fine-grained control over the data that can be actually sent and shared. For example, the user may choose to send his/her current location only when he/she is at the hospital or he/she may decide to share only the phone calls metadata that match some fixed keywords such as "Doctor's phone number" or to share only the multimedia files directly taken through the *MyDDiary* application. Figure 11 shows the screen for information sharing settings.

The prototype has been tested simulating interaction scenarios similar to those described above, also relying on territorial knowledge, on events exposed through Web services and on a set of anonymized data, provided by a company which performs periodic statistics to analyze the care trend of the diabetes at a national level.

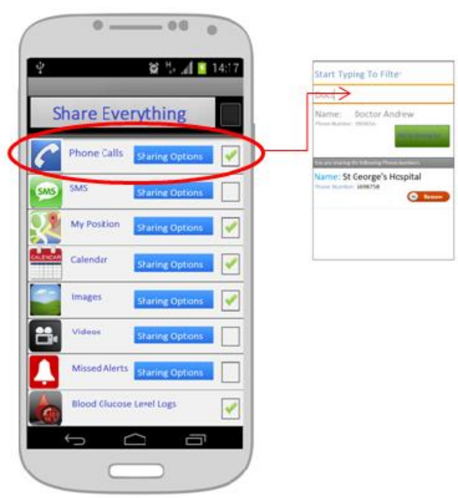


Figure 11. Handling privacy issues with MyDDiary

TABLE I. TRACEABLE METADATA SOURCES ACCESSIBLE THROUGH ANDROID

Metadata sources		
Basics	***Android Telephony framework***	***Android media store framework***
Alarm clock Browser history Browser Bookmarks Calendar Contacts	Calls log and details Service state Signal strength SMS details	Images Videos Audio files
Android Location Framework	***Android Hardware Framework***	
GPS status	Camera details Geomagnetic field Accelerometer Gyroscope Light sensor Pressure sensor Proximity	

TABLE II. THE ALGORITHM TO ADD SPATIAL INFORMATION TO DATA SOURCES

```
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.
```

VII. 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 may produce 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 from 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 developed 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. The results of the testing activity performed so far with *MyDDiary* indicate the technical feasibility of the proposed territory enabled healthcare self-management model.

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.

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ANNEX I.

TABLE III. *MYDDIARY* - LIST OF FUNCTIONALITY

Profile:	it contains basic information about the patient, namely personal data, anamnesis, the warning threshold of glycemic index, medication.
Overview:	to visualize the user's calendar (in terms of realized activities and medications)
Glycemia:	to insert a daily geo-located glycemic index (associated with the place where it is measured); to visualize a weekly trend of the glycemic index (chart); to search the glycemic index within a specified temporal range; to search the temporal range where the glycemic index exceeds a safe threshold.
Insulin:	to register the administration of the medication dosage; to visualize the weekly administration of the medication dosage (chart)
Fitness Activity:	to (automatically) register a geo-located fitness activity; to evaluate the weekly percentage of fitness activity done (wrt the scheduled one); to schedule fitness activity on the basis of physician prescription
Weight:	to periodically insert the body weight; to visualize a weekly trend of the body weight (chart); to search the body weight within a specified temporal range; to search the temporal range where the body weight exceeds a safe threshold.
Meals:	to take a photo of a meal to receive an estimation of its calorie count and to insert the geo-located calorie count of a meal (associated with the place where it occurs); to visualize a weekly trend of the calorie count index (chart); to search the calorie count index within a specified temporal range; to search the temporal range where the calorie count index exceeds a safe threshold.
POI:	to add a new POI (description and coordinates) depending on the GPS availability
TI:	to create and receive customized collective knowledge