# An Intelligent Inference Engine using Ontology based Clinical Pathways for Diagnosis and Management of Diabetes

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Abstract: 'Clinical pathways' for Diabetes Management has attracted the attention of researchers in the last decade. Ontologies have been in use to represent knowledge pertaining to clinical pathways and to arrive at critical patient-specific decisions. This paper proposes an ontological framework to represent the diabetes related data. The main contribution of the paper is in developing an inference model that helps a General Practitioner (GP) to arrive at the most appropriate clinical pathway for a patient specific condition. The mobile application developed for this purpose makes it very useful for a medical practitioner in a remote rural location to follow a systematic process to arrive at patient specific decisions, based on the Ontological inferences received from the remote server.



## 1 INTRODUCTION

The whole world and especially developing countries like India are facing an alarming situation with an increasing number of Diabetes patients. India is termed the "Diabetes Capital" of the world and by 2030, nearly 10% of the population will be affected by the disease. The serious situation is compounded by the fact that a sizable population (nearly 52%) is unaware of the existence of high blood sugar levels which can lead to Type-II Diabetes, mainly due to lack of education. Juvenile onset of Diabetes is also on the rise and if it is not diagnosed in the early stages, it can lead to complications in the later stages of life. Diabetes can lead to serious life threatening diseases such as coronary heart disease and stroke. High levels of sugar in the blood accelerate the filtering of blood by the kidneys. The additional work on the filters can result in leaks in the filters and useful proteins are lost in the urine. This results in deterioration of kidney functionality. If left unattended, Diabetes can cause Diabetic Retinopathy which may result in complete loss of sight. In general, almost every part of the body can get affected by the disease.

Clinical Pathways (CP) are structured, multi-disciplinary plans of care designed to support the implementation of clinical guidelines and protocols. They provide detailed guidance for each stage in the management of a patient (treatment, intervention etc.), with a specific condition over a given time period, and include progress and outcome details. For diagnosis, prescription and patient management, clinical pathways provide various alternatives that are derived for a spectrum of patient conditions and it is for the medical expert to decide on a specific pathway for a patient specific condition.

Diabetic Ontology is the knowledge representation pertaining to Diabetes and it helps to develop models for the entities such as patient, hospital, and doctor etc. to interact with the knowledge provider (Ahmed, 2011). Use of an ontology based model enables separation of domain knowledge from operational logic. It is a significant merit of ontological approach over the traditional if-then rule based approach. It not only captures and expresses the structure and semantics of the domain knowledge, but also enables developing software agents which support decision making. There has been a significant interest in developing ontology for clinical pathways in the last decade (Islam, Freytag, and Shankar, 2012; Ahmed, 2011; Lin, 2011; Nimmagadda, Nimmagadda and Dreher, 2011; Chen, and Hadzic, 2010; Chen, Bau, and Huang, 2010; McGarry, Garfield, and Wermter, 2007). Robust models have been built to represent knowledge in the ontological frame work.

An OWL/SWRL enabled ontological model that aids in the development of a software tool to provide patient specific reminders, advise and action items

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with regard to the prevention of diabetic foot has been developed by Chammas et al (Chammas, 2013). The paper uses a reasoning technique using the semantics and ontological matching. Kurozumi, et al (Kurozumi, 2013) present a Fuzzy Mark-up Language (FML) based Japanese Diet Assessment System. The tool helps a patient to manage his healthy diet level making a judicious choice of a range of available food items. Based on pre-defined ontologies including ingredients of food items, the Fuzzy Inference Mechanism suggests the dietary health constitution on a personalized basis for a one-day meal.

The research work proposed by Ahmed (Ahmad, 2011) focuses on developing ontologies in the OWL language with Protégé as the modelling tool. It suggests a Type-2 diabetes framework that uses a three-layer model to develop the self-management framework. Lee, Wang, and Hagras, (Lee, 2010) propose a fuzzy ontology for a personalized diabetic-diet recommendation in their work. The authors apply the Type-2 Fuzzy set based intelligent ontological agent for recommending the right type of Diet-planning for a patient specific condition.

Personalized diabetic care is very essential to suit the specific patient situation. The patient details such as health information, pharmaceutical care, diet care, sports care have been aggregated and diabetic care ontology has been built by Chen, Su, and Chang, (Chen, 2010). For a new patient needing an advice of care, an ontology querying process has been built in to the system in this research.

In their research on ontology based Decision making, Chen, Chi, & Bau, (Chen, 2011) have proposed a robust model to represent the diabetic knowledge and a "Multiple Criteria Decision Making (MCDM)" has been developed to compute the right medication for a patient. The scheme uses entropy to compute the patient data history and is integrated with the knowledge ontology to arrive at the personalized prescriptions. The research carried out by Alhazbi, et al (Alhazbi, 2012) uses ontology to represent food items and their nutritional information. In addition to assisting patients to log their glucose levels over a period of time via a mobile device to a remote server, the application helps patients to manage their food consumption through the ontological knowledge representation.

A very interesting alternative technique of arriving at inferences based on action rules has been proposed by Hajja, et al (Hajja, 2013). The action rules that describe possible state transitions during the operational life cycle of a system with respect to a decision attribute are extracted from the object driven and temporal systems. The support and confidence computed for the system will influence the strength of action rules and the final inference. The technique has been applied to the speech disorder problem in children called "Hyponasality".

A majority of Indian population is rural. This underserved population entirely depends on the services of a General Medical Practitioner (GP).

GPs in rural areas treat patients with varied medical problems including Diabetes, in the absence of specialists. With advances in technology and medical practices, there would be newer methods and techniques in diagnosis, treatment and management of diabetes that the remotely located GP may not be aware of. Also, there are many newly introduced drugs which are to be administered with caution, taking in to account, their side-effects.

This paper focuses on developing an Ontological framework to represent clinical pathways for Diabetes management. The framework encompasses the representation of all possible clinical pathways in terms of classes and objects in an ontology developed using Protégé platform. An intelligent inferencing mechanism has been developed that uses the ontological knowledge to arrive at the optimal clinical pathway for a patient specific condition. A mobile application has been developed and it can be used by a remotely located medical practitioner to guide him on the optimal pathway. The mobile device takes the patient specific conditions as input attributes. It contacts the remotely located server that has all the clinical pathways represented in the ontological framework. The remotely located server uses the inference engine to arrive at the most optimal patient-specific pathway. The remote mobile device with the GP will be able to receive this pathway prescription and will be able to guide the doctor in suitably advising the patient (in terms of diagnosis, treatment, interventions etc.). It is very important to note that the proposed system is not meant to replace a medical expert in any way. This will only aid in making sure that all the known criteria are taken in to consideration, during diagnosis, treatment and management of the disease.

## 2 ONTOLOGICAL FRAMEWORK

The basic principal that governs the proposed scheme is as follows: The Medical practitioner in a remote location provides the primary symptoms and related details of his patient to a mobile device. This part of the functionality that takes effect on the mobile is termed the "Client Side Activity" developed using the Android. The processed queries are passed on to the server which contains all the server side functions in the form of Servlets. The results of the Ontological processing and decision making using the servlets are passed on to the Client. Figure 1 represents the generic model proposed in this research work.

In Figure 1, the overall framework has two main entities: The Client Side Android Activities and the Server Side Ontological Model. The client prepares the patient data as a string and sends it to the server. At the server, the string is converted to RDF triples. These triples in conjunction with the restrictions defined in the OntModel together facilitate the inferencing process.

## 2.1 Server Side Ontological Model

The Open Source Ontology Tool, Protégé is used to represent the various entities of the model. The model consists of Classes and Subclasses and resources represent the attributes of a class. An example for class representation is shown in Figure 2. "Properties" connect two resources. For example, the property 'has' connects the two resources 'patient_id' and 'excessive_thirst' as depicted below:

```
(Patient_id ) has (excessive_thirst)
```

The Class Hierarchy is represented in the 'OWL' file. The OWL file is loaded to the system memory as "OntModel". Thus the OntModel has the entire Class Hierarchy together with the corresponding resources and more importantly, the restrictions accompanying the classes that will later be used in the inference engine. The server side "Servlets" implement the functionality for the inference engine. In the present work, the three types of Servlets considered are 'Symptoms Servlet', 'Conduct Diagnosis Servlet' and 'Detect Type & Complexity Servlet'. These three servlets receive requests from the client and use Jena APIs to act on the Ontologies.

The three activities that get influenced by the Jena APIs are:

- Load Ontology
- Parse Ontology
- Parse the Result of Reasoner

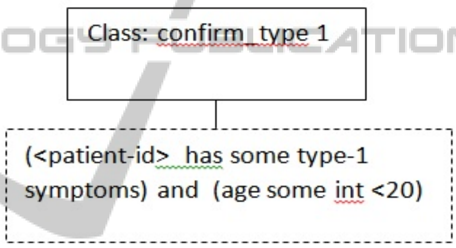


Figure 2: Class and Restrictions.

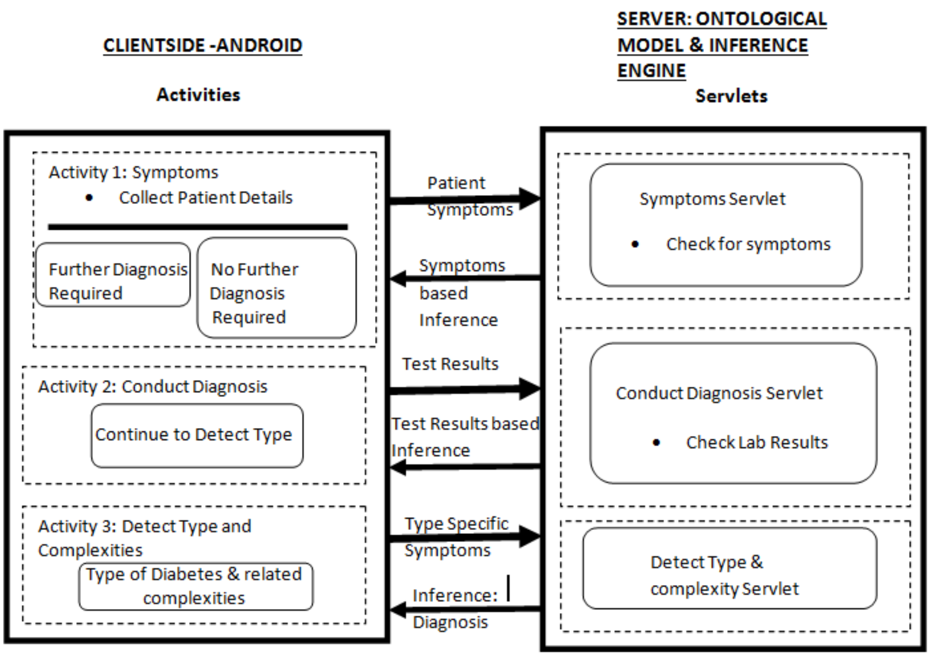


Figure 1: System Model and Framework.

## 2.2 Client Side Activity

When the patient related details are provided at the client side by a mobile device, the data is sent to the server as a string. This string is converted to triples and added to the OntModel. When the server responds with a resolution, the client displays this and initiates further queries for the next level resolution at the server end.

# 3 DESIGN

## 3.1 Class Hierarchy

The ontological representation in its entirety is designed as a set of classes and sub-classes. Each of these classes and subclasses has resources and restrictions that will specifically be used in the inference engine. An example of Class Hierarchy is shown in Figure 3.

In the model developed in this paper, 90 classes have been designed and incorporated in to Protégé.

The complete knowledge representation would need a few hundreds of classes to realistically represent most patient scenarios. This will progressively be addressed in future designs, in consultation with medical experts. In Figure 4, a sample snapshot of one of the possible clinical pathways to diagnose a patient as Type-1 or Type-2 is provided. The level to which the class hierarchy is defined and the inference engine is developed, will determine the number of clinical pathways present in the system developed.

## 3.2 Clinical Pathways

The complete tree structure of the Class Hierarchy together with the class restrictions has been used to represent various possible clinical pathways. Each pathway represents a particular scenario from any one of Diagnosis, Treatment or Management.

## 3.3 Inference Engine

For a patient specific condition, the clinical and other related parameters will be sent from the

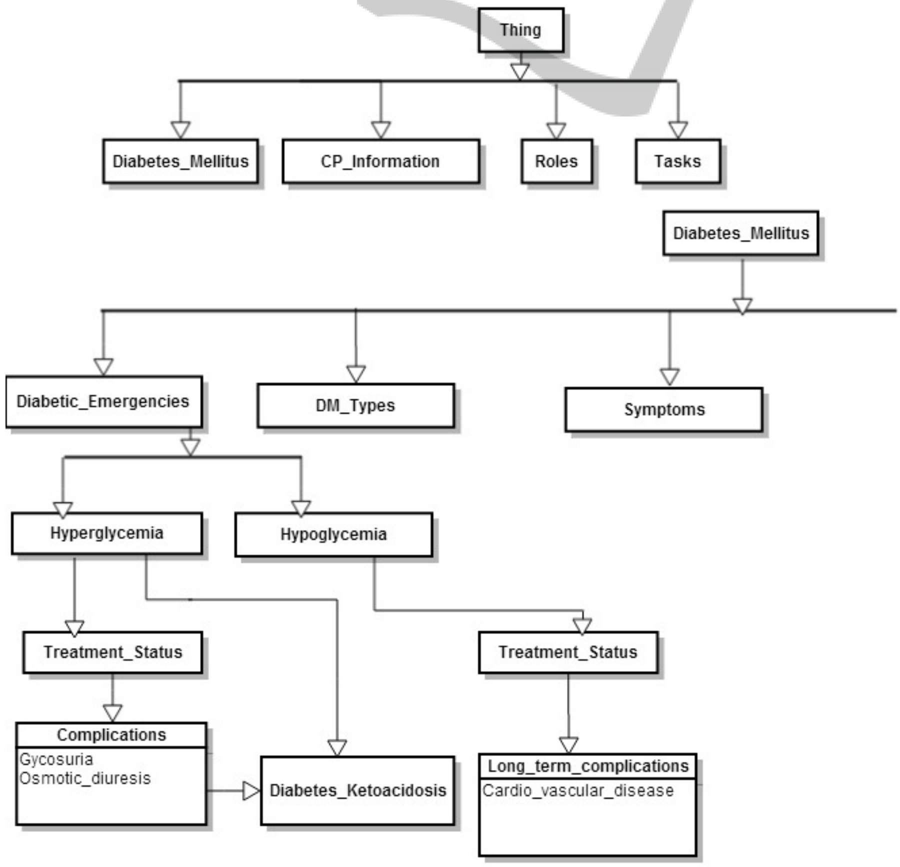


Figure 3: Class Hierarchy.

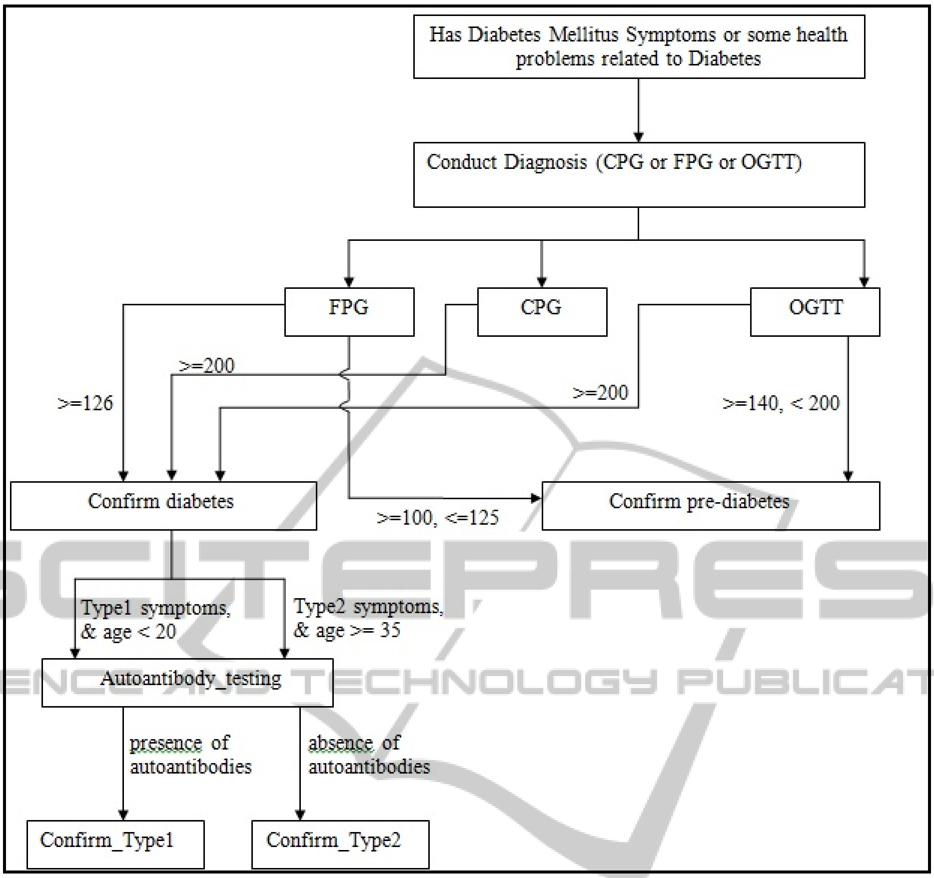


Figure 4: ‘Diagnosis’ Clinical Pathway Scenario.

mobile device to the server. The server performs the inferencing activity via the inference engine and sends out the output. Figure 5 shows the inferencing process. The inferencing process adopts the following steps using Jena APIs: (i) Loads the ontology (from owl file) into an OntModel. (ii) Adds patient data entered by the medico in the form of RDF Triples (iii) The Ontmodel acts as an input to the Pellet Reasoner. The Reasoner generates the Inferred Model (based on classes, properties and more importantly, the restrictions). (iv) The inferred model is parsed using the Jena APIs and the results are sent in the form of strings to the mobile device.

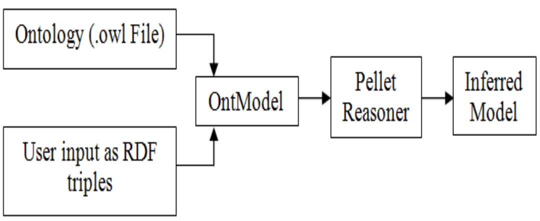


Figure 5: Inferencing Mechanism.

## 4 RESULTS AND DISCUSSION

The generic model brought out in Figure 1 is now applied to two patient specific scenarios at the client end and the results are discussed here.

**Case Study 1: Diabetes Type Detection**

(i) The patient data as indicated in Figure 6 is passed on to the server. The server side program (SymptomsServlet.java) runs the reasoner and gets the inferred results using the restriction:

```
(has some DM_Symptoms) or (has some
Health_problems_related_to_diabetes)
```

This restriction aids the reasoner to infer that the patient has to undergo further clinical tests and this decision is passed on to the client.

(ii) In Figure 6, when “Conduct Diagnosis” is selected, this is passed on to the “Conduct Diagnosis” servlet and with CPG test result value as 221 (Figure 7).

The following restriction on the server side will help to arrive at a decision to detect if the patient is

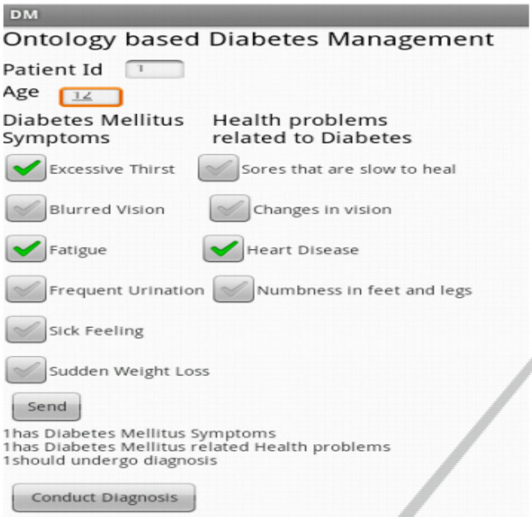


Figure 6: Patient Input Data on the Mobile.

to be classified to have "Diabetes Mellitus" based on Casual Plasma Glucose (CPG), Fasting Plasma Glucose (FPG) and Oral Glucose Tolerance Test (OGTT):

```
(hasCPGValue some int[>= 200]) or
(hasFPGValue some int[>= 126]) or
(hasOGTTValue some int[>= 200])
```

The client module provides further clinical details and the final diagnosis is provided by the servlet as shown in Figure 8, classifying the patent as "Type-1".

The Patient is tested for the presence of Autoantibodies. If Autoantibodies are present, it is confirmed that the patient is Type 1 diabetic. The following restriction helps in this decision.

```
(has some Type1_symptoms) and
(autoantibodies value "present")
```

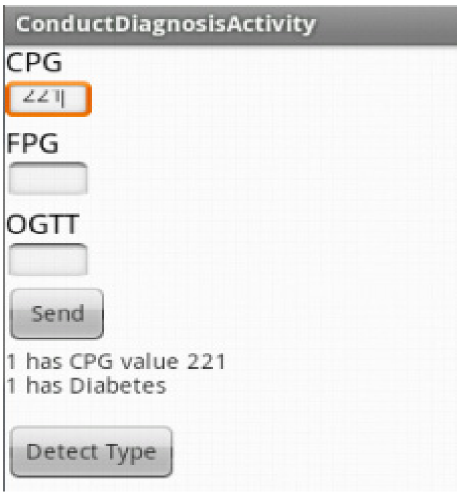


Figure 7: Conduct Diagnosis Activity for Type Diagnosis.

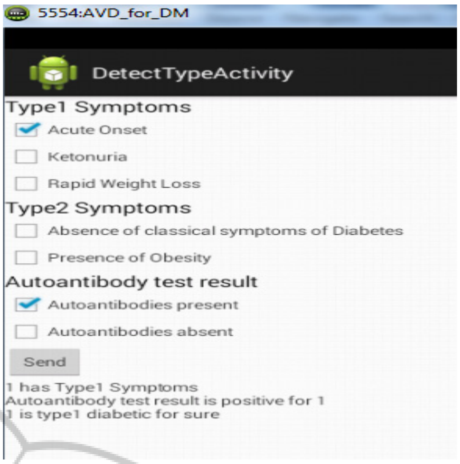


Figure 8: Inference Engine Classifying the Patient as "Type-1".

**Case Study 2: Test for Diabetic Ketoacidosis**

The patient specific data is sent to the server as shown in Figure 9. In this study, since the glucose levels are abnormally high, the "Detect Type & Complexity" servlet uses the Reasoner to infer that the patient is Hyperglycemic.

Once it is confirmed that the patient is Hyperglycemic, severity of Hyperglycemia is decided depending on the treatment history as shown in Figure 10, using the restrictions defined in the ontology.

Figure 10 shows the test for presence of ketones in blood or urine which helps in the diagnosis of Diabetic Ketoacidosis. The following restriction is used:

```
(has some Ketone_Testing)
```

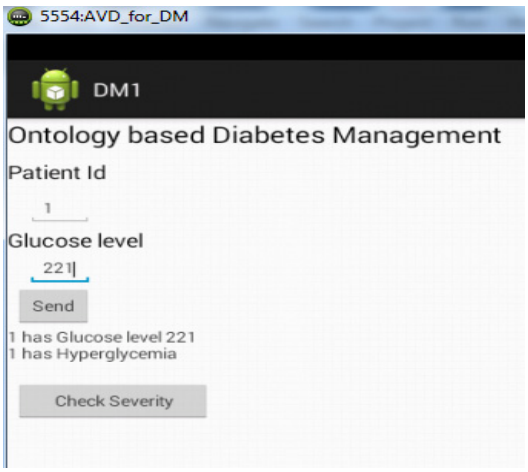


Figure 9: Test for Hyperglycemia.

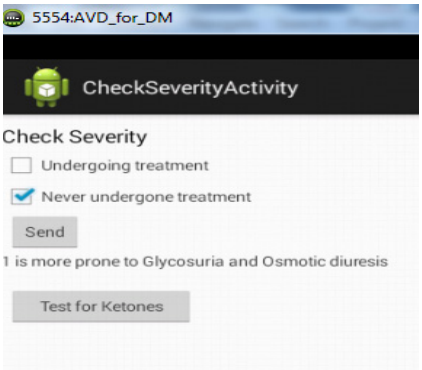


Figure 10: Test for severity of Hyperglycemia.

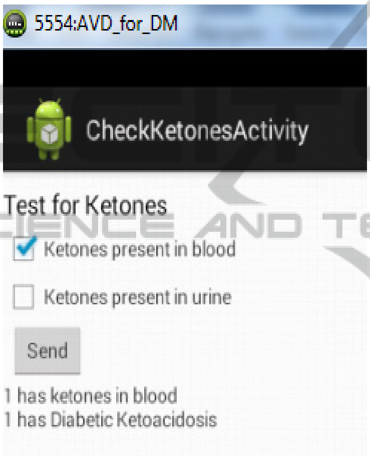


Figure 11: Inference on Diabetic Ketoacidosis.

The Inference engine uses the presence of Ketones in the blood to infer the patient condition as Diabetic Ketoacidosis, as shown in Figure 11.

## 5 CONCLUSIONS

This paper proposes an Ontology based model to represent various possible clinical pathways for differing patient conditions. The classes, properties and restrictions together help the inference model to arrive at appropriate decisions with regard to Diagnosis, Treatment or the Management. The main contribution of the paper is the development of an intelligent inference engine for decision making which can be very useful in remote rural areas where an expert Diabetologist is not easily accessible. The system will be highly useful for General Practitioners to take appropriate reasoning based decisions, taking in to account all the recent developments in diagnosis and treatment methods. The pathways can be further extended to include complications like nephropathy, retinopathy, neuropathy etc. Future works also include providing personalized (patient-specific) management in the form of diet, exercise and drugs (based on parameters like patient's family history, disease history etc). In collaboration with Diabetologists of the institute medical school, the authors propose to add a wide variety of classes to take in to account, the domain experts' decision process. Work is in progress to achieve these goals.

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