# Using FOAF for Interoperable and Privacy Protected Healthcare Information Systems

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**Abstract.** Healthcare information systems needs to share and to reuse the patient's information not only in a department where the information is being formed, but also between the departments of an organization and also among the different organizations. The requirements of health services like providing efficient services and ensuring continuity causes privatization of information. As patient health information is dispersed and specialized, sharing personal health information became more prevalent. A blood test ontology in a clinical information system could help physicians to learn more about the patient's health status. Hence, patients medical history is widely recognized as a good indicator for the patient's treatment plan. In this work, a methodology is proposed to infer the opportunities of using blood test with the help of semantic web knowledge representation. In order to provide a personalized, manageable and privacy protected system, user profiles are fully integrated with blood test ontology and consent management model.

**Keywords:** Medical Knowledge Management, Personalization, Semantic Web, Blood Test Ontology, Consent Management.

## 1 Introduction

Blood as the life fluid, has a major role in the immune system to defense the body against diseases. When a patient consults a physician for any complaint, the physician listens the patient's medical history and requests some medical tests. Among various medical tests, blood test is the first and most important test to analyze the human body. Abnormal results in a blood test might be a sign of a disorder or disease. Many diseases and medical problems couldn't be diagnosed with blood tests alone. However, blood tests help the physician to learn more about the patient's health status and to find potential problems early. In health domain, besides its importance, blood test contains information that might be useful to any clinic. Unfortunately, the same tests are being performed repeatedly when the patient goes to different clinics. This repeat process causes the loss of time for the diagnosis and a rise in the healthcare costs.

Until recently, it was not reasonable to share a patient's data between the departments of the healthcare organizations. In fact, the information obtained from records of a health information system is only the administrative data, such as patient's name, age, insurance information and other personal data. However,

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in recent years, information technologies are focused on using and sharing the clinical data in a higher-level structured form of semantic rich information. Thus, sharing personal health information became more prevalent in distributed healthcare environments.

As patients are the center of medical treatment, user profiles are the center of personalization. Profile gives the demographic properties and history of the patient. Thus, doctors get to know their patients better. Friend of a Friend project (FOAF, `http://www.foaf-project.org/`) is the basic representation of profile in Resource Description Framework (RDF) language (`http://www.w3.org/RDF/`) and most common document to represent the demographical properties of a person. FOAF is widely used inside many different domains to describe personal information. In this work, FOAF is used to describe a patient with demographic and dynamic properties. Moreover, we extend the FOAF description with profile and blood test ontology connections to describe a complete patient profile with full support of different ontological structures. Using FOAF for personal information and integrating FOAF with blood test ontology, provides an interoperable, personalized and more manageable personal data. A personal health care system needs a detailed personal definition. Besides, personal records must be saved accurately. FOAF is the most interoperable data format to describe the patient's personal data. Moreover, it supports extendable, open and sharable data and can be used as the basic description to create a personalized patient system. By using FOAF, the patient can have fully control over her data and the system can give a personalized experience to her during her treatment. However, patient data needs privacy and security. As we extend the FOAF descriptions with blood test ontology, we also connected consent policy to patient's FOAF file to protect patient privacy. Consent management is a policy that allows a patient to determine rights for access control requests to her personal health information. Therefore, FOAF is fully integrated with blood test ontology and consent management to create a personalized, manageable and interoperable system. As a result, the stored personalized blood test result information could be queried and reused. The paper is organized as follows: Section 2 presents the relevant related work. Section 3 explains the proposed model primarily. Later, knowledge representation and development of the blood test ontology is clarified. Also, consent management model for the patient privacy is expressed in this section. The overall architecture of the proposed model is given in Section 4. Finally, Section 5 contributes and outlines the direction of the future work.

## 2 Related Work

Healthcare domain is one of the rare areas that has a huge amount of domain knowledge. Infectious Disease Ontology (IDO) [1,2], Saliva Ontology (SALO) [3] and Blood Ontology (BLO) [4] are ontologies that are described by formal ontology languages. IDO provides a consistent terminology, taxonomy, and logical representation for the domain of infectious diseases [1]. IDO has 185

concepts, but has not any object properties between these concepts and data properties. IDO covers the terms common for all infectious diseases, but diseases themselves are not defined in the ontology. SALO is defined as a consensus-based controlled vocabulary of terms and relations dedicated to the salivaomics domain and to saliva-related diagnostics. SALO is an ongoing exploratory initiative. BLO is designed to serve as a comprehensive infrastructure to allow the exploration of information relevant to scientific research and to human blood manipulation [4]. It is an ongoing project and the ontology is still continued to be developed. BLO describes the structure, diseases and abnormalities of the blood. However, `BloodTest_Ontology` is focused on substances of the blood that are measured to analyze a patient's general state of health.

There are many profile adaptations of patient properties within ontological structures. There are two kinds of patient knowledge: demographic properties of a patient which are not changing over time and dynamic properties such as patient blood test results or treatment plan. In [5] and [6], patient knowledge is dynamic and changing over time. Thus, the patient profile must be updated and managed by administrators over time. Case Profile Ontology [6] is changing and merging with other ontologies that are based on the treatment plan. However, this profile isn't connected to any social status or relationship knowledge bases and there is no description of a manageable user profile or roles, no connection with policies which gives privileges to a patient to control privacy rights over her patient file. A concept profile modeling of general person is presented in [7]. The profile model lacks of the structural development of a user model. Therefore, there will be a problem when the system needs to integrate the patient data with other information systems. Also, the user model ontology neither has any connection to FOAF nor has a meta-modeling structure that gives a manageable and extendable ontological environment. In [8], a multi-layered framework is defined to represent personal profiles. As all of these existing user models don't have an active working online ontology, we couldn't compare any ontological structure with our work at the moment.

The protection of patient information in healthcare system is one of the essential need to provide patient privacy. Consentir [9], Clinical Management of Behavioral Health Services (`http://www.dshs.state.tx.us/cmbhs`), HIPAAT (`http://www.hipaat.com`) and Cassandra [10] are systems for patient consent management and personal health information privacy. Also, [11] focuses on creating and managing of patient consent with the integration of the Composite Privacy Consent Directive Domain Analysis Model of the HL7 and the IHE Basic Patient Privacy Consents profile. The proposed consent management model differs from the relevant works in that we combine access control techniques with personalization based on semantic web technologies and FOAF profiles.

## 3 Combining FOAF with Blood Test Ontology and Consent Policy

In our model, ontologies are centered on patient's FOAF profile. As FOAF is a static description of personal properties, we connected the profile

with the blood test ontology to save the blood test data of the profile. Therefore, this blood test result could be used to diagnose and to treat the possible diseases of a patient. In order to add blood test result; blood type and blood test result should be both described inside the ontology and connected to FOAF. Blood type is already represented inside FOAF (`http://kota.s12.xrea.com/vocab/uranai/`). However, the blood test result that we defined gives more detailed and temporal information about the condition of a patient. In order to represent a blood test inside a FOAF profile, $p$, we are using blood ontology elements to represent results. As a person could have more than one blood test, we described a time stamp for the personal blood test result. `hasBloodTest` property connects the `Person`, $p$, description of FOAF to `BloodTest` description, $a$, of `BloodTest_Ontology`:

$\exists p.hasBloodTest(a)|a \in BloodTest \wedge hasBloodTest \in ObjectProperty$

Our model uses the Meta Object Facility (MOF, `http://www.omg.org/spec/MOF/2.4.1/PDF/` ) description of Ontology Management Group (OMG). MOF is the metadata representation and layering of knowledge representation based on semantic capabilities of elements. It is a Domain Specific Metamodel used to define metamodels. Figure 1 shows the overall structure of our model. At M1 (Model) Level, `BloodTest_Ontology` and FOAF definitions are connected together. `M1` Level stores definitions about blood test result, personal preferences and profiles about these results. Policy and profile ontologies are derived from M2 (Meta Model) Level's Policy and Profile Meta Ontologies. At `M0` (Instance) Level, these definitions are used to create personal FOAF profiles of patients.

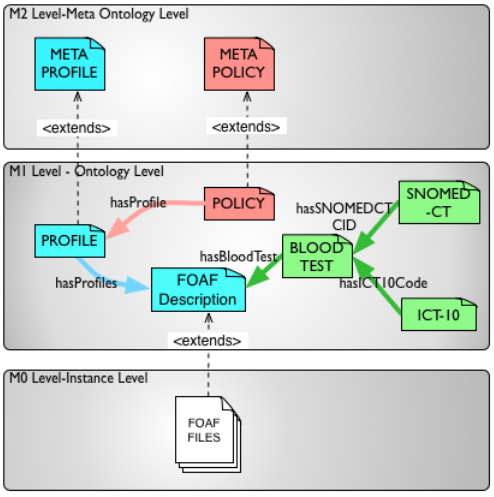


**Fig. 1.** Structure of the proposed model

In our model, ontologies are connected together with object properties. `BloodTest_Ontology` is being connected to FOAF description with `hasBloodTest` property. Profile and consent policy descriptions are being connected together

with `hasProfile` property. Overall ontological descriptions are being connected together inside the patient's FOAF file. As FOAF files are being derived from FOAF descriptions, a patient file has the following properties:

$$\exists Person.hasProfile(p) \wedge Profile(p)$$
$$\exists Profile.hasBloodTest(b) \wedge BloodTest(b)$$
$$\exists Policy.hasProfile(p) \wedge \exists Policy.isOwnerOf(p,b) \wedge Policy.hasConsentPolicy(p)$$

These connections are the central point of our profile management. The knowledge behind the profile, consent policy and blood test ontology are being connected together inside the patient information. This centrality gives an efficiency in twofold: to the doctor to describe a treatment plan for the patient and to the patient to handle with her consent policy description.

### 3.1 Blood Test Ontology

The blood test ontology (`BloodTest_Ontology`) provides information about the blood test results to physicians, health workers and patients. In this work, we aim to represent the recent blood test result status with the `BloodTest_Ontology` and to use it as a part of an information base for the clinical information system. Thus, it could be used to give services to patients and health workers to organize blood information, to support the clinical decision system and to improve the clinical trials. The primary objectives of the `BloodTest_Ontology` are to perform interoperability, information sharing and reusability in the healthcare domain.

A medical test can be any test that is applied to a patient to assess patient's general state of health. In `BloodTest_Ontology`, these tests corresponds to the human body fluids as blood, saliva, stool and urine with the concepts of `BloodTest`, `SalivaTest`, `StoolTest` and `UrineTest`, respectively. In this work, we have focused on the substances of the blood that is measured to analyze a patient's general state of health. The core concepts of a blood test that are defined in `BloodTest_Ontology` like `AST`, `ALT`, `Albumin`, etc. do not exist in the current blood ontologies of the literature. As there are so many blood test concepts, all of these concepts couldn't be explained in this paper. In hospitals, the blood is analyzed in four different laboratories which are endocrinology, biochemistry, microbiology and hematology, in hospitals, respectively. By taking these situations into consideration, we classified the blood test concept into four sub-concepts: `EndocrinologyBloodTest`, `BiochemistryBloodTest`, `MicrobiologyBloodTest` and `HematologyBloodTest`. For example, the blood tests about liver like `AST` and `ALT` are defined as sub-concepts of `BiochemistryBloodTest`, blood tests about thyroid like `FT3` and `FT4` are defined as sub-concepts of `EndocrinologyBloodTest`. As the reference values may vary according to the test laboratory, patients's age or gender, the reference values of the substances, which are test concepts, are not defined as an object or a data property. `BloodTest_Ontology` has $\mathcal{ALCRIF}(\mathcal{D})$ DL (Description Logic) expressivity. The main goal of developing this ontology is using it as an information base for clinical information system. The `BloodTest_Ontology` is still being developed and extended with new concepts, object and data properties.

### 3.2 Patient-Oriented Consent Management

Information sharing has a significant importance in health domain. Patients personal information and medical history provides an essential indicator for the patient's treatment plan. However, patients have the right to know who collects, stores and accesses their data. As different people have different privacy needs, each patient should determine her own privacy level. Therefore, a patient-oriented consent management is used to guarantee patient privacy. European Standards on Confidentiality and Privacy in Healthcare ( `http://www.cpme.eu/european_standards_on_confidentiality_and_privacy_in_healthcare/` ) states that *patient information is confidential and should not be disclosed without adequate justification. The justification for disclosure should normally be consent.* Patient consent policy allows the patient to permit or deny the disclosure of her medical information to particular people.

The proposed model is based on a personal consent management model [12]. The consent management model has the following concepts: `Subject`, `User`, `Role`, `Organization`, `Action`, `Object`, `Quasi-Identifier`, `Constraint`, `Purpose`, `Policy Objects` and `Consent Data Policy`. Details of the related concepts could be found in [12]. In this work, roles of the consent management model is being represented with Friend-Of-A Friend profiles. The following example defines a permission and a prohibition:
*Mary who has a pregnant profile permits her doctor (Bob) to see her blood test results for treatment purpose and prohibits her doctor to publish her blood test results for research purpose.*

$hasProfile(Mary) \equiv Pregnant,\ \ hasProfile(Bob) \equiv Doctor$
$hasDoctor(Mary, Bob),\ \ isOwnerOf(Mary, BloodTest)$
$hasQuasiIdentifier(Mary, (Name, Gender, DateOfBirth, SocialSecurityNumber))$
$hasRequest1(Bob) = (Bob, Mary, Read, BloodTest, Treatment)$
$hasRequest2(Bob) = (Bob, Mary, Publish, BloodTest, Research)$
$CD(Mary) = hasConsentData(Mary, BloodTest)$
$hasConsentPolicy1(Mary) = (Mary, Bob, PermissionDoctor, CD(Mary))$
$hasConsentPolicy2(Mary) = (Mary, Bob, ProhibitionDoctor, CD(Mary))$

The consent policy example has the consent data concept named `CD(Mary)`. Therefore, patients can categorize their records as consent data, control who can access to their health records and for what purposes these data can be used.

## 4 Architecture

A patient treatment system is a complex system. It has to cover medical knowledge fully and should be supported by doctors. A single missing data in a patient information may lead doctors to make wrong suggestions or assumptions while deciding a treatment plan. An efficient system must provide a semantically rich representation for patient's personal, diagnosis, disease and treatment information. Thus, in our work, ontologies are being used to represent fully structured patient information. Patient treatment system have a multi-layered

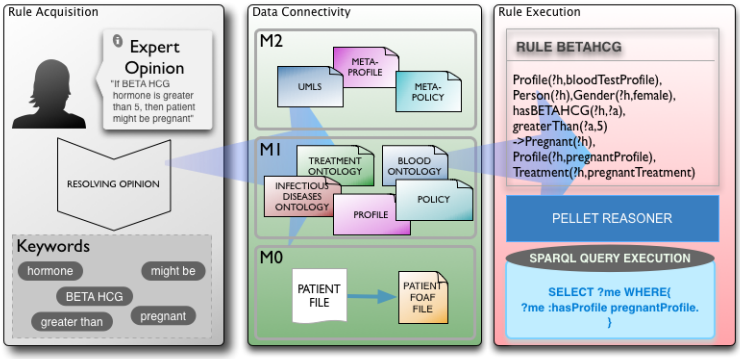


**Fig. 2.** Architecture of the proposed model

ontological structure at the core of our proposed system. In addition to ontological representations, the patient information and doctor's domain knowledge have to be represented in the system. The proposed patient treatment system seen in Figure 2 consists of three parts: a domain knowledge decomposition (rule acquisition pillar), a knowledge representation (data connectivity pillar) and a knowledge reasoning (rule execution pillar). Inside rule acquisition pillar, we take the expert opinions to construct basic rules about the blood test. For example; *If BETA HCG hormone is greater than five, the patient might be pregnant* sentence represents the domain knowledge of a doctor. First, we resolve this opinion into keywords such as `hormone`, `might be`, `BETA HCG`, `greater than` and `pregnant`. In the data connectivity pillar, these keywords need to be matched with the right ontological elements to create a rule about this opinion. Thus, we created a three layered knowledge representation of semantic structures to create blood test result and connected diseases with the user profile and personalized consent policies. In the rule execution pillar, rules are being created, stored and executed. In order to execute a complex rule and to infer new knowledge, we are using DL-based PELLET reasoner (`http://clarkparsia.com/pellet/`). These new discovered pieces of knowledge could cover the missing part of the doctor's opinions and could support the doctor sufficiently in her treatment plan decision.

## 5 Conclusion and Future Work

In this work, we have created the base of a personalized treatment system. In order to support the interoperability and information exchange, we will insert the ICD-10 codes and SNOMED-CT ConceptID inside the `BloodTest_Ontology`. Thus, when there will be an another information system using SNOMED-CT vocabulary, that system could exchange health information with a clinic information system which is using `BloodTest_Ontology` as the information base. Although blood tests are not sufficient to diagnose diseases, some blood tests named markers can show certain diagnose results. For example, if a patient's

HIV blood test result is positive, then the patient could certainly be diagnosed as AIDS. In order to make such decisions, infectious disease ontology is needed. As a future work, we will add a disease ontology to our model. Thus, we will integrate IDO to work with `BloodTest_Ontology`. However, if IDO's descriptions for the diseases do not meet our semantical requirements (our primary researches show that IDO has no concepts like `AIDS`, `Hepatitis`, `Mumps`, etc.), our work would expand to describe the infectious disease to overcome the shortcomings. Also, we will integrate the infectious disease ontology with FOAF to create personal treatment plans for patients. Therefore, we will integrate the treatment ontology [6] within our model. This integration will provide to define interfaces for experts to collect expert opinions, interfaces for doctors to select a possible treatment plan or to create new treatment plan using the diagnoses and interfaces to patients to inspect how their treatment plan is going and how they can manage their personal data.

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