International Journal of Reliable and Quality E-Healthcare
Volume 7 • Issue 3 • July-September 2018

Modeling Historically mHealth Care Environments

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ABSTRACT

This article describes how mobile health (mHealth) has grown from infancy stage to toddler stage due to advances in the technology. It has the potential for further growth as it is low-cost health care. For its further growth, it is necessary to widen its scope. In this article, a proposal is presented to develop a new and advanced mHealth care system, and its first step that is modelling is reported. In modelling, historically, a model of a temporal object system (TOS) is used. The model empowers users of the proposed mHealth care system to define, retrieve and manipulate all objects historically, in a uniform fashion, and also to keep historically the changes that occur to the objects. Later, these historically stored objects can be consulted during making essential and crucial decisions about the patients (objects) and other objects of the system, and it can save both lives and money. Also, the stored objects can be used in the future planning and research.

KEYWORDS

Abad Shah, Complex Temporal Object, Family, Farshad Fotouhi, Object-Oriented Database, Offstage Object, Sadaf Naqvi, Simple Object, Stage, Temporal Database, Temporal Object, Wireless Devices

DOI: 10.4018/IJRQEH.2018070104

INTRODUCTION

Health care is a fundamental necessity of a human being, and it should be available: i) at the right time, ii) at the right place, iii) proper treatment, iv) at an affordable cost. Mobile Health (mHealth) care is an attempt to meet these requirements of health care. The main reasons for its popularity are that it addresses the four (4) essential virtues of a good health care system that are mentioned before. The world population and health care cost are increasing at a tremendous rate. Therefore, in this situation, mHealth care becomes more relevant, and its importance is increased. By anticipating the situation, investments have also been made by the private sector in USA (Whittaker, 2012).

Most of the research in mHealth has been done as case studies (Metelmann & Metelmann, 2017; O'Connor, Heavin, & O'Donoghue, 2015; Vaz, 2017). These case studies investigate a single disease; for example, in (R. Katz, Mesfin, & Barr, 2012; Nasi, Cucciniello, & Guerrazzi, 2015), diabetes and cancer diseases, have been studied. Nursing has been examined in (Kirschner, Kirschner, Seebauer, & Bethke, 2017), surgery in (Witzke & Specht, 2017), quality in (Kastania & Moumtzoglou, 2012) issues, ethics in (Bellina & Nucatola, 2017), nutrition and weight management issues in (Dimitriou et al., 2017; Koumpouros, 2017). Moreover, complete medicine disciplines have not been neglected (Machado, Abelha, Santos, & Portela, 2018; Moumtzoglou, 2016; Pouliakis, Archondakis, Margari, & Karakitsos, 2016; Tamposis, Pouliakis, Fezoulidis, & Karakitsos, 2017).

In some cases, it is entirely possible that a patient is suffering from more than one disease at the same time, and they are inter-related. For example, if a patient has diabetes, then there is a good possibility that he/she also has the heart, eye, and/or kidney problems. In such cases, mHealth care needs new wireless and wearable/implantable (or insert-able) devices to monitor the multiple diseases and transmit the data of the patients who have multiple diseases to the mHealth care system. Some hardware, software and biotech requirements of a future mHealth care system are anticipated and given in the next section. Current challenges to computer scientists and medical professionals are to store and maintain the data transmitted by different heterogeneous sources (including wireless devices), and later to make the stored data useful for the future planning, research and other relevant utilization. To meet these challenges, it is essential to widen the scope of mHealth care so that benefits can reach every patient who lives anywhere, and new data management, analysis tools and techniques are needed. In this paper, an attempt has been made to extend the scope of the existing mHealth care environment, and a new and comprehensive database management system (DBMS) has been suggested for the environment, and it is referred to as the *mHealth care system.* Modeling of the mHealth care system and other requirements are presented in this paper. It is hoped that an utterly developed mHealth care system can increase the use of health care services to remote areas in a better and cost-effective manner. It is further expected that historical data of a mHealth care system can promote the research activities.

Nowadays importance and usefulness of old data especially historical data cannot be denied. A database management system (DBMS) that stores every data and changes to the data with a time dimension is called historical/temporal DBMS (Clifford, 1982; Elmasri & Navathe, 2007; Navathe & Ahmed, 1987). Historical DBMSs do not delete or overwrite the stored data. If objects (data and meta-data) of a mHealth care environment and changes are stored historically, then the data, meta-data, and statistics derived from them can be useful in the future planning of the environment, patient treatment, and doing relevant research. Therefore, keeping in view, the importance of historical data and its usages, the model of the temporal object system (TOS) is used to model mHealth care environment. In the past, the model has been used successfully to model engineering and other application domains (Fotouhi, Shah, Ahmed, & Grosky, 1994; Fotouhi, Shah, & Grosky, 1992a; Shah, Fotouhi, Grosky, Al-Dhelan, & Vashishta, 1993). This model empowers the users of a mHealth care environment/system to store all objects of the system and changes to the objects temporally and uniformly. Later, the objects can be retrieved and manipulated historically and non-historically. The salient feature of the model is that an object and changes to the object both are stored in the same manner, and later a specific change to an object can be identified and retrieved. This feature is helpful in some application domains, even in the mHealth care environment as it is described later.

The remainder of this paper is organized as follows: the basics and the literature survey of mHealth care including its current issues and challenges are given in the next section. Also, a brief survey of the relational database management system and their historical extension, object-oriented database management system, and details of the TOS and its data model are given in this section. The modelling illustration process of a mHealth care environment using the model of TOS is subsequently provided, followed by the future research directions and concluding remarks.

BACKGROUND

This section is devoted to the basics and salient features of the mhealth care, its current issues and challenges. Also, a database management system (DBMS) and its extensions (temporal and object-oriented DBMSs) are described in this section. Later, the temporal object system (TOS) is also described.

Mobile Health Care

Before the introduction of the idea of Mobile health (mHealth) care, information technology (IT) had already been influenced and entered in the field of health care sector as *eHealth care*. However, the recent advances in the wireless computing and mobile devices such as Smartphone, iPad, Tablet etc., have given an additional dimension and power to the eHealth care system and gave birth to the mHealth care environment. Note that in this paper the terms system and environment are used interchangeably. The mHealth care environment can be considered as an up-gradation of an eHealth care environment with support of advanced hardware and software technologies. This (mHealth care) became popular, and now it has grown from an infancy stage to toddler stage. In the USA, the private sector has also invested in this health care environment due to its low-cost feature (Whittaker, 2012). Since both the cost of health care and the world population are increasing at an exponential rate, therefore, in this situation mHealth care becomes more relevant and a right choice.

The methods used by an existing mHealth care system have made convenient for a patient to directly transmit data/information of his/her disease from a remote location to his/her doctor, or to the system of the health care provider. In return, the concerned doctor can transmit to the patient new instructions and/or prescription. In this way, travelling time and cost of the patient can be saved and also the health care cost can be lowered. That is possible mainly in the developed countries like the USA. A recent survey shows that in the developed countries, like the USA, around 80% of medical doctors use mobile devices such as Smartphone, Tablets etc., and between 40- 50% are using tablets (Wicklund, 2012). Even clinicians and clinic technicians like to use tablets to do their essential functions such as patient registration and recording of patient's history and test results. In other words, every group of workers which belongs to health care system likes to use methods/solutions provided by a mHealth care system. Successful adaptation of a mHealth care system in the developed countries is possible due to two significant advantages, and they are: i) availability and affordability of wireless devices, ii) high IT literacy rate. Therefore, a mHealth care system can be made operational at its optimal level in the developed countries.

Patients in the underdeveloped and developing countries are not so lucky because they do not enjoy these two advantages which have been mentioned above. Also, the patients have some other disadvantages of health care in those countries. Some of these disadvantages that pertain to patients of the underdeveloped and developing countries are pointed out in(Gurman, Rubin, & Roess, 2012).Therefore, there is a need to find the ways to spread the benefits of mHealth care to other than the developed countries.

Current Issues and Challenges

As said earlier, mHealth care has grown from an infancy stage to a toddler stage, but still, it has to cover a long way before reaching a mature phase and start giving maximum benefits. To reach this stage, a lot of research efforts and investments are required from both private and government sectors. Both these efforts (research efforts and financial investments) are mainly needed on two fronts, i. e., software, and hardware. On these two fronts, there are significant challenges for software and hardware researchers to bring new software and hardware technologies to meet new and different requirements of a future mHealtth care system. This paper is an effort on the software front to give a new perception of the existing mHealth care, and in this section, some other software and hardware challenges are also identified. It is worth to mention here that the mHealth care system that is being modelled in the next section has some new software and hardware requirements. These requirements are included and given in this section as well as in the future research directions section of the paper.

The issue and challenges to the future mHealth care systems are categorized into two broad categories. This categorization is made based on the two principal components (i.e., software and hardware) of the IT technology. Note that the hardware technology includes bio-technology (bio-tech). There can be a third category of issue and challenges, and they can be faced when mHealth care technology is mapped on the under-developing and developing countries. This third category is an additional, important and complex because the majority of the world population is living in these countries, and they have the diversified and complex types of problems. Due to the space limitation, this category is not considered here. The issue and challenges of the first two categories are listed below. Note that the issue and challenges given below may not be mutually disjoint.

Software Category

An advanced, consolidated and comprehensive information system/DBMS is needed for the mHealth care environment in the future. It should be able to support both types of devices: smart devices (such as smartphone and tablet) and the wearable and implantable (or insert-able bio-devices. These bio-devices are described in the hardware category.

Data protection, (i.e. privacy, security, and trust) are highly required to build the confidence of the users in a mHealth care system:

1. Empowerment of patients and healthcare professionals, and other users of a mHealth care system;
2. Use, classification and categorization of data and information are essential issues in a health care system for its efficient and useful working;
3. Integrating patient systems with a hospital infrastructure. This issue can be resolved through the item (a);
4. Interoperability on all levels/layers of a mHealth care system;
5. Handling of heterogeneity. That is a fundamental requirement of a mHealth care system of the future mentioned in item (a);
6. The design of new architecture and framework for the mHealth care system of the future mentioned in item (a);
7. Development of new data analysis technique and tools;
8. Scalability of the mHealth care system.

Hardware Category

1. Development of smart and straightforward wireless bio-devices/chips (wearable and implantable). The simple wireless bio-device/chip means that can monitor only one disease of a patient. The wearable bio-devices are the devices that can stick to the body of a patient, whereas, the implantable bio-devices are those devices that are an implant in the body of a patient;

2. Development of smart, complex wireless bio-devices/chips (wearable and implantable). A complex wireless bio-device/chip is that device that can monitor more than one disease of a patient simultaneously;
3. Hardware for integrating the smart devices and bio-devices in the health care systems;
4. Development of different types of bio-sensors and bio-transducers for monitoring health-related environments such as an environment where a patient is living;
5. High speed and performance hardware for the proposed advanced health monitoring system (the system mentioned in Software Category (i));
6. Interoperability of the devices that are mentioned above.

Database Management Systems

A software system that provides facilities for storing, retrieving and manipulating of data, is called the database management system (DBMS) (Elmasri & Navathe, 2007). Most of the commercially available DBMSs are the relational DBMSs, and in these systems, data objects (or tuples) are stored in a non-temporal fashion. It means that if the value of attribute changes, then the old data value is replaced by the new data value, and as a result only the latest state of an object is available and retrieved. However, in many database applications such as health care and engineering application domains, it is inappropriate to discard old data and information. In these domains, it is necessary to keep the old data of time for which the data is valid. A time dimension is associated with a database either at attribute level (Clifford, 1982) or the tuple level (Gadia & Yeung, 1991; Ling & Bell, 1990) to keep the history of data. Such a DBMS is referred to as a *temporal database* (Dutta, 1989; Gadia & Yeung, 1991).

Time is modelled as either a time point or a time interval. Both time models are considered equivalent (Dutta, 1989). The value of time associated with a data object is determined by the system or assigned by the user. If a time value is assigned by the system, then it is referred to as a *physical time* such as transaction time, while if a user assigns it, then it is referred to as a *logical time* such as user-defined time (Ling & Bell, 1990).

Relational DBMSs and their temporal extensions are suitable for simple record-based applications, but they are unsuitable for the complex database applications due to their limitations in defining a complex object directly and at one place (Maier, 1986). This inability of relational DBMSs gave birth to the concept of the object-oriented paradigm and later object-oriented DBMSs. Many object-oriented data models and DBMSs have been proposed to support the development of nontraditional and complex applications (Banerjee, Kim, & Kim, 1988; Beech, 1987; Fotouhi et al., 1994; Fotouhi et al., 1992a; Kim, Banerjee, Chou, G.F., & Woelk, 1987). In the object-oriented paradigm, an object is defined by the two parameters: structure and state (Fotouhi et al., 1994). The structure (SR) of an object defines the structural and behavioral capabilities of that object, which is defined by a set of instance-variables, methods and/or rules (or integrity constraints). The state (ST) of an object assigns data values to the instance-variables of the object, and the methods operate on them.

A set of objects sharing the same structure is referred to as a *class*. An object-oriented DBMS is a collection of classes that are organized as a directed acyclic graph (DAG) or a directed graph.

In the existing object-oriented DBMSs, changes to the state of an object are maintained *via* version management (Agrawal, Buroff, Gehani, & Shasha, 1991; Katz, Chang, & Bhateja, 1986). The structural changes are supported in most object-oriented database systems. Such changes to a class are referred to as schema evolution in the literature (Nguyen & Rieu, 1989). There are three (3) types of changes that can occur to a class structure, and they are listed as follows:

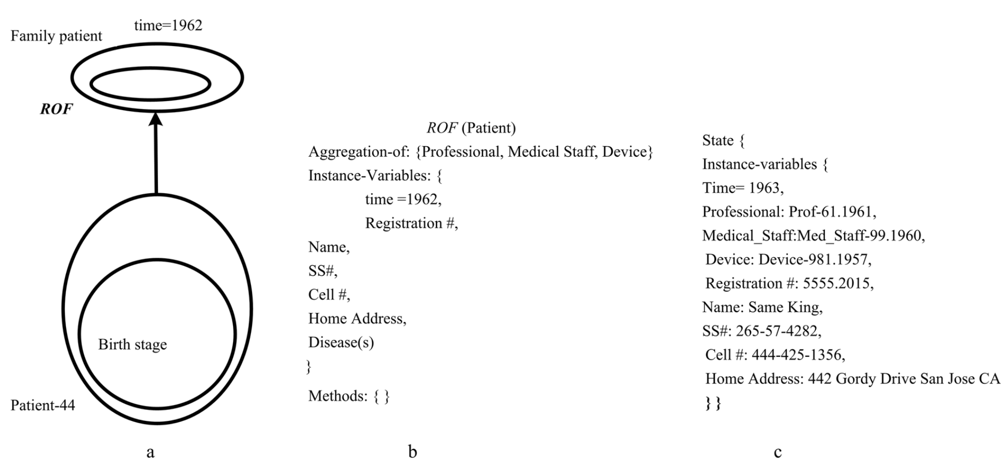
Type I: Addition of new instance-variables and/or methods.
Type II: Deletion of instance-variables and/or methods.
Type III: Changes occur to an instance-variable and/or method.

If Type I changes occur, then there is no loss of data/knowledge in the class because the previous knowledge of the class structure is also retained along with the new one. On the other hand, for Type II and Type III changes, the history of changes in the class structure is not retained because it is overwritten or deleted in the latest version of the class structure. Most of the object-oriented DBMSs keep only the current version of each class structure. After recording any one of Type II or Type III changes, for retrieval of any information/data of a previous version of the class structure, it is necessary to reload the previous version of the database. Note the terms data and information are used interchangeably.

TEMPORAL OBJECT SYSTEM

In the previous section, the temporal object system (TOS) has been described briefly. In this section, the salient features of TOS with more details and its model are described.

Figure 1. (a) Patient family, a TCO and its sub-objects; (b) ROF of patient family; (c) Birth stage of TCO patient-44



As mentioned earlier, the basic elements of TOS are stage, temporal object and family. At the time of the creation of these elements, a time instance is associated with them to keep their history. Note that the elements, that is, stage and family, are at the lowest level and the highest level of abstraction, respectively, and the temporal object is on the middle level. All three types of changes (Type I, Type II, and Type III) that occur to an object are stored, and later on, that specific change can be identified and retrieved. A family is a collection of temporal objects, and a temporal object is further defined as a temporally ordered sequence of stages/prototype (stage is defined later). TOS is a collection of simple and complex families that are created at different time instances.

Stage and Temporal Object

With the passage of time, an object may suffer change to its structure, state or both. By associating a time instance to each change to an object (later it is called as a stage), the history of changes to a temporal object is maintained. Now, we formally define a temporal object (TO) as a temporally ordered sequence of stages that have been created at different time instances. A temporal object is defined as: $TO = <(SRt1, STt1), (SRt2, STt2), \ldots, (SRtn, STtn)>$ where t_i ti_{+1} for all 1 $i < n$, the temporally ordered pair *(SRti, STti*) is the i-th stage of the temporal object which is constructed at the time instance t_i with the structure *SRti* and the state *STti* (Fotouhi et al., 1994; Fotouhi et al., 1992a; Fotouhi, Shah, & Grosky, 1992b).

A stage is maintained in a prototypical form, and a *prototype* can be a structure, a state, or a combination of both (Borning, 1986). For example, if a temporal object suffers a structural change, then a new stage of the temporal object is captured only as a stage of the temporal object. Note that here a time instance is a physical time and modelled as the time point model (Clifford, 1982; Ling & Bell, 1990). A temporal object may also be defined as a temporally ordered sequence/set of stages. The first stage and the last/current stages of a temporal object are significant because they hold the initial and current knowledge of the temporal object. These stages are referred to as the birth stage and the current stage, respectively, of the temporal object. A new stage is appended at the end of the temporally ordered sequence of stages. A stage is created in a temporal object when a change occurs in the temporal object. (See (Fotouhi et al., 1992b; R. H. Katz et al., 1986) for more details).

A new temporal object can also be created from an existing temporal object as its extension, and this temporal object is referred to as an offstage object (Shah, Fotouhi, Grosky, Rana, & Vashishta, 1993). If an offstage is sharing knowledge of only one temporal object that is referred to a participant object, then this is analogous to simple inheritance in the class-based approach, and if an offstage object is sharing knowledge from more than one participant temporal objects, then this is similar to the concept of multiple inheritances in the class-based approach see (Shah, Fotouhi, Grosky, Rana, et al., 1993) for more details. The concept of the offstage object has already been used in the modelling of biological data (Idrees, Khan, & Shah, 2014). If a patient develops another disease during the treatment of the first disease, then this situation can be moulded as an offstage object. It is expected that the concept of the offstage object can increase the modelling power in modelling a health care system especially a mHealth care environment.

Family

A family is an extended concept of the class used in the class-based object modelling technique. It (family) aggregates a group of temporal objects sharing a common context (or common knowledge). All temporal objects in a family can be handled similarly by responding uniformly to a set of messages. A set of structures and/or states define a common knowledge of a family, which is available/known at the creation time of the family, and this common knowledge is referred to as the Root-Of-Family (ROF). It is used by all temporal objects of the family in the future. See (Elmasri & Navathe, 2007; Fotouhi et al., 1992b) for more details). Temporal objects of a family can be defined only after the creation of ROF of the family.

As it has been mentioned earlier, the concept of a family is an extension of a class. However, a family encapsulates more features than a class. For example, in a class, the structure of a class is always shared by all its states (or instances), and a change in its structure affects all its states, subclass structures, and their corresponding states. In a family, however, each temporal object of a family shares only *ROF* of the family at the time instance of its birth. After that, each temporal object is independent, and a change to a particular temporal object does not affect *ROF* or any other object of the family. In other words, *ROF* of a family is read-only; it does not change with the passage of time. Time instances are associated with a temporal object and *ROF*of family at the time instances of their creations.

In TOS, two types of families, simple families and complex families, can be defined (Fotouhi et al., 1992b; Shah, Fotouhi, & Grosky, 1993). A simple family represents an independent object development environment in which temporal objects can be constructed without sharing any knowledge from other families. For example, in Figure 2, the families Med Staff, Professional and Device are simple families. In the class-based object-oriented DBMSs, a complex object is defined as an object that has another object as the value of its particular instance-variable (Kim et al., 1987). Here, a family is a complex family if it has been created by integrating heterogeneous temporal objects belonging to different families. Then the family is referred to as the complex family, and its temporal object is called the temporal complex object (TCO). The components of a TCO are temporal objects of non-homogeneous families (or independent families), and the temporal objects that take part in the construction of a TCO are called sub-objects (or components) of the TCO. For example, in Figure 1a, the Patient family is a complex family, and it has been created by aggregating three (3) TCs of three simple Medical Staff, Professional and Device families (see Figure 1(b)). Note that in Figure 1 and onward figures, double oval, oval, circle, and rectangle represent ROF, temporal object, stage, and family, respectively.

MODELLING HISTORICALLY MHEALTH ENVIRONMENTS

Before starting the proposed modelling process using the model of TOS, the main features of the model are summarized and given as follows:

- Maintains history of an object and all three (3) types of changes to it;
- Both recantation of a family and its objects, and maintenance of changes to the objects are done in the same manner;
- Retrieves and manipulates data historically/temporally and non-historically/temporally uniformly;
- A specific change in a temporal object can be identified and retrieved.

A mHealth care environment, after its development using the model of TOS, is called as the mHealth care system, and the e-system provides the above-mentioned facilities to its users. These facilities and the historical data are valuable, useful and required to the users (i.e., doctors/professionals, administration, health care providers and planners, health insurance companies, researchers, and patients). Historical data of the system is a great asset, and by using it, many valuable statistics can be generated. These statistics can be utilized by the users in treatment for future planning and it can be a valuable data repository for the researchers. This data repository grows with time and becomes a more valuable asset.

To illustrate the modelling historically of a mHealth care environment, four (4) representative entities of the environment are selected, and they are Professional/Doctor, Medical Staff, Device and Patient. Here, an entity is called as a family. The granularity of a time instance is one *year*. There can be more than four families in a mHealth care environment, but for the sake of simplicity only four families are taken, as they contain all important and representative properties of the environment. In this moulding illustration, the family Patient is focused. Since this family (Patient) is a basic family and focal point of every health care environment, therefore, it is taken as a complex family. As mentioned before, in the construction of these complex three simple families, i.e. Professional/Doctor, Medical _Staff, and Device, are used as its sub-objects (see Figure 1 and Figure 2). Figure 1 shows the only birth stage of the TCO, Patient-44, of the Patient family. In Figure 1 and Figure 2, the TCO Patient-44 has been created at the time instance 1963 (denoted by Patient-44.1963) if the temporal condition, i.e. (Patient-44.1963 > Prof-61.1961) and (Patient-44.1963 > Med_Staff-99.1960) and (Patient-44.1963 > Device-961.1957) and (Patient-44.1963 > Patient-Family.1962) were true, where Prof-61.191, Med_Staff-99.1960 and Patient-99.1957 are the time instances when the sub-objects Prof-61, Med_Staff-99, and Device-99 have been created, respectively, and Patient-Family.1962 is the time instance when the family Patient was created. *ROF* of the family Patient has been defined at the time instance 1962 as given in Figure 1 (b).

Within the boundary of a simple family, the offspring technique is used, and the copying technique is used for the knowledge sharing among the families (Borning, 1986). The aggregation and integration of temporal objects into a TCO can generate specific conflicts and compatibility problems such as naming and scaling between a TCO and its sub-objects. For example, the naming conflict occurs when two or more subobjects of a TCO, which contain instance-variables or methods with the same name such as the instance-variable, SS#, which has been defined in the sub-objects belonging to the families Professional and Medical Staff as well as in TCO of the Patient family. This problem can be resolved by adding the family name at the end of the instance-variable name or method name, e. g. SS#.Patient.

SCHEMA OF MHEALTH CARE SYSTEM

Figure 2 shows the model/schema (or logical view) of the mHealth care environment that has been moulded historically using the data model of TOS. The double rectangle represents the root of the TOS (*RTOS*), it is a system object. As said before, the mHealth care system has four families: Professional, Medical Staff, Device and Patient. They are designed at the time instances 1961, 1959, 1956 and 1962, respectively. The families Professional, Medical Staff, and Device are designed as the simple families, while the family Patient is a complex family. This complex family is designed as an aggregation of the other three (3) simple families. In Figure 3, *ROF's* of the three simple families are shown, and *ROF* of the complex family is given in the previous section (see Figure 1(b)).

The temporal object Prof-61 is defined in the simple family Professional (see Figure 4(a) when the temporal condition, i.e. (Professional.1961 Prof-61.1961) was true, where the time instance Professional.1961 was the time instance when the family Professional was defined in the mHealth care system, and the time instance Prof-61.1961 is time instance when the temporal object was defined in the family. Similarly, the temporal objects Med_Staff-99, Device-961 and Patient-44 were defined when the temporal conditions, i.e. (Medical_Staff.1959 < Med_Staff-99.1960), (Device.1956 < -961.1957) and (Patient.1962 < Patient -44.1963) were true, respectively. Note that there can be more than one devices attached and/or with a patient, but for the sake of simplicity only one type of device is considered here with the patient.

Current stages of the temporal objects, Devicr-961 and Patient-44 were created at the time instances 1958 and 1964, respectively, and they were added to the life-sequence of the temporal objects (see Figure 4(c) and Figure 4(d), after the validation of the temporal condition, (S_2,Device-961.1958 > S_1, Device--961.1957) (S_2,Patient-44.1964 > S_1, Patient--44.1963). The stages S_2, Device-961.1958 and S_1, Device-961.1957 are the current stage and previous/birth stage of the temporal object Device-961 (see Figure 4(c), respectively, and the stages S_2, Patient-44.1964 and S_1, Patient-44.1963 are the current stage and previous/birth stage of the temporal object Patient-44 (see Figure 4(d), respectively. In the present/current stage of the temporal object Device-961, the change has occurred to both structure and state of the temporal object, while in the temporal object Patient-44 the change has only occurred in the state (see Figure 4(c) and Figure 4(d).

Figure 2. Schema of mHealth care system

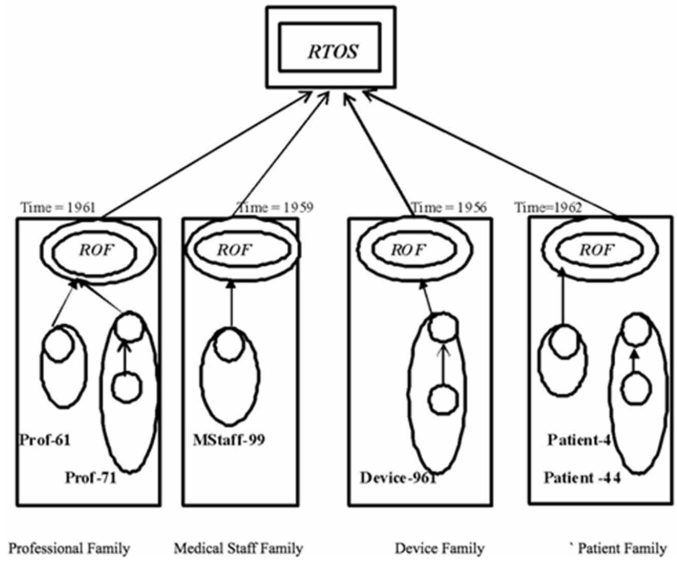
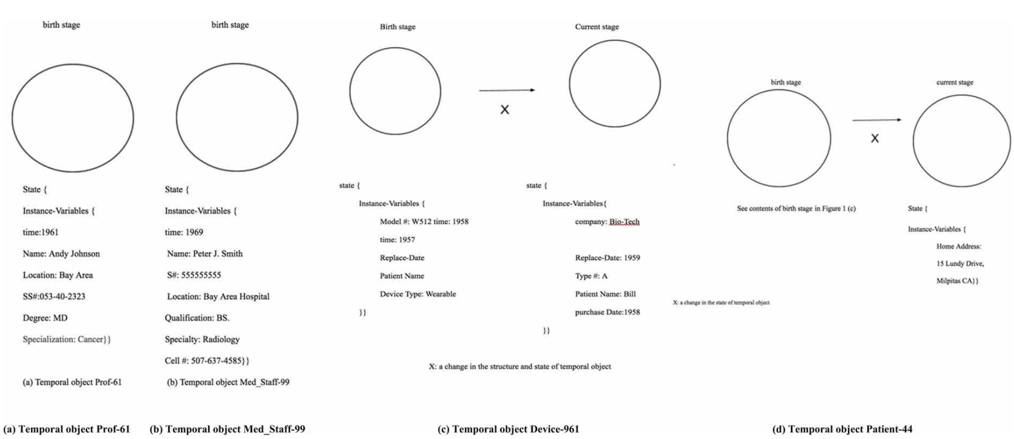


Figure 3. ROF's of professional, medical staff, and device families

ROF (Professional)	*ROF* (Medical Staff)	*ROF* (Device)
Instance- variables	Instance-variables	Instance-variables
{Time: 1961,	{Time: 1959,	{Time: 1956,
Name,	Name,	Device Type,
Location,	SS#,	Model #,
SS #,	Location,	Manu_Comany,
Degree,	Cell #,	Type #,
Specialization}	Qualifications,	Purchase Date,
Methods	Specialty }	}
{Consultancy}	Methods { }	Methods { }

Figure 4. (a) Evolution of Prof-61; (b) Med_Staff-99; (c) Device-961; and (d) Patient-44 temporal objects



The complex family Patient is constructed in the mHealth care system at the time instance *1962* (see Figure 1). The existence of the aggregated families (i e. Professional, Medical Staff and Device) is validated by the system at the construction time of the complex family. Figure 2 shows two temporal complex objects Patient-41 and Patient-44 of the complex family but in Figure 1only birth stage has been shown. The temporal complex object Patient-44 is constructed by using temporal objects (sub-objects) Prof-61, Med_Staff-99 and Device-961.

Later, any new family and/or temporal object (simple or complex) can be constructed similarly in the schema (shown in Figure 2) of the mHealth care system. Also, if any change occurs to an existing temporal object, then it can be incorporated by creating a stage and appending it at the end of lifespan sequence of the object. To perform all these functions, a complete set of operators has already been defined, and they are available in (Shah, Fotouhi, Grosky, & Al-Muhtadi, 2004).

History Object-Oriented Query Language

Many history/temporal query languages are available for history relational DBMSs in the literature (Alashqur, Su, & Lam, 1998; Beech, 1987; Gadia & Yeung, 1991; Navathe & Ahmed, 1987; Tansel, 1991). These languages are usually super-sets of some existing not-history query languages such as SQL, QUEL etc., and they are qualified to answer history and non-historical queries.

The relational DBMSs provide a powerful and variety of history query languages, whereas, the object-oriented history could not provide a real object-oriented query language, so far (Tansel, 1991). Most of the query languages which are proposed for the object-oriented DBMSs are extensions of the already available query languages such as SQL or QUEL (Alashqur et al., 1998; Yu & Osborne, 1991). They are designed for those DBMSs that are using the class-based approach in modelling its objects, and the semantics of class-hierarchy reflect in their query models. These query languages have limited domain since they impose certain restrictions, for example, the Orion database management system restricts its query model to only a single class-single-operand query (Kim, 1989).

To the best of the author's knowledge, the concept of the time dimension is not incorporated in any object-oriented query language. TOS has proposed a history object-oriented query language (HOOL) for the system. The query language is a superset of SQL, and it can answer the historical and non-historical queries on families (both simple and complex families), and uses a set of logical operators {=,,,, , } and a set of historical operators {Before, After, During, Equivalent, Adjacent, Overlap, Follows, Precedes} of SQL and TSQL, respectively (Clifford, 1982). TSQL also adds a new clause WHEN, and this clause evaluates historical predicates by checking relative chronological ordering of time instances of a family. This clause is used, but here it works on families and temporal objects. A parameter time is introduced that is the time instance-variable in *ROF* and each stage of a temporal object. If Time is mentioned as during $[t_1, t_2]$ in a query, then it means that the value of the instance-variable Time lies in the time interval $[t_1, t_2]$. In other words, it is a range query.

The query language has a WHEN clause, if a query contains this clause, then it is a historical query. Otherwise, it is a non-historical query. If a historical query includes the WHEN clause, then its search-space is time-dependent. On the other hand, since a non-historical query does not include any time parameter, therefore, its search-space is complete life-span of the temporal object. In general, we can say that the search-space for a non-historical query is greater than search-space for a historical query.

To demonstrate the retrieval of sample historical and non-historical queries we poise on the schema mHealth care system which has been modelled in the previous section.

Q1: "Find model number and purchased date of devices that are purchased from the company Bio-Tech in 1957." This is an example of a historical query on the family device:

```
SELECT Model #,Purchase Date
FROM Device Family
WHERE Manu_Comany = Bio-Tech
WHEN Time = 1957
```

Q2: "Find all doctors who did MD after 1965". That is an example of a historical query poised on the simple family Professional:

```
SELECT Name, SS#
FROM Professional Family
WHERE Degree = 'MD'
WHEN Time > 1965
```

Q3: "Find the Patients who have wearable devices." That is an example of a non-historical query on the complex family Patient:

```
SELECT Name, SSd#
FROM Patient Family
WHERE Device Type = Wearable
```

Q4: "Find all professionals who are working at Bay area hospital." This is a non-historical query on the simple family Building:

```
SELECT Name, SS#
FROM Professional Family
WHERE Location = 'Bay Area'
```

FUTURE RESEARCH DIRECTIONS

In the development process of a database management system (DBMS), the first step is designing a data model (or simply called model) if the available models are not suitable to use due to different characteristics of the application domain for which the system (DBMS) is being developed. Since the model of a temporal object system (TOS) has been used to model a mHealth care environment, therefore, the next step of the development process is redesign and development of the different modules of DBMS, which are architecture of the system, a set of operators, syntax of HOOL and some other modules, and these modules of TOS have already been designed, and they can be used with slight modifications. Therefore, the next step of the process is to study existing designs of all modules of TOS, and identify and incorporate the necessary modifications in the design of the modules. Then, the next tasks of the process are the implementation/coding and testing of all redesigned and developed modules, and their integration as the system. The first step of the development process has been reported, and the next step of the process is the future work. Another future direction that is closely related to this work is the development of data analysis tools to get useful statistics and results from the huge volume of the data repository. Different types of wireless devices described in Section 2 (Background) are also needed for the proposed mHealth care system. As a final note, new software and hardware technologies are needed to be developed and run the proposed mHealth care system, and serious research and development efforts are needed to achieve these targets.

CONCLUSION

In this paper, a new prescription of a mHealth care environment has been presented by widening its current scope, and the environment has been modelled using the model of TOS. That is the first step of developing a complete DBMS of a mHealth care environment. After the development, the mHealth care system can capture and store all activities and functions of the environment historically. Later, these activities can be identified and retrieved historically and non-historically. After its deployment, the system will have a valuable data repository of huge volume. As said earlier, this data repository will be a significant asset not only for the organization but also for other users, i.e. doctors and other medical professionals, researchers, health care planners, health insurance companies, etc. To get these benefits of the proposed mHealth care system, lot of research and development efforts are needed both in the software and hardware fields, as it has been mentioned in Section 2 and the previous section. In this paper, a mHealth care system of the future has been perceived and its potential and benefits have been described.

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