MASTER THESIS

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering at the University of Applied Sciences Technikum Wien
Degree Program Bio-Medical Engineering

Development of an Interoperable Exchange, Aggregation and Analysis Platform for Health and Environmental Data

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Vienna, 2017

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Kurzfassung

Interoperabilität zwischen Systemen im Gesundheitswesen herzustellen, ist zurzeit für Gesundheitsbehörden, vorallem durch kontinuierlich wachsendener Nachfrage nach Telemonitoring-Systemen, eine große Herausforderung. Es existiert eine Vielzahl von Daten die als wertvolle Quelle versteckter Informationen dienen können, z.B. umKorrelationsmuster zwischen öffentlichen Datensets und medizinischen Daten von Patientenfinden.

Diese Arbeit ist Teil eines Projekts, mit dem Ziel, ein System herzustellen, das Gesundheitsakten eines Patienten verwaltet und analysiert, unter Miteinbeziehung hochgradiger Interoperabilität der unterschiedlichen Systemkomponenten und der anzuwenden Normen.

Health Level 7 (HL7) Fast Healthcare Interoperability Resources (FHIR) und PHP YII Framework bilden die Basis für ein interoperables System, das in einer genormten Weise alle einkommenden Daten eines Telemonitoring-Systems im HAPIFHIR oder FHIRBASE Server aufzeichnet und verwaltet, sowie Pollen-Messwerte verschiedener Orte in Wien in FHIR speichert.

Die Analyse von Pollenkonzentration in der Luft in Kombination mit Blutdruckwerten von Teilnehmern, durch Korrelationsfunktionen ermöglicht es Zusammenhänge zu berechnen und zu erkennen.

Das System wurde im medizinischen Verwaltungsbereich bewertet. Es erlaubt unterschiedliche Operationen auf FHIR Ressourcen, wie z.B. das Erstellen oder das Lesen. Ebenso kann festgestellt werden, ob eine erhöhte Pollenkonzentration bei Teilnehmern eine allergische Reaktion und dadurch einen Anstieg des Blutdrucks verursacht.

Die Ergebnisse sind vielversprechend. Der Einsatz des Systems als Kern eines gesamten Analysesystems, das verschiedenste Arten von Big Data, wie Transport-, Verkehrs- und Wetterdaten, verwendet ist in Erwägung gezogen worden. Zusätzlich ist es möglich andere FHIR Ressourcen die administrative und finanzielle Aspekte abdecken miteinzubinden.

Schlagwörter: FHIR, Interoperabilität, FHIRBASE, HAPIFHIR

Abstract

Achieving interoperability between health care systems is one of the big current challenges, especially with the continuous increase of demand on tele-monitoring systems. Furthermore, there is a huge amount of different environmental data, that is being recorded and can be considered a valuable source of hidden information needed to be extracted to conclude correlation patterns between datasets and participants records.

This thesis is part of a project that aims to create a system to manage and analyze patients' health records. A system based on a high level of interoperability between the different system's components, by applying current health interoperability standards.

The Health Level 7 (HL7) Fast Healthcare Interoperability Resources (FHIR) standard and the PHP YII framework were used as a base to build an interoperable system that stores and manages all data coming from the tele-monitoring systems (such as blood pressure measurements) in a standardized form in the HAPIFHIR or FHIRBASE server, which in turn retrieves pollen records from various places in Vienna and stores them in FHIR form. After that, using analyzing correlation functions, the correlation coefficient was calculated between pollen records concentration in the air and blood pressure values of the participants.

The system was evaluated in the field of managing medical records, allowing many operations on the FHIR resources, such as creating and reading. The system also detected that, when the pollen concentration increased in the air, it caused an allergic reaction in some people, which lead to an increase in the participant's blood pressure.

The results were encouraging, and consideration of deploying the system as a core of a full analysis system to analyze various kinds of big data such as transportation, traffic, and weather has been made.

In addition, it is extendable to include other FHIR resources, which allow for covering aspects like administration and finance along with healthcare.

Keywords: FHIR, Interoperability, FHIRBASE, HAPIFHIR

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1 Introduction

Interoperability between health care systems is a vital aspect that developers must consider. Several health care standards have been developed to make medical data exchanging more stable and effective [1]. New health care telemonitoring systems are based on these standards. Telemonitoring systems provide telehealth services for various chronic diseases like diabetes, heart failure and others. In Austria, between 250,000 and 300,000 people are effected by heart failure, so using telehealth services could provide additional support and improve their health situation [2].

This thesis is part of the "Interoperable Exchange, Aggregation and Analysis Platform for Health and Environmental Data" project. As part of this project, an exchange and analysis platform was developed to receive, store and manage patient's records in standardized form. In addition to telemonitoring data, pollen records are retrieved from a web service offered by the Medical University of Vienna. The analyzing platform was used to search for possible relations between patient records (e.g. blood pressure) and pollen records.

1.1 General Project Structure

In figure 1, the three main parts of the project are depicted, namely "Vital signs acquisition and sending ", the "Aggregation server and analysis platform" and the "Big data retrieval ". These parts are now described in more detail. This thesis will focus on the server side with the analyzing platform and the big data retrieval.

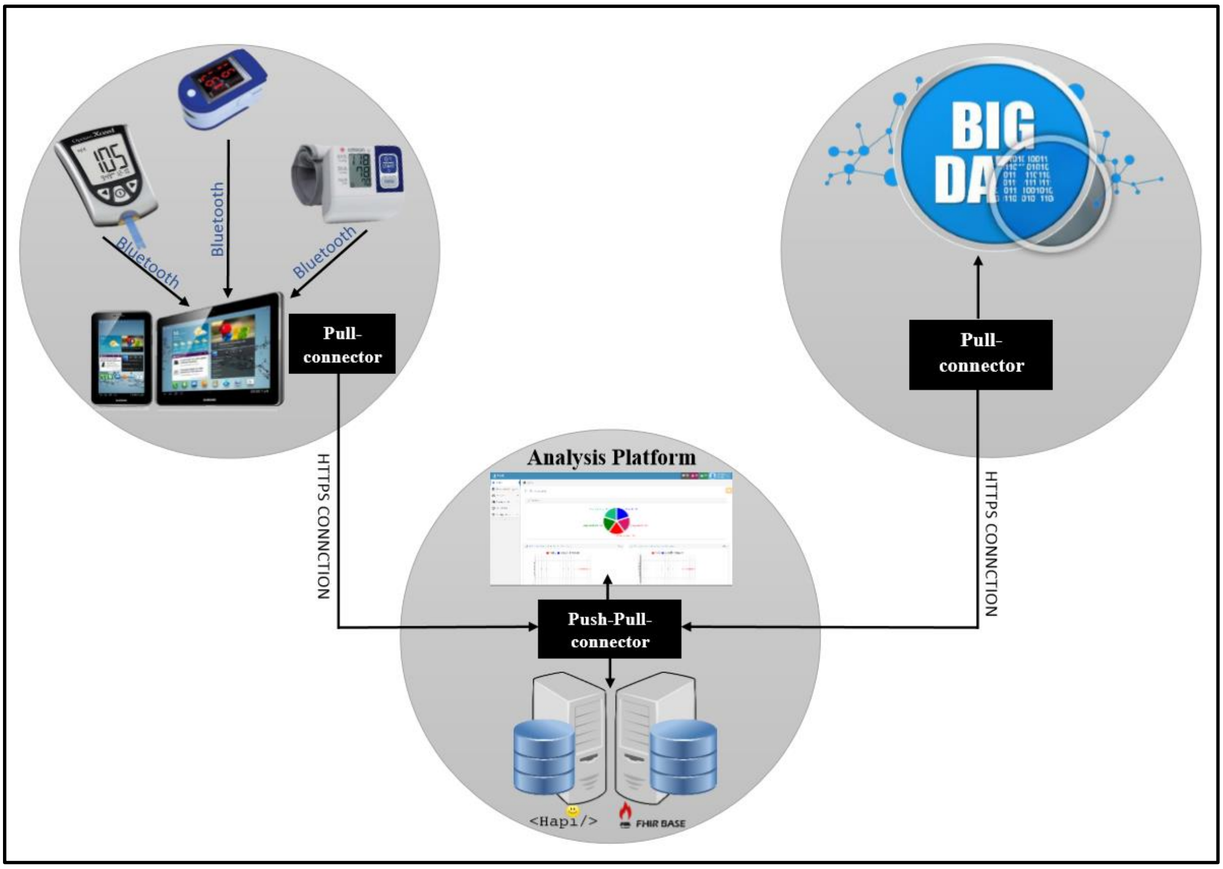


Figure 1: The general structure for all system

1.1.1 Vital Signs Acquisition and Sending

As the starting point, this stage is used to collect data from participant and make the required transmission and conversion process to supply the second stage with proper data.
This stage covers two principal tasks:

1.1.1.1 Vital Data Acquisition:

Different monitoring devices were operated to acquire various vital signs from participants. These measurements are then transmitted to a smart mobile or tablet devices.
A variety of personal health devices have been developed in recent years to monitor chronic diseases.
The personal health devices used during this stage supported Bluetooth low energy as a prerequisite, to take advantages of the Bluetooth low energy ready-made medical/health care profiles that support applications to communicate and interact with the monitoring devices [3]. The following profiles were considered as data sources for vital signs measurements:

- Blood Pressure Profile (BLP) — which is used in this project. This profile enables a device to connect and interact with a Blood Pressure Sensor device for use in consumer and professional health care applications [4]

- Health Thermometer Profile (HTP) — for medical temperature measurement devices
- Glucose Profile (GLP)— for blood glucose monitors
- Continuous Glucose Monitor Profile (CGMP)
- Body Composition Service (BCS)
- Cycling Speed and Cadence Profile (CSCP)— for sensors attached to a bicycle or exercise bike to measure cadence and wheel speed
- Cycling Power Profile (CPP)
- Heart Rate Profile (HRP) — for devices that measure heart rate
- Location and Navigation Profile (LNP)
- Running Speed and Cadence Profile (RSCP)
- Weight Scale Profile (WSP)
- Internet Protocol Support Profile (IPSP)
- Environmental Sensing Profile (ESP)
- User Data Service (UDS)
- Proximity Profile (PXP)
- Alerts and Time Profiles
- Battery Profile

In addition to the specified profiles, Bluetooth low energy also provides many critical features for medical devices such as data protection, privacy and power consumption.

In the initial stage of the project, a wireless upper arm blood pressure monitor device was used to collect sample data, the “boso medicus system” [5], manufactured by the German manufacturer Bosch & Sohn GmbH (short Boso) was used.

1.1.1.2 Vital Data Transmission:

After acquiring vital data from participant, the monitor device sends the data via Bluetooth to a smart mobile or tablet device.

A special software was developed to receive data from personal health devices via Bluetooth, process the messages to extract targeted data from Bluetooth low energy messages, and map the vital data to Fast Healthcare Interoperability Resources (FHIR) resources [6].

The developed Android mobile app provides a user-friendly interface to facilitate the pairing and communication between the mobile device, the personal health device and the aggregation server programming interface. The development of the Android mobile app was not part of this thesis.

1.1.2 Aggregation Server and Analysis Platform

The main focus of this thesis is to provide the capacity to retrieve and send data to external peripherals using standardized communication, and showing the results of analytical processing in suitable forms and graphs (Analysis platform).

1.1.2.1 Aggregation Server:

The main aim of this task is to provide a secure, extensible, and interoperable storage reservoir for well-structured data. Standardized communication should be used to exchange data with external sites.

To achieve these aims, the new HL7 standard FHIR (i.e. currently available as standard for trial use, in this thesis the draft standard for trial use was used) was chosen for data communication. Based on a database system, a new interface software and management system was developed. This developed system permits a wide range of basic and advanced management actions such as creation, editing, removing of FHIR resources and viewing a browsing history. Furthermore, the ability to configure database parameters and the switching between different profiles is included.

1.1.2.2 Analysis Platform

The Analysis platform offers the ability to analyze the data stored in the aggregation server. It is responsible for extraction of the final desired results from vital signs data and pollen data in the aggregation server.

Special interfaces have been developed to show the correlation patterns between different user-selected datasets and to carry out analytical mathematical processes. To show clear appropriate graphically results, different types of charts were utilized.

1.1.3 Big Data Retrieval

Using an application programming interface (API) from the Medical University of Vienna, the exposure concentration values of pollen of different fine particles in Vienna’s ambient air were retrieved [7].

This API provided the exposure concentration for ten pollen types in semi-real time, and can deliver data based on different times and locations. This provides a variety of inputs for the analytical platform to analyze.

1.1.4 Sample Workflow in the Project

1. Using the developed mobile application, the patient will create a profile and connect the monitoring device to the App. The App will retrieve the measurements from the device and store it as FHIR observation resource linked to the patient resource.
2. By RESTFULL API services, the App will send the resources to the platform and it will receive a confirmation that data was received successfully.
3. In the platform, the resources will store in the FHIR format.
4. The patients can login to the platform and see their records, without ability to change anything.
5. The platform retrieves the environmental data using an existing API and stores the data in FHIR resources using so called extensions.
6. Administrators can login and see all events in the platform and can start an analysis process to detect correlations between observation records and environmental data. All results can be viewed as graphs. Admins can create, read, update and delete all FHIR resources (patient, organization, diagnostic, observation and practitioners resource).
7. Admins can switch between different FHIR storage solutions for evaluation purposes (HAPIFHIR and FHIRBASE).

1.2 Goals of This Thesis

The thesis aims to achieve the following goals:

- Finding solutions to enable interoperability, information security, patient privacy and to dealing with Big data challenges
- Developing a telemonitoring system, that will include data from mobile application and personal health devices
- Developing an analysis and exchange platform, that includes a server and analyzing tools
- Retrieve data and store it in the exchange platform using big data connector

1.3 Challenges

This project faced some challenges, for which solutions were searched.

1.3.1 The Interoperability Challenge

Medical facilities should exchange medical data between each other to improve the provided health care services [8] and enable continuity of care.

If a medical facility has its own independent medical information system for each of its departments, it will face an interoperability problem. The medical facility will have to store all medical data for each department in the center server. To prevent an interoperability problem, the server must store the data in a standardizing form to make data retrieving and analyzing easier and faster [8].

Medical data of a patient stored in a standardizing form can be retrieved much easier when a patient encounters medical problems when traveling from one country to another.

1.3.2 The Long Hospital Stay Challenge

Hospitals are usually places where people can gain back their health. On the other hand, nobody wants to spend longer time at these healthcare facilities if it is not needed, because people feel more comfortable at their own home. The risk of severe infections in hospitals should be also mentioned. Furthermore, it is more economical to discharge treated patients as early as possible, [9] so this is also one interest of insurance companies. However, the risk of re-hospitalization must be as minimal as possible.

A solution could be to use a monitoring system at home. There are several kinds of mobile healthcare devices, that can be used at home without professional control (also called Personal Health Devices (PHDs)). A software is needed to ensure a reliable, standard-based data transmission between PHDs and mobile phones and the transmission to the server of a telemedicine center in a relevant hospital [10].

1.3.3 The Information Security Challenge

Information security is an important aspect that must be considered when dealing with medical information. Medical information is considered highly sensitive information [11]. Since the cyber world is an unsafe environment for information, and because there is a big risk of being hacked or having information stolen, it is vital to find a solution to this problem.

1.3.4 The Patient Privacy Challenge

Every patient has the right to check and review their medical information, and to find out if anyone has seen it. Additionally, patients have the right to determine who is and isn’t allowed to review their information [11].

This project will provide a platform in which the patient will be able to read, review the information and give authorization to others.

1.3.5 The Big Data Challenge

There are several data sources in different domains, like health, environment and social networks that contain valuable information. Those huge amounts of data (Big Data) are expected to contain hidden values only visible by combining the data from different domains. This could lead to the cure or improved treatments and care of diseases [12].

This project has an analysis platform that will be able to compare different information sources with the medical information to find the relationship between them and how they effect each other. Through this platform, it will be possible to do statistical studies for specific diseases and to predict the behavior of the diseases.

1.4 Available Tools and Technologies

To solve and face these challenges, and to achieve the stated goals, it was necessary to search for the available tools to fulfill these requirements.

1.4.1 Health Level 7 (HL7)

The HL7 standards are an internationally wide spread solution and try to solve the compatibility problems. HL7 started 30 years ago, and it developed some of the most widely used standards with HL7 version 2 and HL7 version 3. Currently, HL7 Fast Healthcare Interoperability Resources (FHIR) is in development (see figure 2 [13]), FHIR is one of the available solutions to solve the Interoperability problems, because its features and advantages [14].

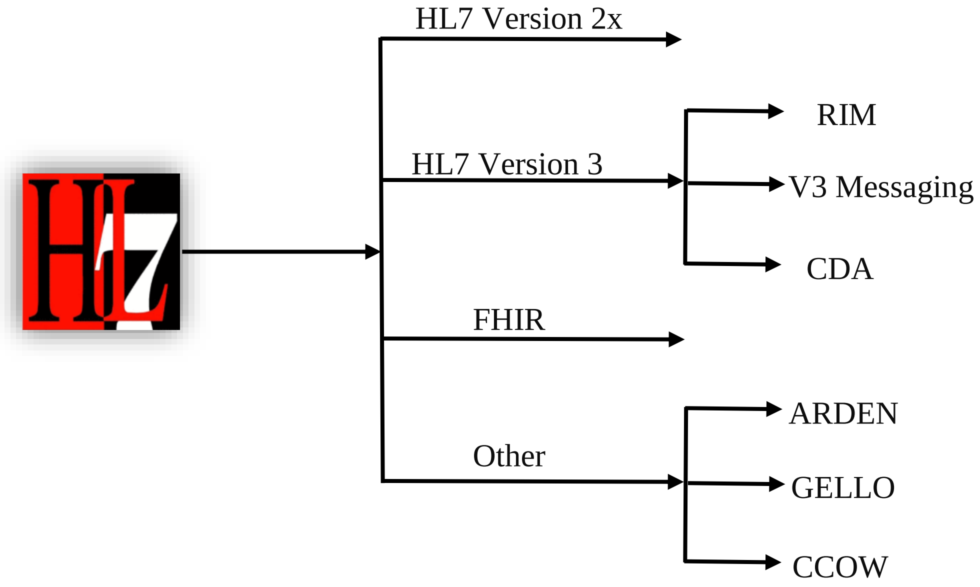
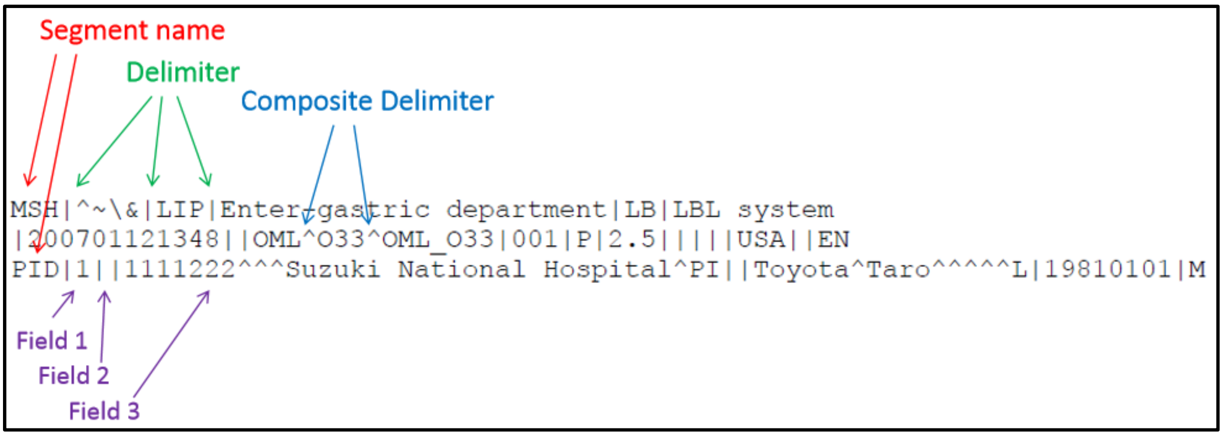


Figure 2: Overview of the various standards developed by HL7 [13]

HL7 and its members provide a framework (and related standards) for the exchange, integration, sharing, and retrieval of electronic health information. These standards define how information is packaged and transmitted from one party to another, and they set the language, structure, and data types required for seamless integration between systems. HL7 standards support clinical practice; the management, delivery, and evaluation of health services; and are recognized as the most commonly used in the world [15].

As mentioned before, HL7 developed various standards that differ from each other in the field they are applied and in terms of the messages structure. For example, in the HL7 v2.x, the messages consist of the segments as it is shown in figure 3 [13].



```
MSH|^~\&|LIP|Enter-gastric department|LB|LBL system
|200701121348||OML^O33^OML_O33|001|P|2.5||||USA||EN
PID|1||1111222^^^Suzuki National Hospital^PI||Toyota^Taro^^^^^L|19810101|M
```

Figure 3: An example for HL7 version 2.x message [13]

In HL7 version 3, HL7 started to use a reference information model (RIM) that is the cornerstone of the HL7 Version 3 development process. An object model created as part of the HL7 version 3 methodology, the RIM is a large pictorial representation of the HL7 clinical data (domains) and identifies the life cycle that a message or groups of related messages will carry (See figure 4). It is a shared model between all domains and, as such, is the model from which all domains create their messages [13].

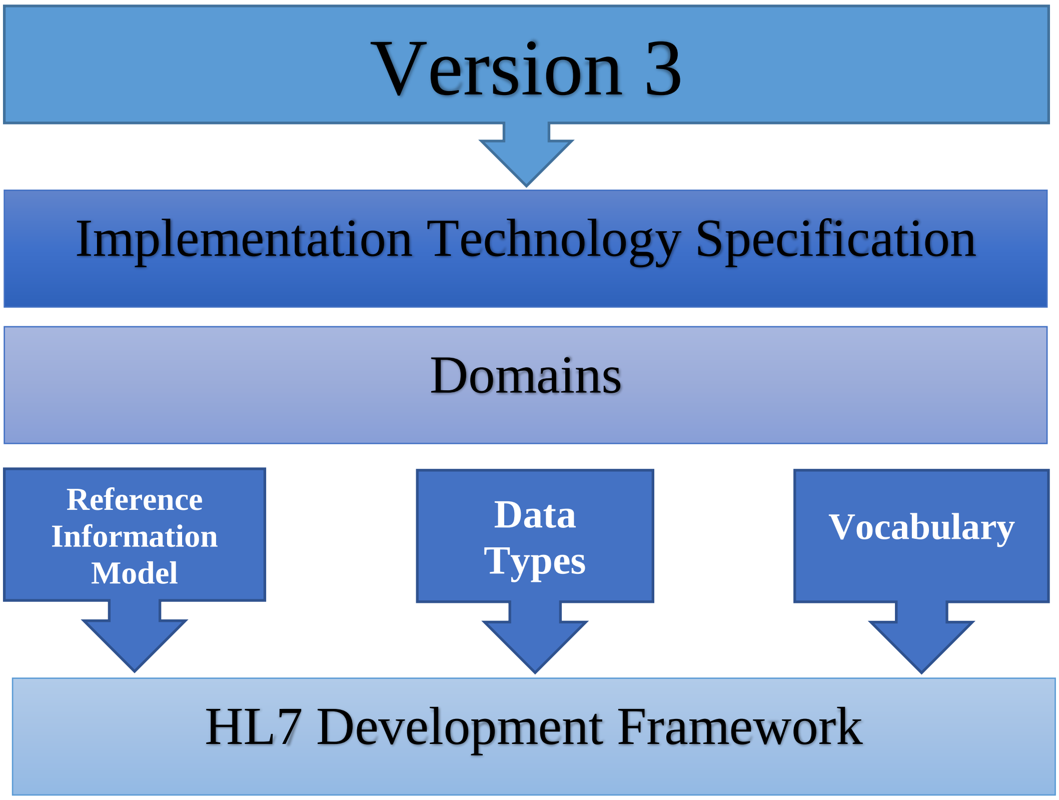

Version 3
Implementation Technology Specification
Domains
Reference Information Model
Data Types
Vocabulary
HL7 Development Framework

Figure 4: Overview of the HL7 version 3 building blocks [13]

1.4.2 Clinical Document Architecture (CDA) Document

The Clinical Document Architecture (CDA) is part of the HL7 version 3 standards. The CDA is a document markup standard for the structure and semantics of an exchanged "clinical document" [16].

CDA has the following characteristics [17]:

- Persistence: the documents exist for a defined period
- Stewardship: maintenance by an organization
- Potential for authentication: clinical documents are “signed” by people not organization, also has electronic signature
- Context: provides additional information beside the clinical information
- Wholeness: complete set of information showing the medical status at a certain point in time
- Human readability

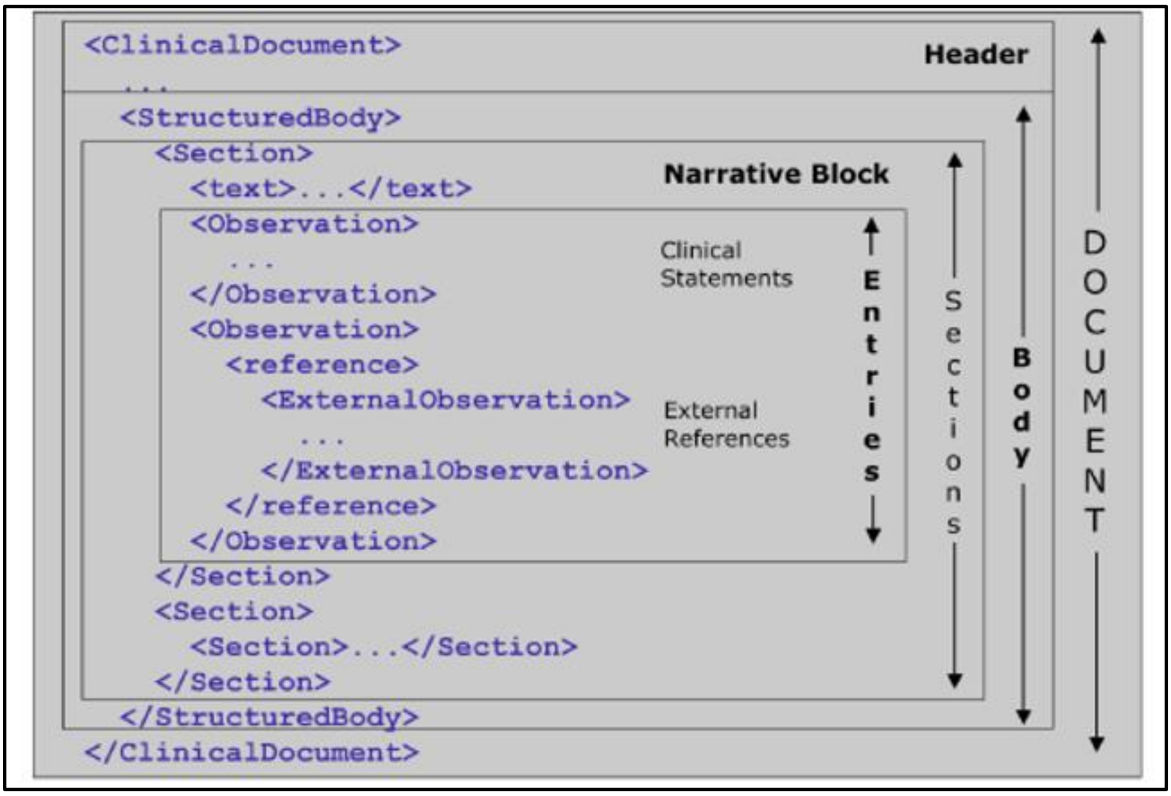
CDA documents can include text, images, sounds, and other multimedia content.

Key aspects of the CDA are:

- CDA documents are encoded in Extensible Markup Language (XML), this gives an advantage to the CDA in the exchanging aspect [17]

- CDA documents derive their meaning from the HL7 Reference Information Model (RIM) and use the HL7 Version 3 Data Types [17]
- The CDA specification is richly expressive and flexible

The major components of a CDA Document are the CDA header and the CDA body.
A CDA document is wrapped by the <ClinicalDocument>element, and contains a header and a body. The header lies between a <ClinicalDocument> and the <StructuredBody> elements, and identifies and classifies the document and provides information on authentication, the encounter, the patient, and the involved providers. The body contains the clinical report, and can be either an unstructured blob, or can be comprised of structured markup as shown in the figure 5 below [17] [13].

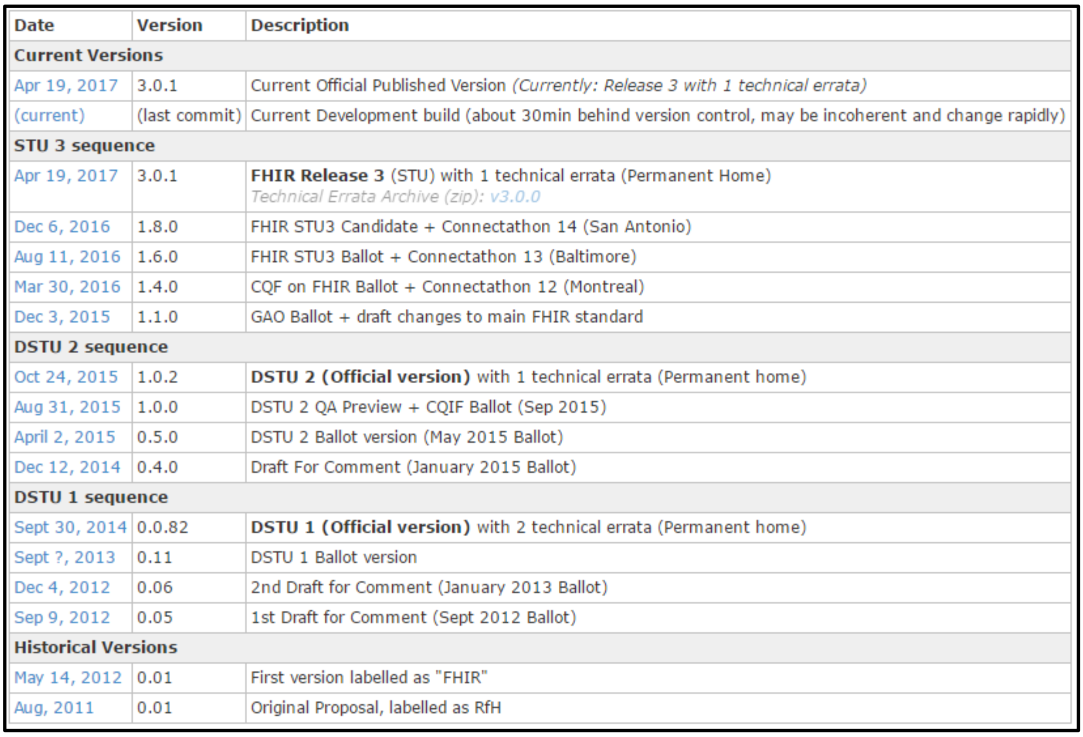


```
<ClinicalDocument>
  ...
  <StructuredBody>
    <Section>
      <text>...</text>
      <Observation>
        ...
      </Observation>
      <Observation>
        <reference>
          <ExternalObservation>
            ...
          </ExternalObservation>
        </reference>
      </Observation>
    </Section>
    <Section>
      <Section>...</Section>
    </Section>
  </StructuredBody>
</ClinicalDocument>
```

Figure 5: CDA structure [13]

1.4.3 HL7 FHIR Standard

HL7 FHIR was created by HL7 as a next generation standard. FHIR already has many versions. In each version, new resources are added and old resources are removed or changed to cover more aspects in the reality as it is shown in the figure 6.



Date	Version	Description
Current Versions		
Apr 19, 2017	3.0.1	Current Official Published Version *(Currently: Release 3 with 1 technical errata)*
(current)	(last commit)	Current Development build (about 30min behind version control, may be incoherent and change rapidly)
STU 3 sequence		
Apr 19, 2017	3.0.1	**FHIR Release 3** (STU) with 1 technical errata (Permanent Home) *Technical Errata Archive (zip): v3.0.0*
Dec 6, 2016	1.8.0	FHIR STU3 Candidate + Connectathon 14 (San Antonio)
Aug 11, 2016	1.6.0	FHIR STU3 Ballot + Connectathon 13 (Baltimore)
Mar 30, 2016	1.4.0	CQF on FHIR Ballot + Connectathon 12 (Montreal)
Dec 3, 2015	1.1.0	GAO Ballot + draft changes to main FHIR standard
DSTU 2 sequence		
Oct 24, 2015	1.0.2	**DSTU 2 (Official version)** with 1 technical errata (Permanent home)
Aug 31, 2015	1.0.0	DSTU 2 QA Preview + CQIF Ballot (Sep 2015)
April 2, 2015	0.5.0	DSTU 2 Ballot version (May 2015 Ballot)
Dec 12, 2014	0.4.0	Draft For Comment (January 2015 Ballot)
DSTU 1 sequence		
Sept 30, 2014	0.0.82	**DSTU 1 (Official version)** with 2 technical errata (Permanent home)
Sept ?, 2013	0.11	DSTU 1 Ballot version
Dec 4, 2012	0.06	2nd Draft for Comment (January 2013 Ballot)
Sep 9, 2012	0.05	1st Draft for Comment (Sept 2012 Ballot)
Historical Versions		
May 14, 2012	0.01	First version labelled as "FHIR"
Aug, 2011	0.01	Original Proposal, labelled as RfH

Figure 6: History of the different HL7 FHIR versions [18]

The HL7 website described FHIR as:

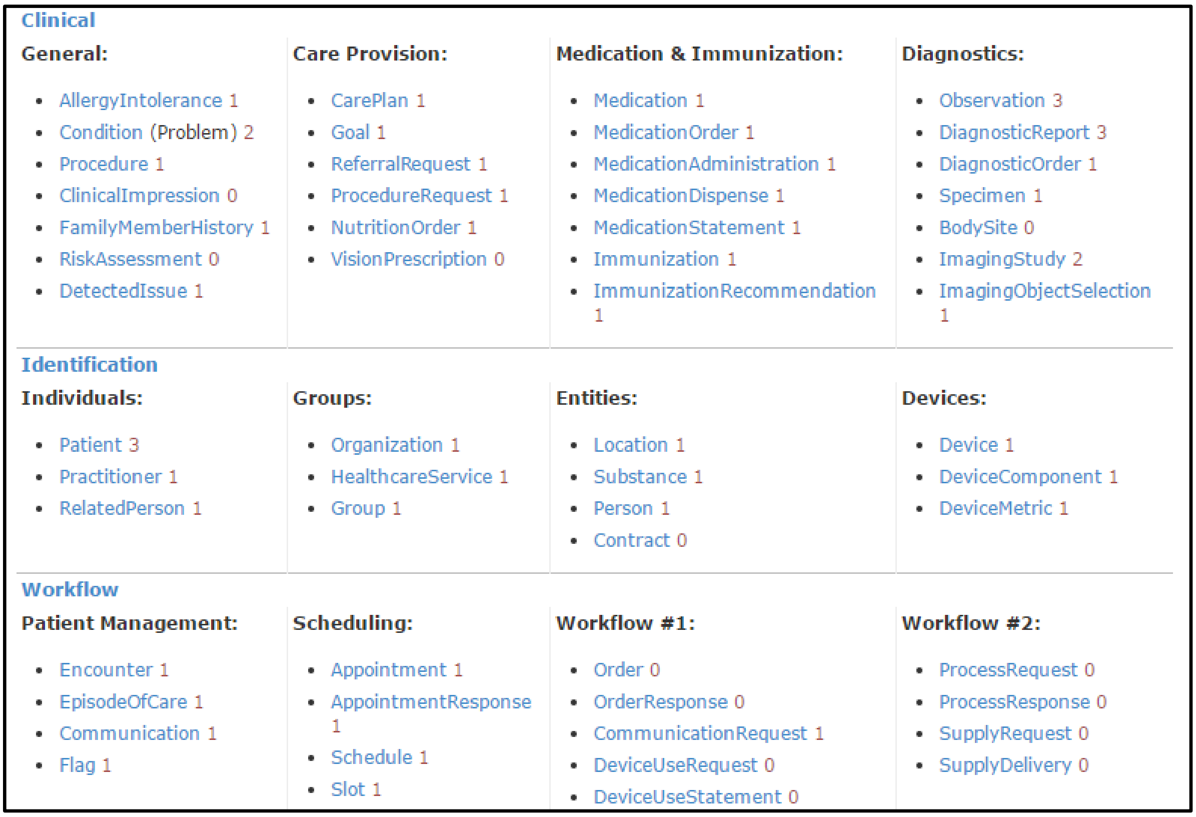
"FHIR – Fast Healthcare Interoperability Resources is a next generation standards framework created by HL7. FHIR combines the best features of HL7's v2 , HL7 v3 and CDA product lines while leveraging the latest web standards and applying a tight focus on implement ability" [18].

The advantages of the FHIR are:

- Fast and easy to implement
- Multiple implementation libraries in many programming languages
- Open Source
- Using resources as the core of FHIR, the resources can easily integrate into any system
- It is the upgraded version of HL7 2 and CDA, standards can co-exist and leverage each other [18]
- Work properly with Web standards and Web applications
- Support RESTFULL API within its core concept because it is built as object (resources). This will make document level and data level exchange more flexible
- Extensibility: the resources in FHIR were built according to global healthcare requirements, so it is more likely to find most healthcare specifications already exist as resources, but in case something does not exist, it is possible to use the extensions to add anything else. Furthermore, you can contact the FHIR community to find a new one

- In FHIR, every resource should have a human readable expression, in this way, it can be directly rendered or human entered
- The references, by using the references, all resources for example for the same patient could be connected in a way that allows to retrieve all of them in the same time by calling for an example patient id [18]

FHIR concept is built on the classification of different health information domains in distinct groups called resources (See figure 7 [19]), alongside using a clear API (RESTFUL API) as information carrier to exchange data among different systems [20].



Clinical

General:

- AllergyIntolerance 1
- Condition (Problem) 2
- Procedure 1
- ClinicalImpression 0
- FamilyMemberHistory 1
- RiskAssessment 0
- DetectedIssue 1

Care Provision:

- CarePlan 1
- Goal 1
- ReferralRequest 1
- ProcedureRequest 1
- NutritionOrder 1
- VisionPrescription 0

Medication & Immunization:

- Medication 1
- MedicationOrder 1
- MedicationAdministration 1
- MedicationDispense 1
- MedicationStatement 1
- Immunization 1
- ImmunizationRecommendation 1

Diagnostics:

- Observation 3
- DiagnosticReport 3
- DiagnosticOrder 1
- Specimen 1
- BodySite 0
- ImagingStudy 2
- ImagingObjectSelection 1

Identification

Individuals:

- Patient 3
- Practitioner 1
- RelatedPerson 1

Groups:

- Organization 1
- HealthcareService 1
- Group 1

Entities:

- Location 1
- Substance 1
- Person 1
- Contract 0

Devices:

- Device 1
- DeviceComponent 1
- DeviceMetric 1

Workflow

Patient Management:

- Encounter 1
- EpisodeOfCare 1
- Communication 1
- Flag 1

Scheduling:

- Appointment 1
- AppointmentResponse 1
- Schedule 1
- Slot 1

Workflow #1:

- Order 0
- OrderResponse 0
- CommunicationRequest 1
- DeviceUseRequest 0
- DeviceUseStatement 0

Workflow #2:

- ProcessRequest 0
- ProcessResponse 0
- SupplyRequest 0
- SupplyDelivery 0

Figure 7: Overview of available FHIR Release 1.0.2 (DSTU2) resources [19]

The system used five resources:

- Patient resource
- Practitioner resource
- Organization resource
- Observation resource
- Diagnostic resource

1.4.3.1 The Patient Resource

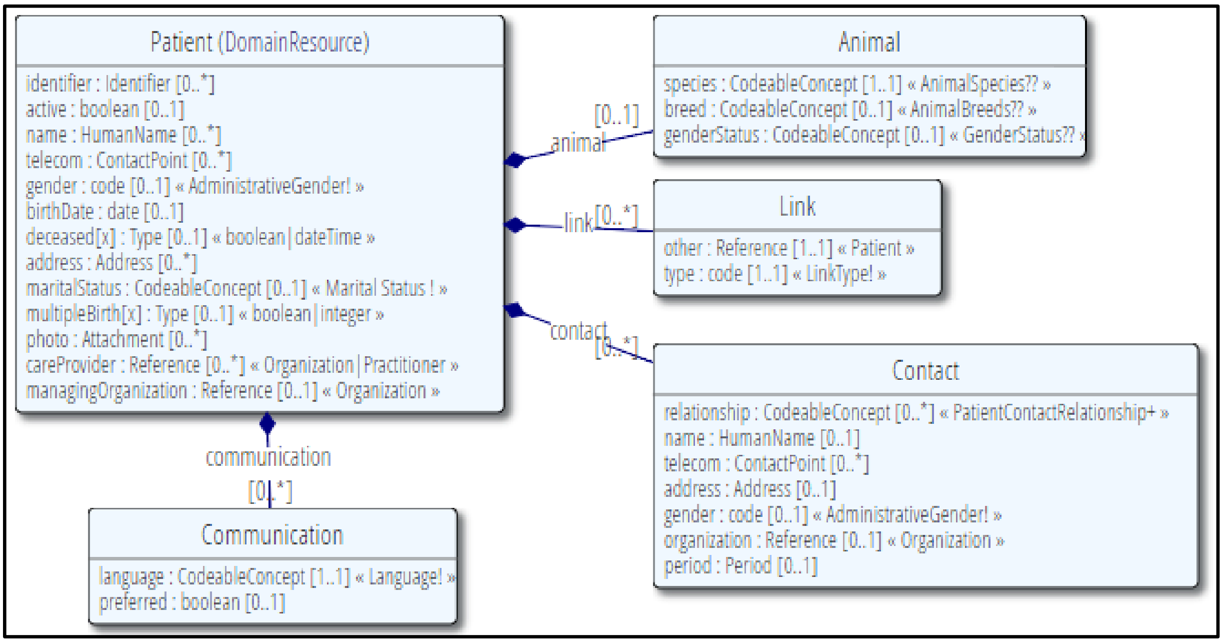
As it is mentioned in the HL7 FHIR official website, the patient resource “includes Demographics and other administrative information about an individual or animal receiving care or other health-related services” [6].

To know exactly how and when to use the patient resource, it is necessary to know the data to include if it is within the range that this resource covers. This resource deals with a wide range of health-related activities, including:

- Curative activities
- Psychiatric care
- Social services
- Pregnancy care
- Nursing and assisted living
- Dietary services
- Tracking of personal health and exercise data

Patient’s information is normally published by the organization that provides care for the patient, but also it is possible that the patient receives care from multiple organizations, in this case, it would be multiple patient resources and there are references between each other.

The patient resource has standard elements which link to each other. These elements present the patient or animal information (See figure 8), but sometimes it is not possible to include all information in the resource elements, in this case, using the resource patient – profiles or standard extensions would be a solution.



Patient (DomainResource)
identifier : Identifier [0..*]
active : boolean [0..1]
name : HumanName [0..*]
telecom : ContactPoint [0..*]
gender : code [0..1] « AdministrativeGender! »
birthDate : date [0..1]
deceased[x] : Type [0..1] « boolean | dateTime »
address : Address [0..*]
maritalStatus : CodeableConcept [0..1] « Marital Status ! »
multipleBirth[x] : Type [0..1] « boolean | integer »
photo : Attachment [0..*]
careProvider : Reference [0..*] « Organization | Practitioner »
managingOrganization : Reference [0..1] « Organization »
Animal
species : CodeableConcept [1..1] « AnimalSpecies?? »
breed : CodeableConcept [0..1] « AnimalBreeds?? »
genderStatus : CodeableConcept [0..1] « GenderStatus?? »
[0..1]
animal
link
[0..*]
Link
other : Reference [1..1] « Patient »
type : code [1..1] « LinkType! »
contact
[0..*]
Contact
relationship : CodeableConcept [0..*] « PatientContactRelationship+ »
name : HumanName [0..1]
telecom : ContactPoint [0..*]
address : Address [0..1]
gender : code [0..1] « AdministrativeGender! »
organization : Reference [0..1] « Organization »
period : Period [0..1]
communication
[0..*]
Communication
language : CodeableConcept [1..1] « Language! »
preferred : boolean [0..1]

Figure 8: Patient resource Unified Modeling Language (UML) diagram [6]

1.4.3.2 The Practitioner Resource

The practitioner resource covers all individuals who are engaged in the healthcare process and healthcare-related services as part of their formal responsibilities [21].

Practitioners include physicians, dentists, nurses, radiographers, social workers and many other individuals. It is necessary to understand the boundaries between the practitioners and other persons, because this resource should be used for persons who have formal responsibility in the healthcare facilities, but for other persons like friends or relatives, these can be considered as related persons in the RelatedPerson resource or patients contact.

It is possible to have more than one resource for each practitioner in the same or different organizations if this practitioner has multiple roles within the organizations.

As in the patient resource, if the practitioner elements don’t cover all the practitioner information (See figure 9), extensions can be used to extend the elements.

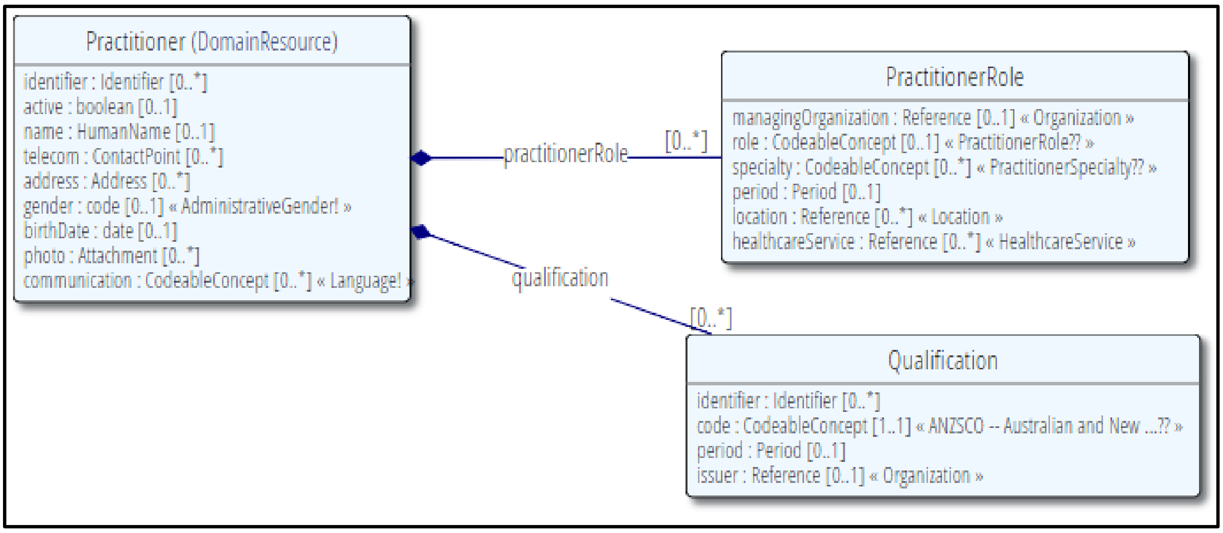
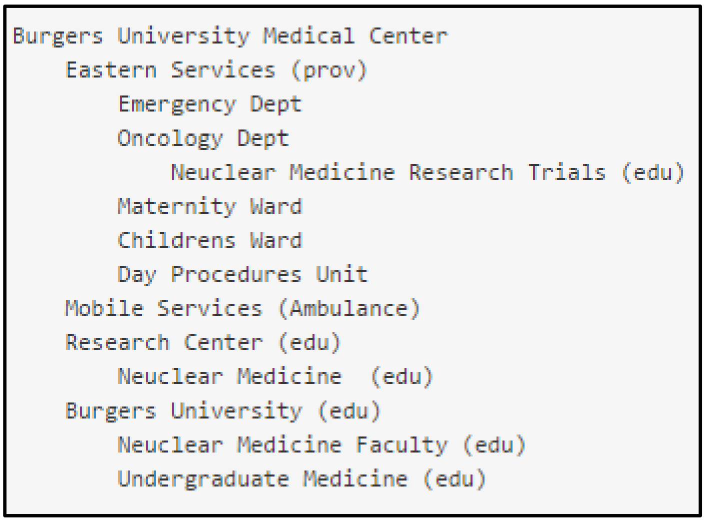

Practitioner (DomainResource)
identifier : Identifier [0..*]
active : boolean [0..1]
name : HumanName [0..1]
telecom : ContactPoint [0..*]
address : Address [0..*]
gender : code [0..1] « AdministrativeGender! »
birthDate : date [0..1]
photo : Attachment [0..*]
communication : CodeableConcept [0..*] « Language! »
practitionerRole
[0..*]
PractitionerRole
managingOrganization : Reference [0..1] « Organization »
role : CodeableConcept [0..1] « PractitionerRole?? »
specialty : CodeableConcept [0..*] « PractitionerSpecialty?? »
period : Period [0..1]
location : Reference [0..*] « Location »
healthcareService : Reference [0..*] « HealthcareService »
qualification
[0..*]
Qualification
identifier : Identifier [0..*]
code : CodeableConcept [1..1] « ANZSCO -- Australian and New ...?? »
period : Period [0..1]
issuer : Reference [0..1] « Organization »

Figure 9: Practitioner resource UML diagram [21]

1.4.3.3 The Organization Resource

The organization resource covers the contact and other information for the organizations and could support other resources that need to reference organizations. The resource also covers a collection of people who achieve together an objective. To differentiate between practitioner resource and group resource, group resource is used for a collection of people who gather for analyzing purpose, so they are the experiment tools [22].

The organization resource helps by providing the association between the parent organization and its branches, this is called organization hierarchy (see figure 10), and this is done by using the location resource, which provides the physical representation of the hierarchy.



```
Burgers University Medical Center
    Eastern Services (prov)
        Emergency Dept
        Oncology Dept
            Neuclear Medicine Research Trials (edu)
        Maternity Ward
        Childrens Ward
        Day Procedures Unit
    Mobile Services (Ambulance)
    Research Center (edu)
        Neuclear Medicine  (edu)
    Burgers University (edu)
        Neuclear Medicine Faculty (edu)
        Undergraduate Medicine (edu)
```

Figure 10: organization hierarchy [22]

The resource has many elements (see figure 11) like name of the organization, telecom, and address, and in the case of needing more details, using the extensions property would be enough.

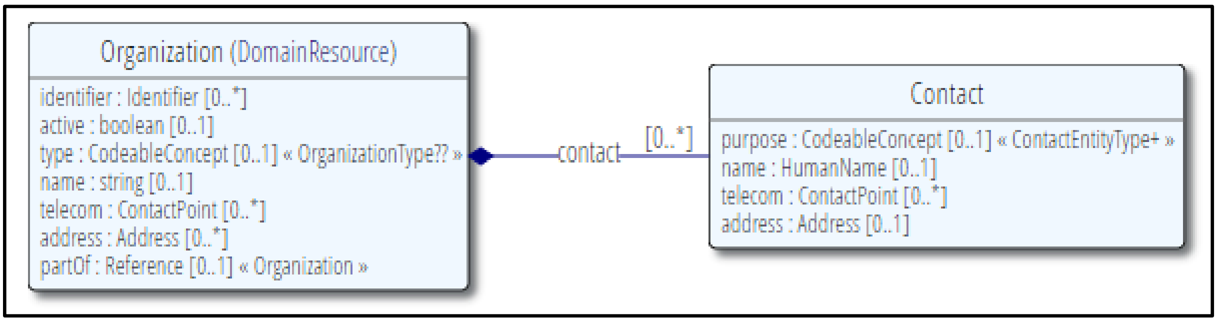

Organization (DomainResource)
identifier : Identifier [0..*]
active : boolean [0..1]
type : CodeableConcept [0..1] « OrganizationType?? »
name : string [0..1]
telecom : ContactPoint [0..*]
address : Address [0..*]
partOf : Reference [0..1] « Organization »
contact
[0..*]
Contact
purpose : CodeableConcept [0..1] « ContactEntityType+ »
name : HumanName [0..1]
telecom : ContactPoint [0..*]
address : Address [0..1]

Figure 11: organization resource UML diagram [22]

1.4.3.4 The Observation Resource

The observation resource plays an important role in this thesis. This resource supports other resources like diagnostic resource and it contains the measurements, which are documented for a patient, device or other subject [23]. Expected uses for the observation resource include:

- Vital signs: like blood pressure
- Laboratory data
- Imaging results: like bone density
- Devices measurements: like EKG
- Clinical assessment tools
- Personal characteristics: like weight
- Social history: like family supports
- Core characteristics: like pregnancy

There is some confusion between the diagnostic report and the observation resource. The diagnostic report contains additional clinical context but the observation resource is referenced by the diagnostic report to provide the atomic results for a particular investigation. Figure below shows the observation elements and their links.

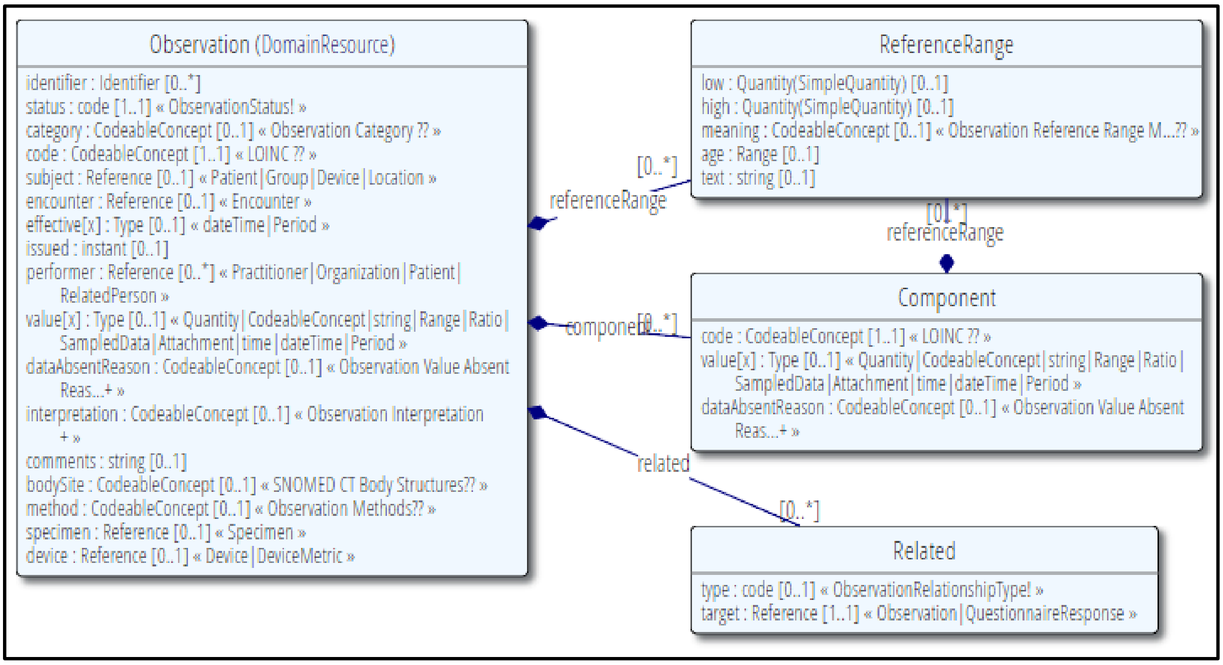

Observation (DomainResource)
identifier : Identifier [0..*]
status : code [1..1] « ObservationStatus! »
category : CodeableConcept [0..1] « Observation Category ?? »
code : CodeableConcept [1..1] « LOINC ?? »
subject : Reference [0..1] « Patient|Group|Device|Location »
encounter : Reference [0..1] « Encounter »
effective[x] : Type [0..1] « dateTime|Period »
issued : instant [0..1]
performer : Reference [0..*] « Practitioner|Organization|Patient|RelatedPerson »
value[x] : Type [0..1] « Quantity|CodeableConcept|string|Range|Ratio|SampledData|Attachment|time|dateTime|Period »
dataAbsentReason : CodeableConcept [0..1] « Observation Value Absent Reas...+ »
interpretation : CodeableConcept [0..1] « Observation Interpretation + »
comments : string [0..1]
bodySite : CodeableConcept [0..1] « SNOMED CT Body Structures?? »
method : CodeableConcept [0..1] « Observation Methods?? »
specimen : Reference [0..1] « Specimen »
device : Reference [0..1] « Device|DeviceMetric »
ReferenceRange
low : Quantity(SimpleQuantity) [0..1]
high : Quantity(SimpleQuantity) [0..1]
meaning : CodeableConcept [0..1] « Observation Reference Range M...?? »
age : Range [0..1]
text : string [0..1]
[0..*]
referenceRange
[0..*]
referenceRange
Component
code : CodeableConcept [1..1] « LOINC ?? »
value[x] : Type [0..1] « Quantity|CodeableConcept|string|Range|Ratio|SampledData|Attachment|time|dateTime|Period »
dataAbsentReason : CodeableConcept [0..1] « Observation Value Absent Reas...+ »
component [0..*]
related
[0..*]
Related
type : code [0..1] « ObservationRelationshipType! »
target : Reference [1..1] « Observation|QuestionnaireResponse »

Figure 12: Observation resource UML diagram [23]

1.4.3.5 The Diagnostic Report

A diagnostic report is the set of information that is typically provided by a diagnostic service when investigations are complete. The information includes a mix of atomic results, text reports, images, and codes [24].

It could contain different kinds of the diagnostic reports like laboratory, pathology and another diagnostics cardiology [25].

Figure below gives an overview about the elements and their links in this report.

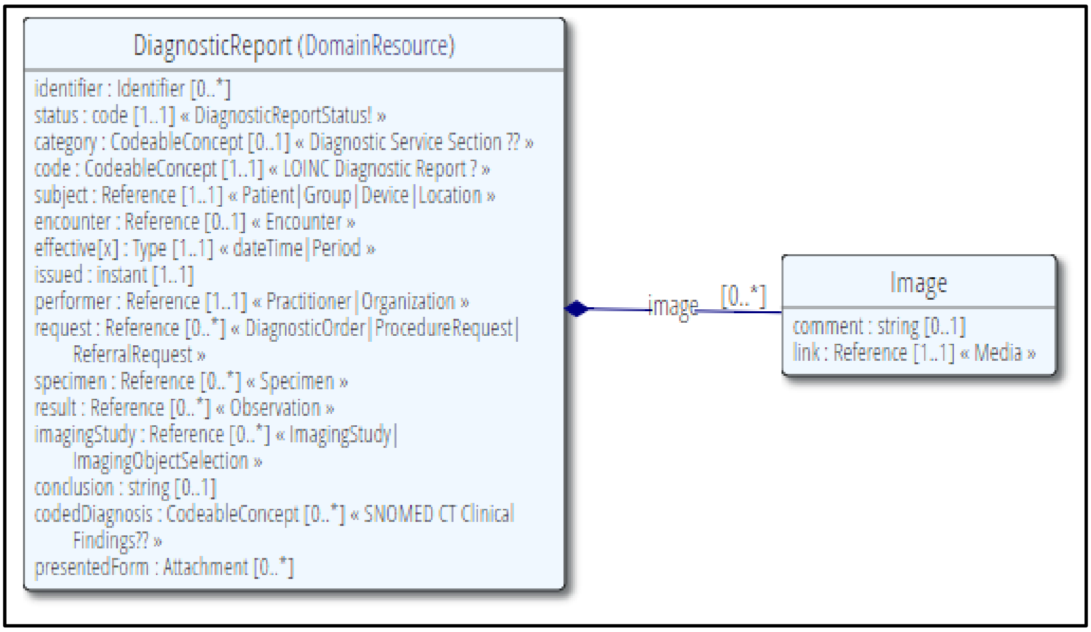

DiagnosticReport (DomainResource)
identifier : Identifier [0..*]
status : code [1..1] « DiagnosticReportStatus! »
category : CodeableConcept [0..1] « Diagnostic Service Section ?? »
code : CodeableConcept [1..1] « LOINC Diagnostic Report ? »
subject : Reference [1..1] « Patient|Group|Device|Location »
encounter : Reference [0..1] « Encounter »
effective[x] : Type [1..1] « dateTime|Period »
issued : instant [1..1]
performer : Reference [1..1] « Practitioner|Organization »
request : Reference [0..*] « DiagnosticOrder|ProcedureRequest|ReferralRequest »
specimen : Reference [0..*] « Specimen »
result : Reference [0..*] « Observation »
imagingStudy : Reference [0..*] « ImagingStudy|ImagingObjectSelection »
conclusion : string [0..1]
codedDiagnosis : CodeableConcept [0..*] « SNOMED CT Clinical Findings?? »
presentedForm : Attachment [0..*]
image
[0..*]
Image
comment : string [0..1]
link : Reference [1..1] « Media »

Figure 13: Diagnostic resource UML diagram [24]

1.4.3.6 The FHIR Extensibility

The FHIR exchange specification is based on the agreed common requirements across healthcare [26], covering many domains and approaches. This is clear in the number of resources and its functionality. As mentioned before, sometimes the resources elements are enough to cover all the data that is needed to exchange, but sometimes it is not enough. Because of that, the extension element has been added. Every element in a resource or data type has an option to have extension elements, which can present any number of times.

The extension element has two attributes, the URL attribute which is mandatory and shall be a URL, and the value[x], which has an actual name of "value" and then the TitleCased name of one of these defined types (see figure 14).

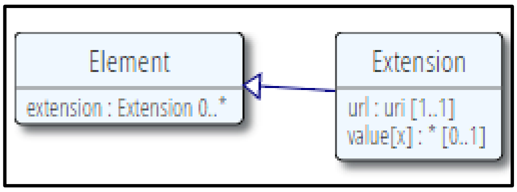
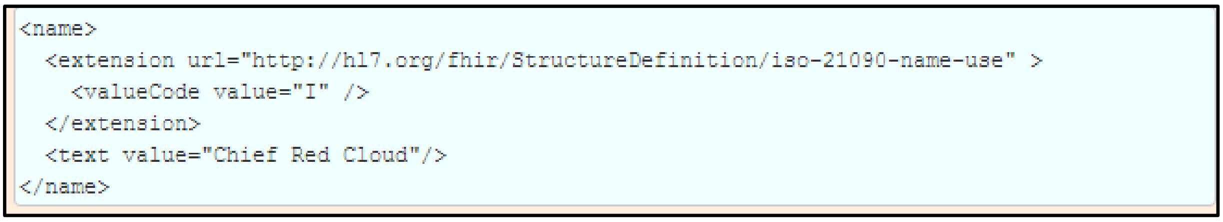


Figure 14: FHIR extension element [26]

In figure 15 an example for extension in the XML format is shown:



```
<name>
  <extension url="http://hl7.org/fhir/StructureDefinition/iso-21090-name-use" >
    <valueCode value="I" />
  </extension>
  <text value="Chief Red Cloud"/>
</name>
```

Figure 15: Example FHIR extension in the XML format

1.4.3.7 The FHIR RESTFUL API

FHIR is described as a 'RESTFUL' specification based on common industry level use of the term REST [27], but it supports Level 2 of the REST Maturity mode [28] which uses the HTTP verbs as closely as possible to how they are used in HTTP itself as it is shows in the figure 16.

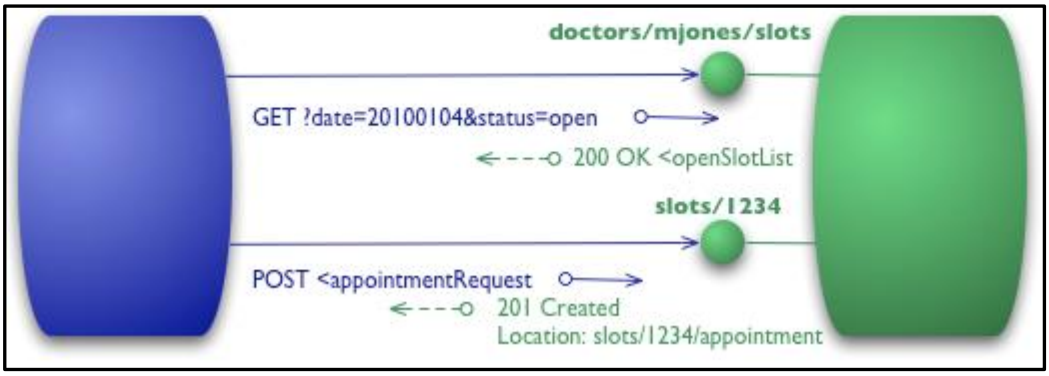


Figure 16: FHIR RESTful API level 2 [27]

The RESTFUL API supports FHIR resources in the set of interactions (see table 1), which use to manage the resources and communicate with the server which in turn recognizes these interactions and which resources they support [29].

Instance Level Interactions	
read	Read the current state of the resource.
vread	Read the state of the specific version of the resource.
update	Update an existing resource by its id (or create it if it is new).
patch	Update an existing resource by posting a set of changes to it.
delete	Delete a resource.
history	Retrieve the change history for particular resource.
Types Level Interactions	
create	Create a new resource with a server assigned id.
search	Search the resource type based on some filter criteria.
history	Retrieve the change history for a particular resource type.
Whole System Interactions	
capabilities	Get a capability statement for the system.
batch/transaction	Update, create or delete a set of resources in a single interaction.
search	Retrieve the change history for all resources
history	Search across all resource based on some filter criteria.

Table 1: FHIR interactions [29]

The interactions have the following structure, which is included in the FHIR specification:

VERB [base]/[type]/[id] {? -format=[mime-type]}

Every thing surrounded by [ ] is mandatory and by { } is optional. The HTTP verb is one of the POST, GET, DELETE or PUT, and the other elements are:

- Base: The Service Base URL
- Mime-type: The Mime Type
- Type: The name of a resource type (e.g. "Patient")
- Id: The Logical Id of a resource

1.4.4 Available FHIR Servers

There are various FHIR servers available for the implementers to reuse. These servers differ from each other in respect to the implemented FHIR version and the purpose of the server. In the following, some of the FHIR servers are described.

1.4.4.1 The HSPC Sandbox

Sandbox is a platform that helps the developers to test their medical application, and it allows the implementers to run their application again on their own FHIR servers. The HSPC Sandbox supports DSTU2 and STU3 FHIR versions [30].

1.4.4.2 Vonk FHIR Server

This server implements FHIR STU3 and was built with MongoDB and ASP.NET Core. It is an open source server for testing and education purposes [31].

1.4.4.3 SPARK FHIR Server

This server is an implementation for the FHIR DSTU2. It was built based on the C# FHIR API. It is also open source and helps C# developers to start quickly with FHIR implementation [32].

1.4.4.4 FHIRBASE Server

FHIRBASE provides developers with storage to develop Health IT solutions such as EHRs, patient and physician portals [33]. FHIRBASE is designed in accordance with the FHIR standard. Thus, the server uses the Postgres as a core for it because PostgreSQL is an open source object-relational database system. It has more than 15 years of active development and an architecture that has earned it a reputation for reliability, data integrity, and correctness [33].

1.4.4.5 HAPIFHIR Server

It operates with a high compliance to the FHIR specification. It has support for chained queries, which can be useful when trying to do complex queries with plain FHIR [34].

The library is designed to support several main usage patterns (see figure 17) to allow each developer to use HAPIFHIR according to their requirements as shown in the figure 34 below.

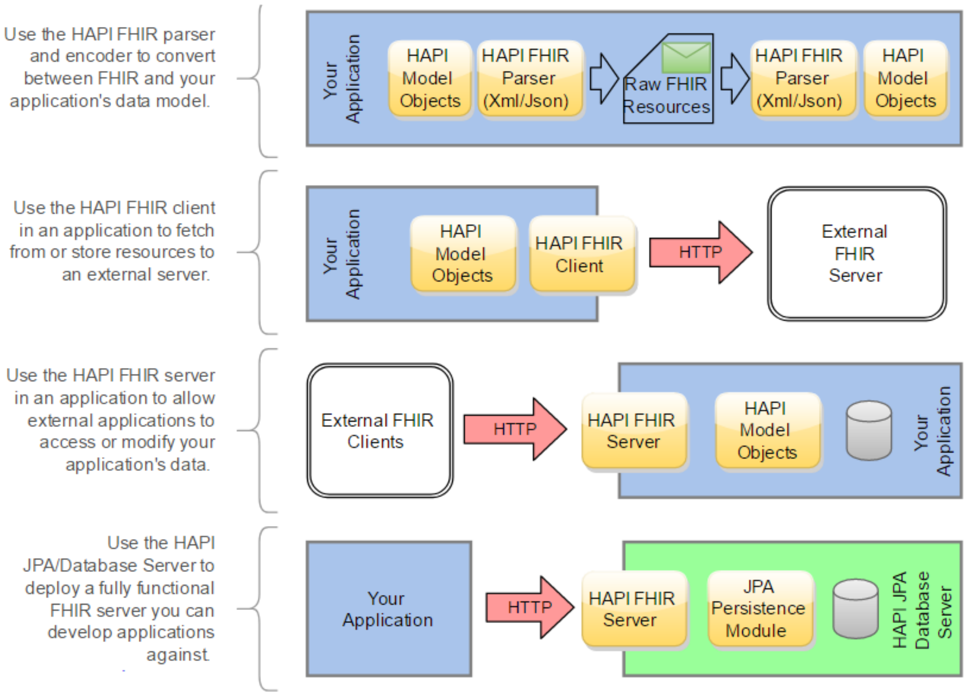

Use the HAPI FHIR parser and encoder to convert between FHIR and your application's data model.
Your Application
HAPI Model Objects
HAPI FHIR Parser (Xml/Json)
Raw FHIR Resources
HAPI FHIR Parser (Xml/Json)
HAPI Model Objects
Use the HAPI FHIR client in an application to fetch from or store resources to an external server.
Your Application
HAPI Model Objects
HAPI FHIR Client
HTTP
External FHIR Server
Use the HAPI FHIR server in an application to allow external applications to access or modify your application's data.
External FHIR Clients
HTTP
HAPI FHIR Server
HAPI Model Objects
Your Application
Use the HAPI JPA/Database Server to deploy a fully functional FHIR server you can develop applications against.
Your Application
HTTP
HAPI FHIR Server
JPA Persistence Module
HAPI JPA Database Server

Figure 17: HAPIFHIR structure [34]

1.4.5 Web Application Framework „Yes, it is” (YII)

YII is “a high-performance modern PHP framework best for developing both web applications and APIs.” as the official website defines it [35] (See figure 18).

YII is a web development framework designed to support web applications including resources, databases connections and data exchanging. It aims to facilitate the common repeated web development procedures via evoking available models and structures that support implementations [36].

The crucial point could be the ability to develop API (application programming interface) for distribution systems such as this project to allow communications between different parts like mobile devices. Furthermore, superior engineering architecture provides a stable base for application extensibility.

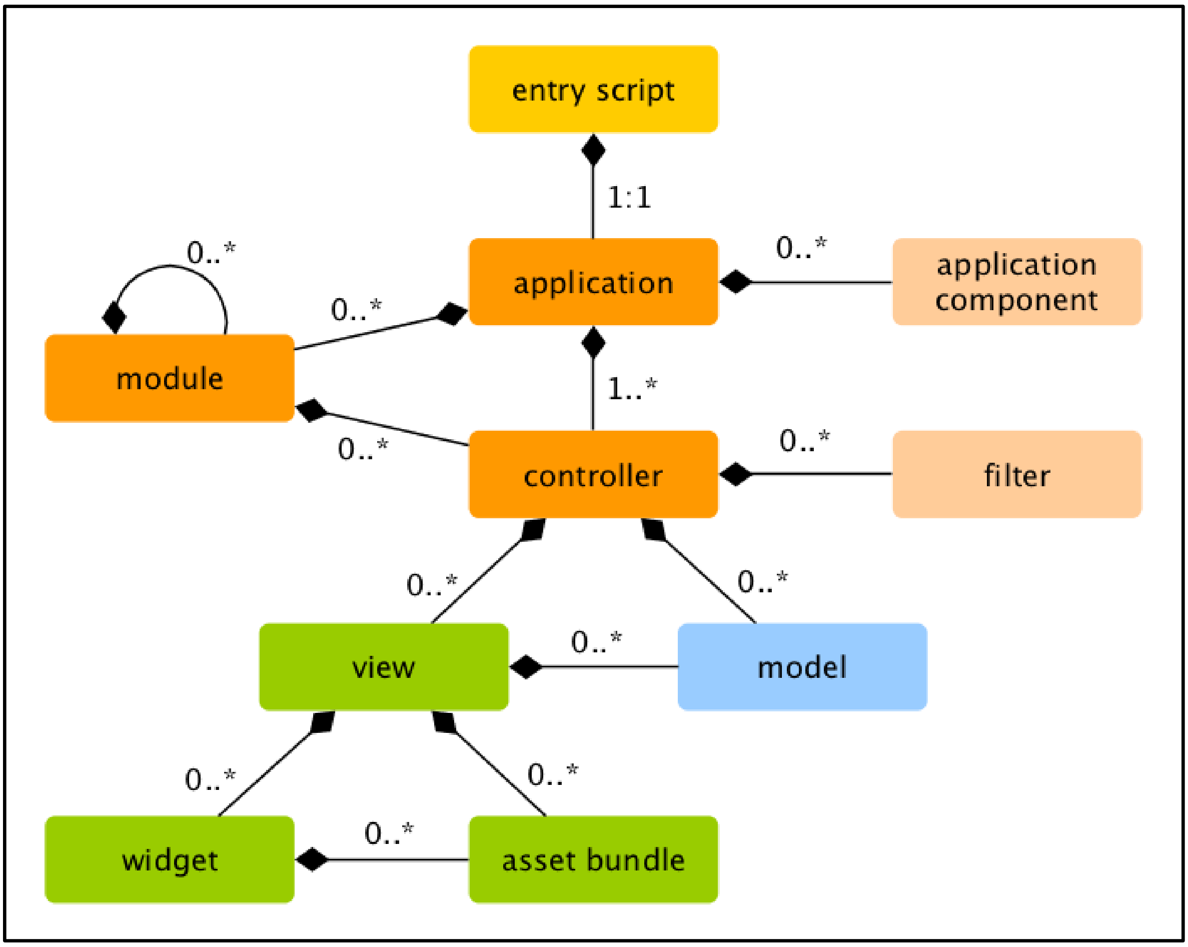


Figure 18: YII-framework workflow [36]

1.5 Alternative Approaches Compared to FHIR

HL7's standards generally and FHIR specifically are not the only approaches facing the interoperability challenges in health care facilities. Here are some alternative standards that were developed to face the interoperability challenges:

SS-MIX

SS-MIX (Standard Structured Medical Information exchange) is a standard for health information exchange published by the Japanese Ministry of Health, Labor and Welfare. SS-MIX is based in part on HL7 [37].

xDT

xDT is a set of standards used in Germany for the exchange of health information between healthcare providers and insurance companies [37].

NCPDP

NCPDP is an organization providing standards for information exchanges related to medications, supplies, and services within the healthcare system. These standards help improve safety, privacy, and healthcare outcomes for patients and healthcare consumers, while reducing costs in the system [37].

ITK

The Interoperability Toolkit (ITK), developed by the United Kingdom's National Health Service (NHS), is a set of common specifications, frameworks, and implementation guides to support interoperability within local organizations and across local health and social care communities. ITK uses open international standards and is aligned with HL7 and Integrating the Healthcare Enterprise (IHE) [38].

OpenEHR

"OpenEHR is a virtual community working on means of turning health data from the physical form into electronic form and ensuring universal interoperability among all forms of electronic data. The primary focus of its endeavor is on electronic health records (EHR) and related systems" [39].

OpenEHR creates specifications and implementations and uses them as a base to develop an open, interoperable health computing platform that supports many requirements, some of them are [40]:

- The ability to record any clinical information: including lab results, imaging, diagnoses, care plans, and many others
- Integration with terminology systems: this allows for example sharing of laboratory data without any problems
- Ability to integrate with messaging systems like HL7 version 2x

- Ability to connect to the existing databases and integrate with existing hospital information systems
- Communicating with other applications via a published API

CEN/ISO EN13606

"The CEN/ISO EN13606 is a European norm from the European Committee for Standardization (CEN), it is also approved as an international ISO standard. It is designed to achieve semantic interoperability in the electronic health record communication" [41]. Following this standard provides an interoperable communication between an EHR system or repository and clinical applications or middleware components (such as decision support components) that need to access or provide EHR data, or as the representation of EHR data within a distributed (federated) record system [42].

Continua Health Alliance

A non-profit organization convening global technology industry standards to develop end-to-end, plug-and-play connectivity for personal connected health. The organization does not define standards, but gives guidance on how to use them. At the same time, Continua Design Guidelines are proven to decrease time to market and reduce development costs [43].

1.5.1 Integrating the Healthcare Enterprise (IHE)

IHE is an initiative by healthcare professionals and industry to improve the way computer systems in healthcare share information. It provides the guidelines, technical framework and profiles that support exchanging medical documents like clinical documents in the secure and safe way. Also, IHE coordinate with established standards like Digital Imaging and Communications in Medicine (DICOM) and HL7 [44].

1.5.1.1 XDS

Cross-Enterprise Document Sharing (XDS) is an interoperability profile that facilitates the registration, distribution, and access across health enterprises of patient electronic health records [45]**.**

XDS can deal with different kinds of documents which include:

- XDS-SD: Scanned document, plain text or PDF
- XDS-MS: Medical summary in HL7 CDA format
- XDS-I: Radiology report in plain text of PDF format, or reference to a collection of DICOM SOP Instances format

XDS is used to exchange documents between a physician's office**,** a client, and a healthcare facility, like a hospital. XDS depends on the specific structure that provides exchanging documents across health facilities. This structure contains the following components (See figure 19):

- A document Repository: which stores the documents in a clear and secure manner, and gives a response to the retrieval requests
- A document Registry: which stores the information and the metadata about those documents and the details about where they are stored. This will make finding and retrieving specific documents from the repository easier.
- Document Sources: which provide the documents
- Document Consumers: which accesses the documents and retrieves them
- Patient Identity Source: provides a unique identifier for each patient and maintains a collection of identity traits [46]

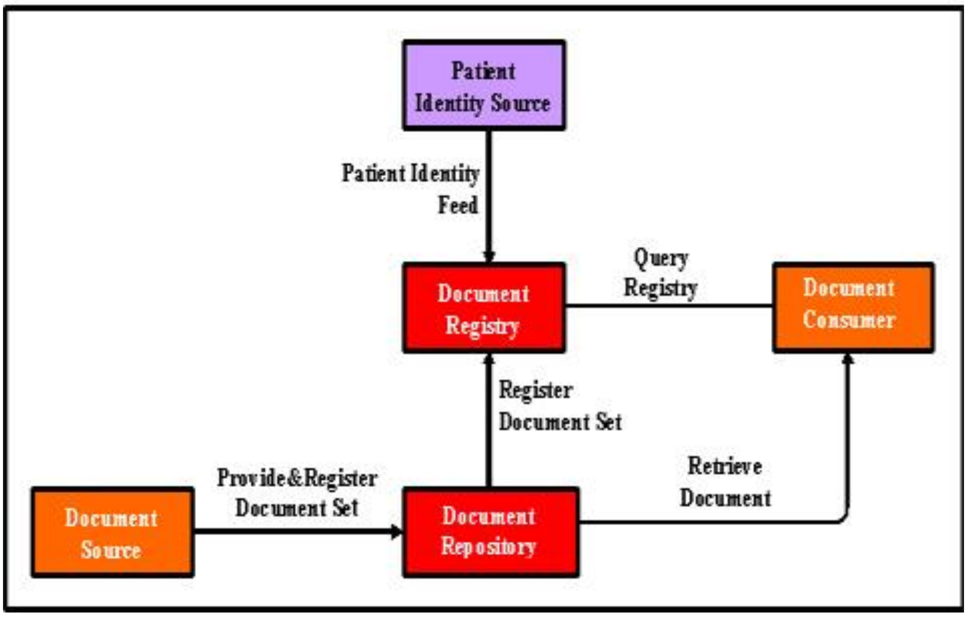


Figure 19: IHE XDS profile structure [46]

XDS Flow and Interactions

1. Sources post document packages to the Repository
2. Repository registers the documents metadata and pointer with the Registry
3. Consumers search for documents with specific information
4. Consumers retrieve selected documents from Repository

It is possible to combine between FHIR resources and the XDS profile. IHE Mobile access to Health Documents (MHD) profile defines a simple HTTP interface to an XDS like environment. The MHD profile is intended for any system that prefers the simplified HTTP RESTFUL technology rather than the more robust technology used in XDS [47], It is possible to do that by using A DocumentReference resource or DocumentManifest which is used to describe a document that is made available to a healthcare system. The DocumentReference resource can be used with any document format that has a recognized mime type and that conforms to this definition [48].

There is somehow a relation between the XDS transactions and the FHIR resource end points. The transactions after applying the FHIR resource in the XDS are (see figure 20):

- A document source can submit the document and metadata to the repository via a transaction in the same way that FHIR RESTFULL API does.
- The repository updates the registry by posting a resource to the registries DocumentReference endpoint
- A consumer searches for documents via a query against the registries DocumentReference endpoint, and retrieves the document via a GET against the repositories /binary endpoint
- A SecurityEvent resource that records accesses of significance

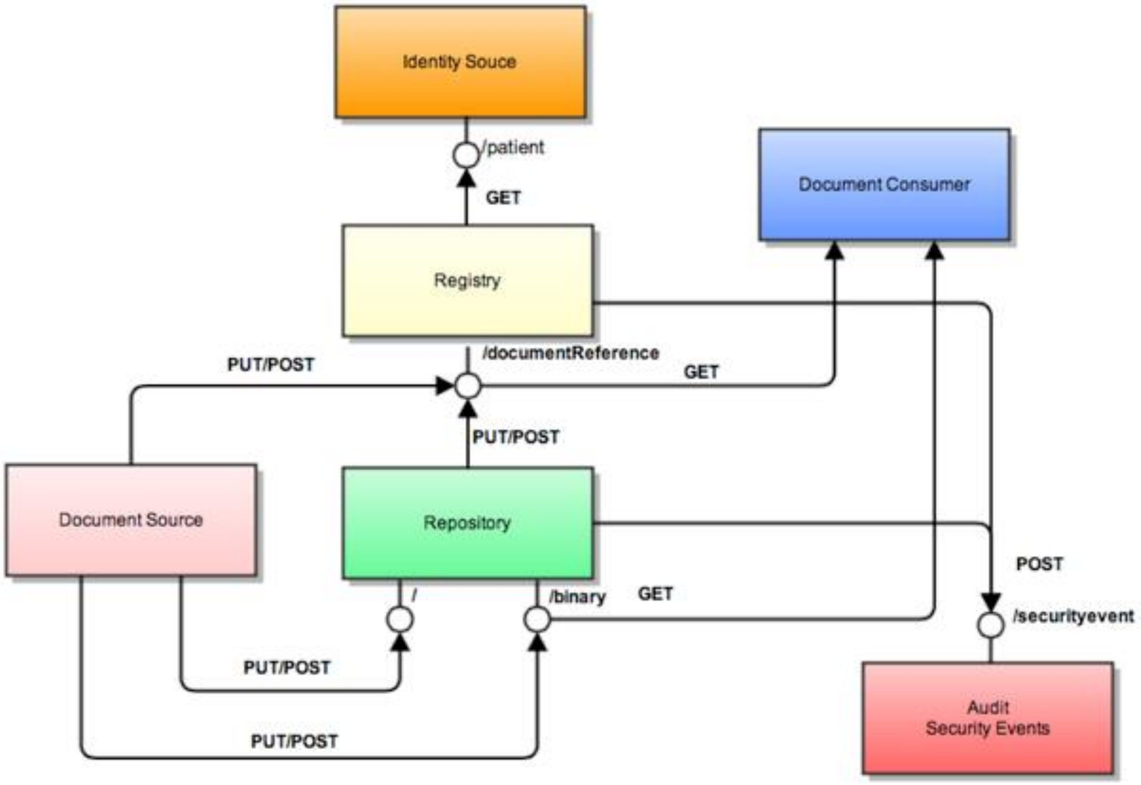


Figure 20: Architecture for combining XDS and FHIR together [48]

2 Methods and Materials

To achieve the goals, the working plan is divided into the two steps:

- Literature Research
- System Development

2.1 Literature Research

In this part, a primary research about HL7 standards [49], web development frameworks [50] and HL7 servers [51] were done. In this way, a knowledge about these concepts and how they work was achieved, because finding the hidden relationship between pollen concentration in the air and blood pressure was one of the projects goals, it was necessary to research the relationship between them from a medical point of view.

2.2 System Development

In this section, three steps were followed:

- Identification of the appropriate technologies
- The implementation
- Testing and verification

2.2.1 Identification of the Appropriate Technologies

Depending on the researching step and personal experience, the following tools were used:

- Choosing PHP as programming language for the development step.
- D-Carbone/ PHP-FHIR library to deal with FHIR classes.
- Choosing a proper HL7 standard: because the HL7 has many versions, it was important to choose which HL7 version should be used and why. HL7 FHIR was used in this project as mentioned in the result chapter.
- Choosing a proper web development framework: there are many frameworks that could be used, but it was important to choose the appropriate one to facilitate the system implementation. YII framework was used as mentioned in the result chapter.
- Choosing a proper HL7 server: After choosing a proper HL7 standard and web framework, it was necessary to choose one of the HL7 servers to use as a storage method for the resources and the big data that was analyzed. HAPIFHIR and FHIRBASE were used as mentioned in the result chapter.

2.2.2 The Implementation

The implementation process consisted of the two steps:

- Mobile application
- Analyzing platform with the server side

The mobile application and all parts related to it are not included in this thesis. Mr Adnan Jouned will be the responsible person for this part. In this thesis, it will be considered that blood pressure values are received from the mobile side and start from this point.

2.2.2.1 The Server Side

This part contains two main parts:

- Resources management implementation
- Analyzing tool implementation

Resources Management

In this part, the user can create, read, update and delete the following resources:

- Patient resource: this resource contains all patient’s personal information and there is a possibility to refer to the organization and practitioner resources
- Practitioner resource: this contains all the information about the practitioner who could be a doctor and there is a possibility to refer to an organization resource
- Organization resource: this resource contains the organization information like the name and the contact information, also the user can add reference to the other organization resource
- Diagnostic resource: the diagnostic report is the set of information that is typically provided by a diagnostic service when investigations are completed. The information includes a mix of anatomic results, text reports, images, and codes. There is a possibility to make references to the patient, practitioner, observation and organization resources
- Observation resource: this resource used to support diagnosis, also contains our measurement results like blood pressure values. Also, there is a possibility to make references to the patient, practitioner and organization resources

Also, all historical information for each resource can be reviewed to view the events that were done on this resource. The figure 21 below shows the possible transaction on the resources.

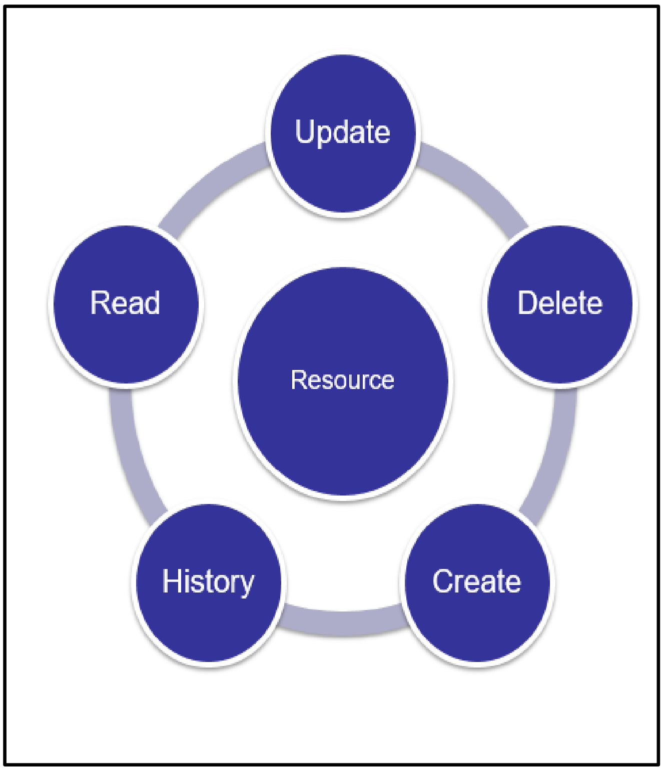


Figure 21: the transaction in the system

A FHIR programming library was used to generate and parse FHIR resources. Alongside with a web development framework, the necessary FHIR API's were created to achieve the following resources interactions:

- Resource creating
- Resource updating
- Resource deleting
- Resource searching
- Resource history

FHIR API specification was followed to get unified API for all interactions in the system. This gives the system parts the ability to communicate with each other and with other systems without any interoperability problems. This is very important in this project, because there is a telemonitoring part that sends the resources by the mobile application to the server and retrieves the responses from the server about the status of the sending data.

Analyzing Tool Implementation

In this step, pollen values were retrieved from an available source, then the correlation coefficient between these values and the systolic and diastolic pressure and heart rate (which came from the mobile application as observation resource) was calculated.

The correlation coefficient has a value between -1 and +1. All the results near +1 will be considered as a high level of correlation and vice versa, as is shown in the figure 22 below.

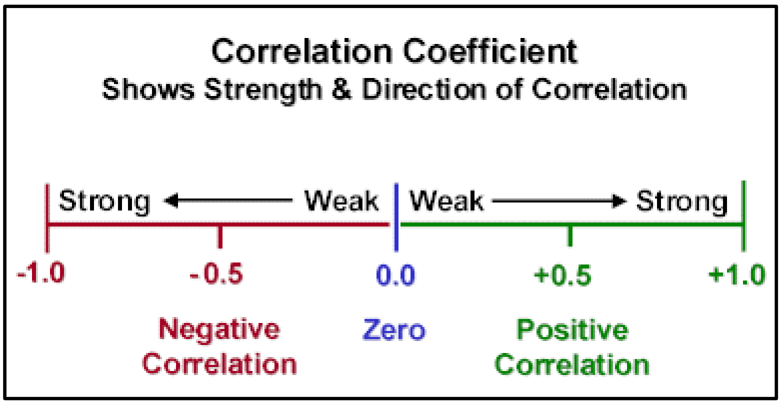


Figure 22: The strength and direction of correlation

After that, a visualizing tool was used to visualize the results in graphs beside one of the bootstrap admin templates, which use as a complete kit or use to start something more complex [52]. It is necessary to use a template to make the system more understandable for all users and the transactions more ordered.

2.2.3 Testing and Verification

After finishing the implementation step, the system was subjected to a testing phase. All transactions in the system were tested, sent, and received many FHIR resources from and to another server, to be sure that all API's were done according to the FHIR API specifications.

Also, as a part of testing phase, all resources structures were validated to prevent sending incorrect resources that do not fulfill FHIR specification to the server.

3 Results

This chapter contains the results that were obtained after finishing all thesis parts.

3.1 Results of Literature Research

As results for the literature research, the following was found:

3.1.1 FHIR as Interoperability Standard

As a part of the literature research, FHIR was selected as interoperability standard to handle the exchange of medical data between system parts and between the telemonitoring system and the Server. Because this project was done in Austria, which heavily uses CDA as a part of “Die Elektronische Gesundheitsakte (ELGA)” [53], an important question arises here, why FHIR not CDA?

3.1.1.1 Comparison between CDA and FHIR

Because the CDA is HL7's most widely adopted HL7 v3 standard, and FHIR is the latest version of the HL7 standards, it is necessary for the developers to know the exact differences between each other to choose the suitable solution for their application. There are the following points regarding the comparison between CDA and FHIR [54]:

- CDA deals with the clinical use cases. It does not support exchanging other information like financial information. FHIR resources have no limitation on their content, not only clinical data, but also financial and administration data
- CDA and FHIR both have rules that define how the human readable text is presented, so in both, the content is readable for humans
- CDA uses the Clinical Statement that allows for the implementers to represent any clinical concept that they need, but with some clinical concepts, it is difficult to express them in a convenient way. For example, it is not clear until now how to represent things like allergies or surgery out of the box, and common clinical concepts do not have a unified model in all circumstances. Per contra, FHIR handles clinical and not clinical content by using resources that provide a unified structure to exchange the data and by using resources, it will be clear how to represent common structures like allergies “out of the box”. Furthermore, resources provide and ensure that there is one way to represent the content [55]
- FHIR uses XHTML which is more expressive than CDA markup XML
- FHIR is modular, so every resource covers a small amount of coherent data. It’s easy to build small application that cover only the data you need. The CDA merges a lot of data together, because of that and in some cases, you have to implement more than you need

The most important aspect that, FHIR can exchange and handle traditional CDA document by using DocumentReference resource, which considers the CDA as a binary attachment.

3.1.2 FHIR Servers

In order to store FHIR resources and because their features, two FHIR servers were chosen. HAPI FHIR 1.3 - 2.2 and FHIRBASE-plv8 servers, both support FHIR Draft Standard for Trial Use (DSTU2).

Why FHIRBASE Server

Depending on the researching and implementation steps, FHIRBASE server was chosen to implement in this project. Most features come from the using the Postgres database, which gave the system the following advantages: [56]

- Immunity to over-deployment
- Better support than the proprietary vendors
- Extensible
- Cross platform
- Designed for high volume environments (using MVCC)
- GUI database design and administration tools
- Monitoring system for data health by the Dynatrace monitors
- GiST and GIN Index Types: There are two kinds of indexes that can be used to speed up full text searches
- Inheritance: it is a concept from object-oriented databases, which makes some transactions, like updating, accurate and fast.
- All FHIR operations are done efficiently in a database. This allows developers to use FHIRBASE from their preferred language/platform, and the developers can break FHIR specification abstraction and go into the database by generic SQL interface
- Searching, one of most important operations, is optimized by the GiN and GiST indices
- FHIRBASE perf utility can be used to generate test data

Why HAPIFHIR

After the literature research, HAPIFHIR was chosen. The achieved advantages of using the HAPIFHIR were:

- HTTP E-tags: a method to provide faster ways to read the resources when the content of the resource has not changed
- Using JPA API: a Java application programming interface to manage and store data in any chosen database. Using JPA also provided Java Persistence Query Language (JPQL), which makes queries against entities stored in a relational database, and it provides support for the collection of embedded objects, linked in the ORM with a many-to-one relationship [34]

- HAPIFHIR provides Maven plugin, which provides the ability to export the configuration to allow easy installing for clients and non-expert users
- Command line tool: HAPIFHIR offers a command line tool that invokes main processes in the server such that validation, start and stop server and many other options are available

3.1.3 The YII framework

YII framework was chosen as a web development framework to integrate with the FHIR concept to increase the performance of FHIR as mentioned before, and this was because of the YII features that serve FHIR requirements [57]. Which are:

MVC

YII follows the pattern of Model, View and Controller, which is a widespread technology that separates the software into three interconnected parts to ease the development and separate software logic from user interfaces. Thus, the development process could occur to each part individually without affecting other parts. For example: updating application interfaces without prejudice to other components.

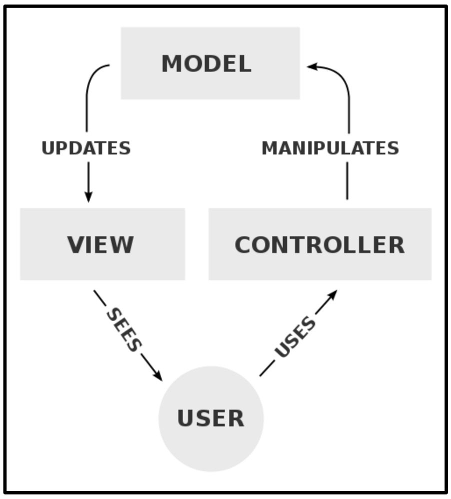


Figure 23: MVC [57]

Part of MVC pattern (see figure 23):

- Model: usually the main component, it deals directly with the rules, data, and logic. It’s independent from user interfaces and experience
- Controller: manages the communication between users, model, and sometimes influences Views behavior
- View: output that the user can see, containing text, pictures, and any other interface elements [36]

In addition to MVC, YII integrates the main controller that receives the requests and collects user e-environment data and redirects the request to the appropriate part. This technique is a kind of pre-exploratory behavior to reach acquired information.

Access to Different DBMS

Using DAO (Data Access Object), YII allows access to different databases using PDO (PHP Data Object) extensions. Accordingly, switching between different database management systems could occur without modifying querying codes. This feature will provide the possibility to connect to many FHIR databases at the same time without any problems [36].

Active Records

Using the Object-Relational Mapping (ORM) approach, YII can represent database and implicitly tables as objects with attributes. In this way, database queries will be a type of objective oriented programming Instructions, and this is exactly what FHIR specifications need [36].

Three Layers of Input Validation

Interface forms and fields creation is always associated with the concerns of validation and display of appropriate messages, such as warning or error message. In YII, the MVC architecture, there are three generated layers of validation, starting with databases model constraints validation, then the controller rising exception errors, and finally, the user interface direct or indirect validation. With this, all incorrect entries to the system were avoided, and this allowed all errors to be corrected before the entry phase [36].

Authentication and Authorization

Using a built-in authentication/authorization (Auth) framework, YII can provide a wide range of user identity verification. For example: email-password pairs, Username-password pairs, and two-factor authentication.

Other types of authentications for distributed systems could be integrated, such as, tokens which are used frequently in web service authentication design. This is vital for systems that require a high level of authentication and authorization to manage the access control for the system users and admins [36].

Access Levels Control

Using a preliminary authorization scheme, YII can check whether a user has the permission to access a certain Controller or for a specific action.

The authorization could be based on user credentials, IP address, or based on HTTP requests types, and the patient should have the ability to give the permission to the specific practitioners to view their records and make some analysis processes for it [36].

Web Service Support

Web service is the communication way between two or more E-Systems via the World Wide Web network achieved by different technology such as XML, JSON, and HTTP.

YII simplifies the design and implementation of web services using certain classes that allow the inheritance for child customized classes.

Also, by using class mapping, data types definition, and MVC pattern design, a coherent web service could be achieved. This will serve the goals of this project [36].

Languages Translation

In YII, the developer can set the parameters of localization and languages, displaying messages and variables in the user's preferred language, and there is a possibility to switch between different date, time, and number formats based on the preferred localization settings.

These changes could be addressed without changing the logic (main code parts) of the application [36].

Cache

Caching is the best way to improve the performance of a certain application without wasting big hardware resources. The basic idea behind web-caching is to store frequent requests in forms of ready generated files and use it as a response instead of making repeated queries. YII delivers a strong technique to generate different cache types. This gives systems the ability to work fast and analyze a high number of queries [36].

High Security

By using the advantages of MVC pattern design and active records hierarchy, the generated queries and input/output procedures are highly protected. YII is immune to many common web threats, such as: Cross-site Scripting, Cross-site Request Forgery, and Cookie Attacks [36].

Extensibility

Extensibility and scalability could be the most important feature in any open source software, and YII carefully designed tools to integrate 3rd-party libraries to extend YII functionalities by using most modern concepts, such as: name spaces, autoloaders, and composer-integration. This allows the system to be extended when needed. [36].

3.2 Results of the Developed System

After finishing the implementation and testing step, the following results were obtained.

3.2.1 Used Tools

The following tools and technologies were used in this project:

- Windows 10 as operating system
- PHP 5.6.25
- MYSQL 5.7.14
- Apache server 2.4.23
- YII 2.0 framework
- PostgresSQL 9.6.1
- FHIR standard DSTU2, 1.0.2
- HAPIFHIR 1.3 - 2.2
- FHIRBASE-Plv8 server
- D-Carbone/ PHP-FHIR library

These tools were used in the implementation step to achieve all required project goals.

3.2.2 The Implementation

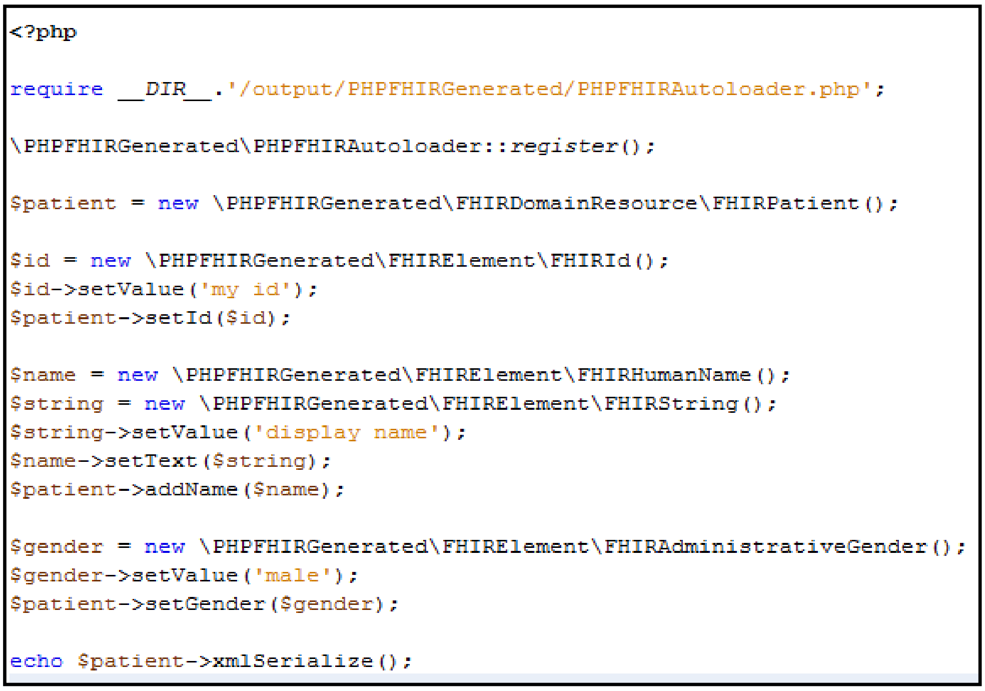
As mentioned before, the chosen tools were used and integrated to each other to build the system, which is the focus in this thesis on the server side.

3.2.2.1 The Server Side

As mentioned before, this part contains implementation of the resource management and analysis tools. The results for this part are as follows:

Resources Management Tool

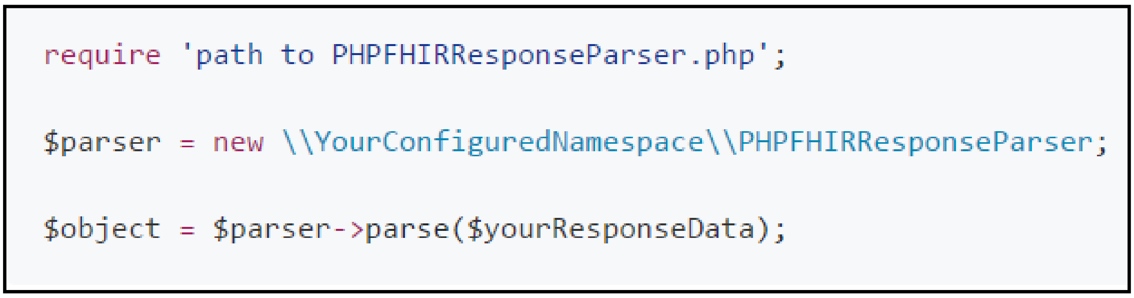
This tool was implemented in a way that allowed the user to create, delete, update, search, and see the history activities for the patient, practitioner, organization, observation, and diagnostic resources. All transactions were done according to the FHIR API’s specification. By using D-Carbone/ PHP-FHIR library, which is a PHP library, gave the system the possibility to generate the FHIR classes, which are the resources (See figure 24).



```php
<?php

require __DIR__.'/output/PHPFHIRGenerated/PHPFHIRAutoloader.php';

\PHPFHIRGenerated\PHPFHIRAutoloader::register();

$patient = new \PHPFHIRGenerated\FHIRDomainResource\FHIRPatient();

$id = new \PHPFHIRGenerated\FHIRElement\FHIRId();
$id->setValue('my id');
$patient->setId($id);

$name = new \PHPFHIRGenerated\FHIRElement\FHIRHumanName();
$string = new \PHPFHIRGenerated\FHIRElement\FHIRString();
$string->setValue('display name');
$name->setText($string);
$patient->addName($name);

$gender = new \PHPFHIRGenerated\FHIRElement\FHIRAdministrativeGender();
$gender->setValue('male');
$patient->setGender($gender);

echo $patient->xmlSerialize();
```

Figure 24: The D-Carbone library

Also, the D-Carbone allowed the parsing of all objects that were received from other systems (or from telemonitoring systems), and here is an example of the parsing process as it is shown in the figure 25 below:



```php
require 'path to PHPFHIRResponseParser.php';

$parser = new \\YourConfiguredNamespace\\PHPFHIRResponseParser;

$object = $parser->parse($yourResponseData);
```

Figure 25: parsing part in D-Carbone

After installing the library and testing it, YII framework was integrated to execute all the transactions that related to the resources.

The reading transaction for each resource was done in many steps. A web interface that provides the user a readable part to choose the searching parameters, like searching for patient resource for specific patient ID was created. After that, the GET request is sent by HTTP connection to the API client, which then contacts the FHIR server, which in its turn returns the required message to parse by FHIR PHP class, and then it is converted to the readable form and presented it in the interface. The figure 26 below shows the reading process.

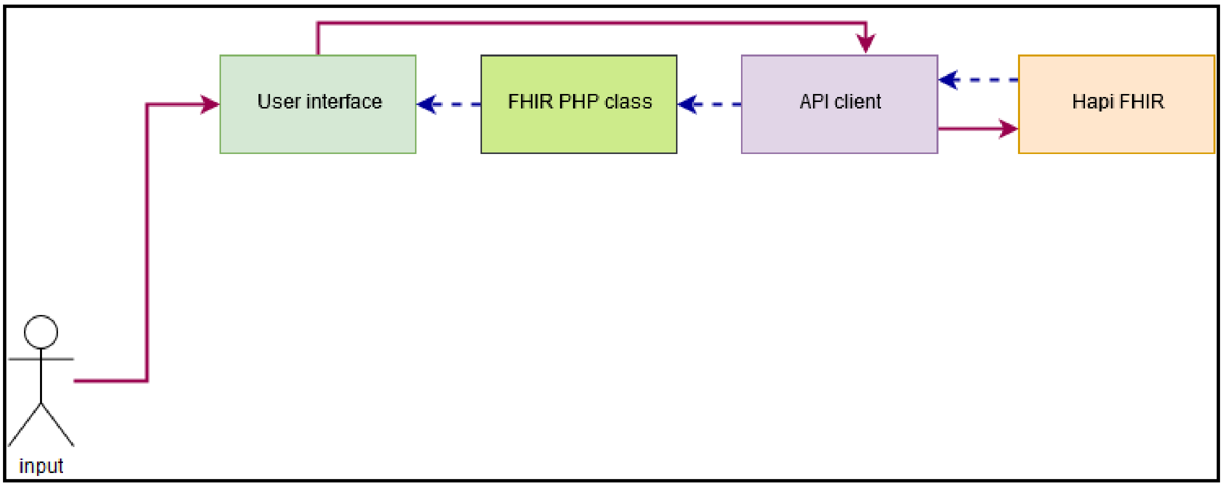


Figure 26: Resources reading

Creating the resources are done in a similar way, by using the web interface. The user enters the data in the resources fields, which were creating according to the FHIR resources structure, after that, the FHIR PHP class will convert all this data to the FHIR message, and by using POST request and API client, the message will submit to the FHIR server (See figure 27).

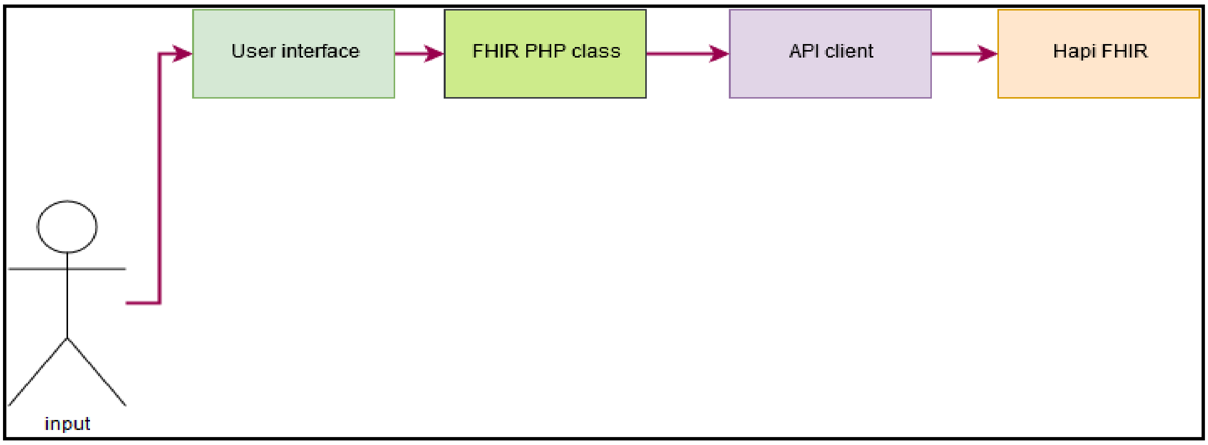


Figure 27: Resources creating

The validation action is like creating. The only difference is that in the validation process, the user makes a validation for the specific resource by sending the request to the server, and after that, they will receive a response from the server about the validation result. Figure 28 below shows the validation step.

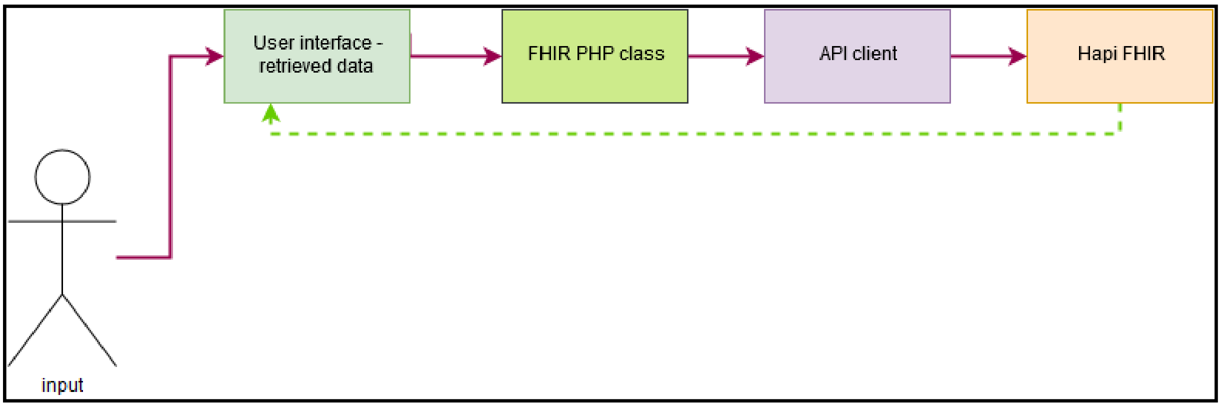


Figure 28: Resources validation

The history step is like creating, the difference is in the response message. In the history phase the response will be about the events that happened for the resources, like when other users update a resource or delete it. Figure 29 below show the history step.

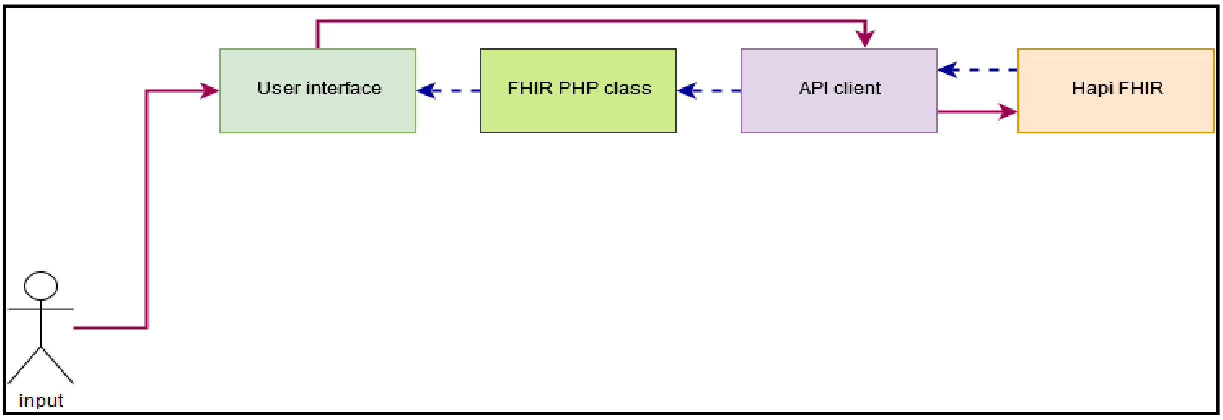


Figure 29: Resources history transaction

DELETE request was used to delete specific resources. The user sends a delete request by API service to the server and deletes it. After that, the user will receive a confirmation that the resource was deleted (see figure 30).

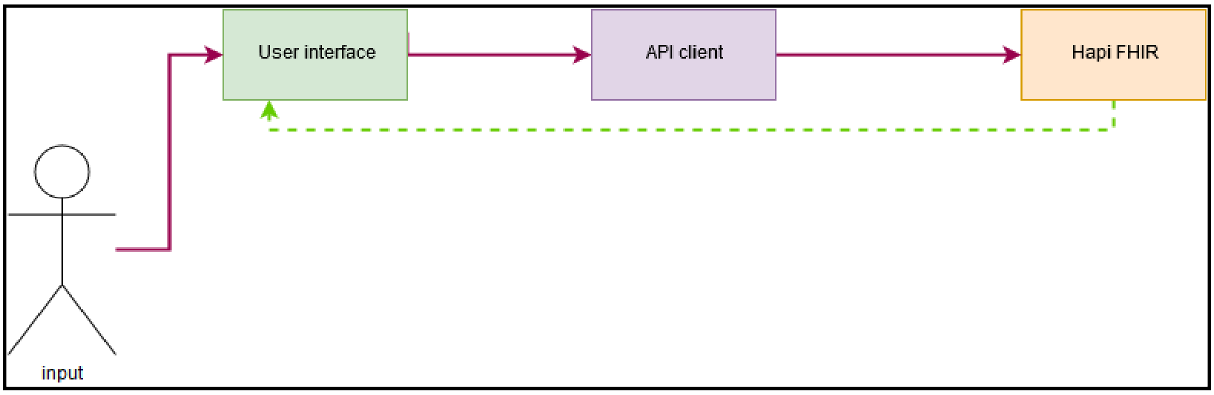
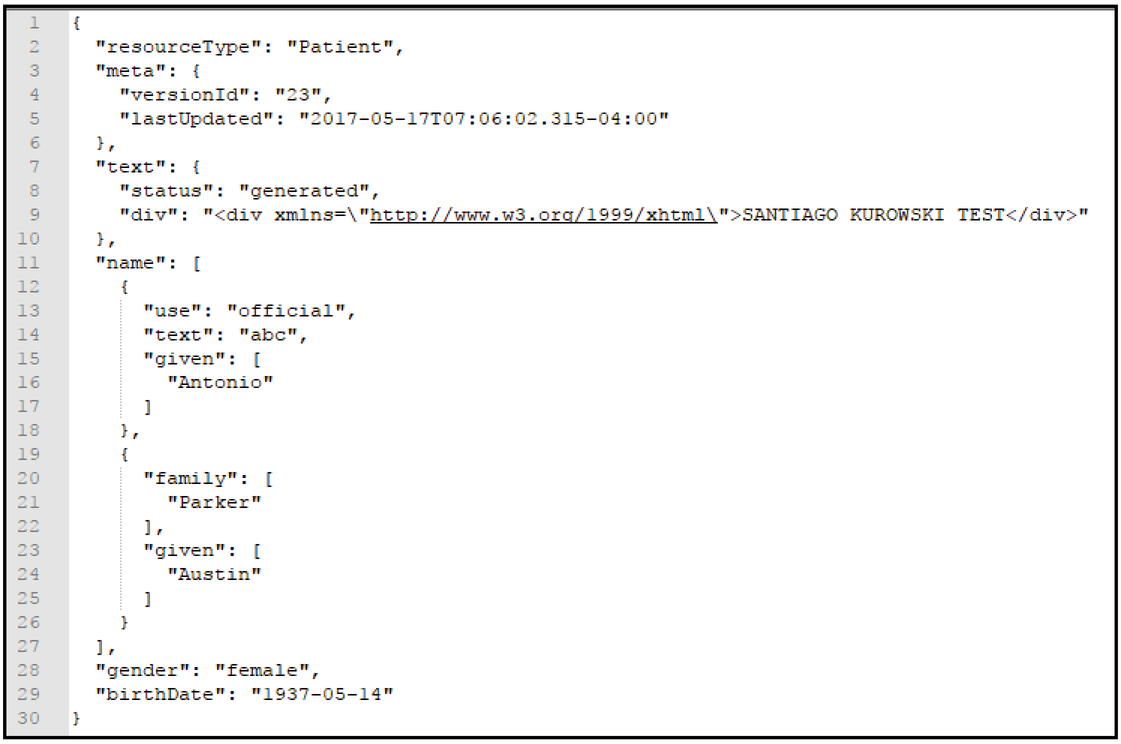


Figure 30: Resources deleting

The other systems (or the telemonitoring system) create a new patient resource in the system by using the HTTP verb POST with this API URL:
http://localhost/fhir/admin/api/Patient?_format=json&_pretty=true&auth_key=1jmfFnqDeX85oxrD6P9OP0A3CPVYty7b

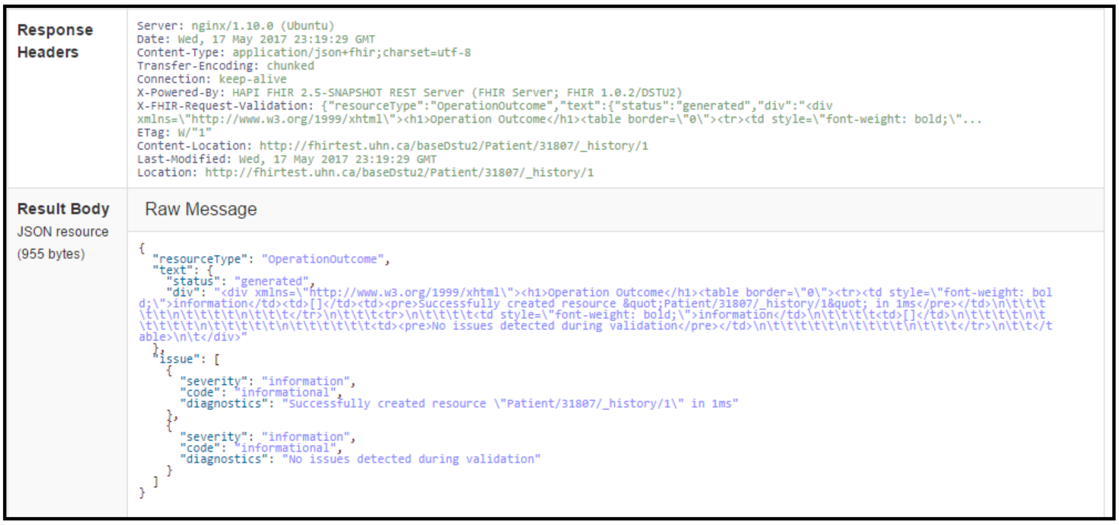
The new patient resource should be added after creating an account on the system site. As mentioned before, the admin can create a patient account in the system to allow users to view their medical records. After creating a new account for the patient, the mobile application sends the patient resource (see figure 31) by using the API to the server where the resource is stored, and then it receives a confirmation from the server that a new resource was added successfully (see figure 32).
Each user has one patient account, so this API should be used only once, and after that, the user can use the update API for changing patient data.



```
{
  "resourceType": "Patient",
  "meta": {
    "versionId": "23",
    "lastUpdated": "2017-05-17T07:06:02.315-04:00"
  },
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\">SANTIAGO KUROWSKI TEST</div>"
  },
  "name": [
    {
      "use": "official",
      "text": "abc",
      "given": [
        "Antonio"
      ]
    },
    {
      "family": [
        "Parker"
      ],
      "given": [
        "Austin"
      ]
    }
  ],
  "gender": "female",
  "birthDate": "1937-05-14"
}
```

Figure 31: Mobile patient resource

And the response for this query is:



Response Headers

```
Server: nginx/1.10.0 (Ubuntu)
Date: Wed, 17 May 2017 23:19:29 GMT
Content-Type: application/json+fhir;charset=utf-8
Transfer-Encoding: chunked
Connection: keep-alive
X-Powered-By: HAPI FHIR 2.5-SNAPSHOT REST Server (FHIR Server; FHIR 1.0.2/DSTU2)
X-FHIR-Request-Validation: {"resourceType":"OperationOutcome","text":{"status":"generated","div":"<div
xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bold;\"...
ETag: W/"1"
Content-Location: http://fhirtest.uhn.ca/baseDstu2/Patient/31807/_history/1
Last-Modified: Wed, 17 May 2017 23:19:29 GMT
Location: http://fhirtest.uhn.ca/baseDstu2/Patient/31807/_history/1
```

Result Body
JSON resource
(955 bytes)

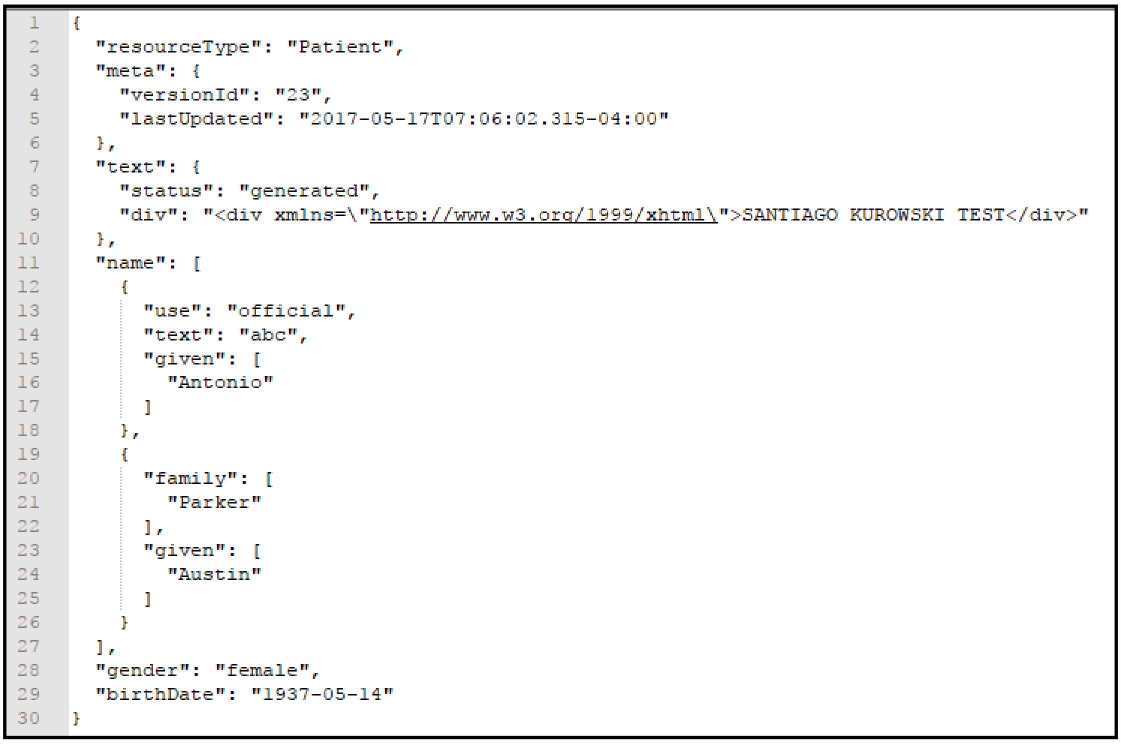
Raw Message

```
{
  "resourceType": "OperationOutcome",
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bol
d;\">information</td><td>[]</td><td><pre>Successfully created resource &quot;Patient/31807/_history/1&quot; in 1ms</pre></td>\n\t\t\t
\t\t\n\t\t\t\t\n\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">information</td>\n\t\t\t\t<td>[]</td>\n\t\t\t\t\n\t
\t\t\t\n\t\t\t\t\t\n\t\t\t\t\t\t<td><pre>No issues detected during validation</pre></td>\n\t\t\t\t\t\n\t\t\t\t\t\n\t\t\t</tr>\n\t\t</t
able>\n\t</div>"
  },
  "issue": [
    {
      "severity": "information",
      "code": "informational",
      "diagnostics": "Successfully created resource \"Patient/31807/_history/1\" in 1ms"
    },
    {
      "severity": "information",
      "code": "informational",
      "diagnostics": "No issues detected during validation"
    }
  ]
}
```

Figure 32: Server response

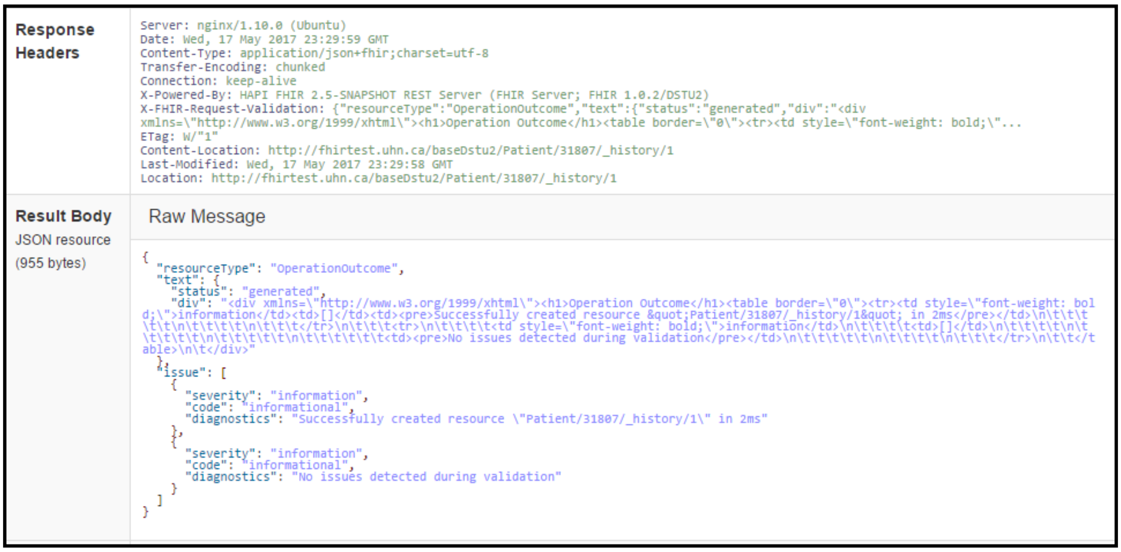
When the users want to update their resources, they use the HTTP verb PUT with the following API:
http://localhost/fhir/admin/api/Patient/31807?_format=json&_pretty=true&auth_key=1jmfFnqDeX85oxrD6P9OP0A3CPVYty7b

After submitting the updated resource to the server (see figure 33), the client receives a response from the server (see figure 34) about the status of the resource.



```
{
  "resourceType": "Patient",
  "meta": {
    "versionId": "23",
    "lastUpdated": "2017-05-17T07:06:02.315-04:00"
  },
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\">SANTIAGO KUROWSKI TEST</div>"
  },
  "name": [
    {
      "use": "official",
      "text": "abc",
      "given": [
        "Antonio"
      ]
    },
    {
      "family": [
        "Parker"
      ],
      "given": [
        "Austin"
      ]
    }
  ],
  "gender": "female",
  "birthDate": "1937-05-14"
}
```

Figure 33: Mobile patient resource to update



Response Headers

```
Server: nginx/1.10.0 (Ubuntu)
Date: Wed, 17 May 2017 23:29:59 GMT
Content-Type: application/json+fhir;charset=utf-8
Transfer-Encoding: chunked
Connection: keep-alive
X-Powered-By: HAPI FHIR 2.5-SNAPSHOT REST Server (FHIR Server; FHIR 1.0.2/DSTU2)
X-FHIR-Request-Validation: {"resourceType":"OperationOutcome","text":{"status":"generated","div":"<div
xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bold;\"...
ETag: W/"1"
Content-Location: http://fhirtest.uhn.ca/baseDstu2/Patient/31807/_history/1
Last-Modified: Wed, 17 May 2017 23:29:58 GMT
Location: http://fhirtest.uhn.ca/baseDstu2/Patient/31807/_history/1
```

Result Body
JSON resource
(955 bytes)

Raw Message

```
{
  "resourceType": "OperationOutcome",
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bol
d;\">information</td><td>[]</td><td><pre>Successfully created resource &quot;Patient/31807/_history/1&quot; in 2ms</pre></td>\n\t\t\t
\t\t\n\t\t\t\t\n\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">information</td>\n\t\t\t\t<td>[]</td>\n\t\t\t\t\n\t
\t\t\t\n\t\t\t\t\t\n\t\t\t\t\t\t<td><pre>No issues detected during validation</pre></td>\n\t\t\t\t\t\n\t\t\t\t\n\t\t\t</tr>\n\t\t</t
able>\n\t</div>"
  },
  "issue": [
    {
      "severity": "information",
      "code": "informational",
      "diagnostics": "Successfully created resource \"Patient/31807/_history/1\" in 2ms"
    },
    {
      "severity": "information",
      "code": "informational",
      "diagnostics": "No issues detected during validation"
    }
  ]
}
```

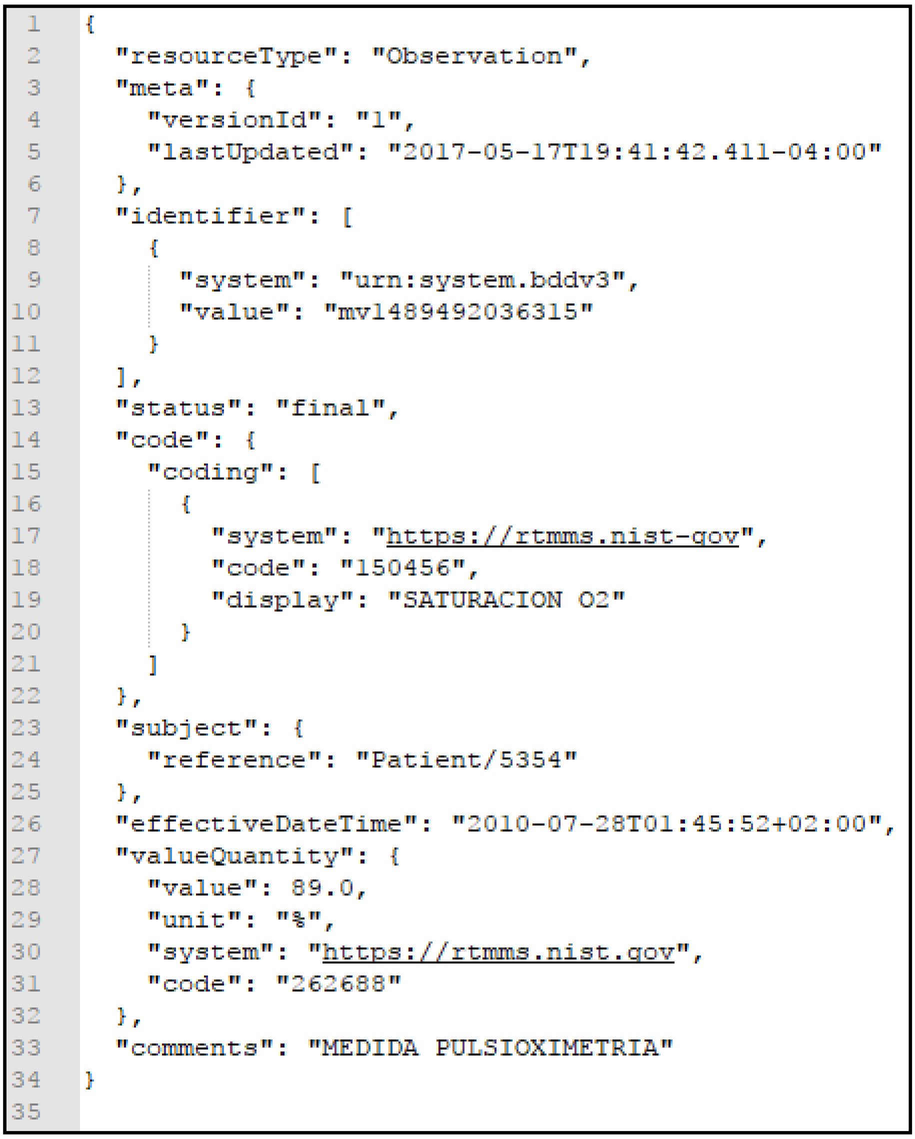
Figure 34: Server response for updating

In the observation resource, the process is done in the same way as the patient resource, which achieves the FHIR specification regarding the API.

The user sends the observation resource (see figure 35) by using the following API:

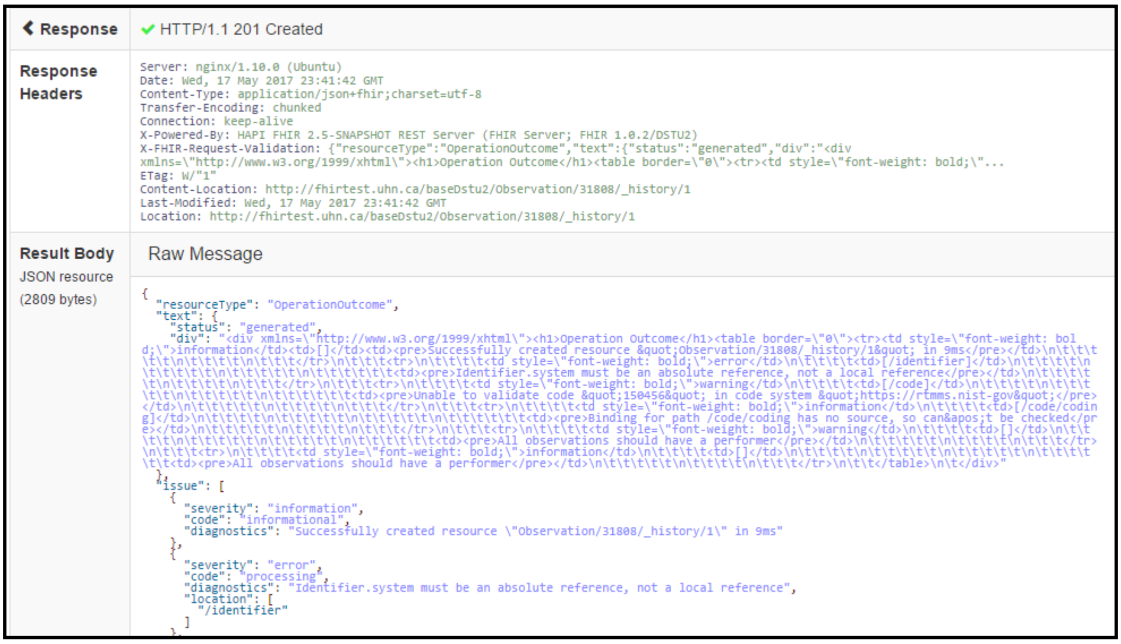
http://localhost/fhir/admin/api/observation?_format=json&_pretty=true&auth_key=1jmfFnqDeX85oxrD6P9OP0A3CPVYty7b

After that, they will receive a response from the server (see figure 36) about the result of this creating including the ID of this resource with the errors and warnings.



```json
{
  "resourceType": "Observation",
  "meta": {
    "versionId": "1",
    "lastUpdated": "2017-05-17T19:41:42.411-04:00"
  },
  "identifier": [
    {
      "system": "urn:system.bddv3",
      "value": "mv1489492036315"
    }
  ],
  "status": "final",
  "code": {
    "coding": [
      {
        "system": "https://rtmms.nist-gov",
        "code": "150456",
        "display": "SATURACION O2"
      }
    ]
  },
  "subject": {
    "reference": "Patient/5354"
  },
  "effectiveDateTime": "2010-07-28T01:45:52+02:00",
  "valueQuantity": {
    "value": 89.0,
    "unit": "%",
    "system": "https://rtmms.nist.gov",
    "code": "262688"
  },
  "comments": "MEDIDA PULSIOXIMETRIA"
}
```

Figure 35: Mobile observation resource



```
Server: nginx/1.10.0 (Ubuntu)
Date: Wed, 17 May 2017 23:41:42 GMT
Content-Type: application/json+fhir;charset=utf-8
Transfer-Encoding: chunked
Connection: keep-alive
X-Powered-By: HAPI FHIR 2.5-SNAPSHOT REST Server (FHIR Server; FHIR 1.0.2/DSTU2)
X-FHIR-Request-Validation: {"resourceType":"OperationOutcome","text":{"status":"generated","div":"<div
xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bold;\"...
ETag: W/"1"
Content-Location: http://fhirtest.uhn.ca/baseDstu2/Observation/31808/_history/1
Last-Modified: Wed, 17 May 2017 23:41:42 GMT
Location: http://fhirtest.uhn.ca/baseDstu2/Observation/31808/_history/1
```

```
{
  "resourceType": "OperationOutcome",
  "text": {
    "status": "generated",
    "div": "<div xmlns=\"http://www.w3.org/1999/xhtml\"><h1>Operation Outcome</h1><table border=\"0\"><tr><td style=\"font-weight: bol
d;\">information</td><td>[]</td><td><pre>Successfully created resource &quot;Observation/31808/_history/1&quot; in 9ms</pre></td>\n\t\t\t
\t\t\n\t\t\t\t\t\n\t\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">error</td>\n\t\t\t\t<td>[/identifier]</td>\n\t\t\t\t\n
\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t\t\t\t<td><pre>Identifier.system must be an absolute reference, not a local reference</pre></td>\n\t\t\t\t\t
\t\n\t\t\t\t\t\n\t\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">warning</td>\n\t\t\t\t<td>[/code]</td>\n\t\t\t\t\t\n\t\t\t\t\t
\t\t\n\t\t\t\t\t\t\n\t\t\t\t\t\t\t<td><pre>Unable to validate code &quot;150456&quot; in code system &quot;https://rtmms.nist-gov&quot;</pre>
</td>\n\t\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">information</td>\n\t\t\t\t<td>[/code/codin
g]</td>\n\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t\t\t\t\n\t\t\t\t\t\t\t\t<td><pre>Binding for path /code/coding has no source, so can&apos;t be checked</pr
e></td>\n\t\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t</tr>\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">warning</td>\n\t\t\t\t<td>[]</td>\n\t\t\t
\t\t\n\t\t\t\t\t\t\n\t\t\t\t\t\t\t\n\t\t\t\t\t\t\t\t<td><pre>All observations should have a performer</pre></td>\n\t\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t</tr>
\n\t\t\t<tr>\n\t\t\t\t<td style=\"font-weight: bold;\">information</td>\n\t\t\t\t<td>[]</td>\n\t\t\t\t\t\n\t\t\t\t\t\t\n\t\t\t\t\t\t\t\n\t\t\t\t\t
\t\t<td><pre>All observations should have a performer</pre></td>\n\t\t\t\t\t\n\t\t\t\t\t\n\t\t\t\t</tr>\n\t\t</table>\n\t</div>"
  },
  "issue": [
    {
      "severity": "information",
      "code": "informational",
      "diagnostics": "Successfully created resource \"Observation/31808/_history/1\" in 9ms"
    },
    {
      "severity": "error",
      "code": "processing",
      "diagnostics": "Identifier.system must be an absolute reference, not a local reference",
      "location": [
        "/identifier"
      ]
    },
```

Figure 36: Observation Server response

To read a specific observation resource, users should use the following API:
http://localhost/fhir/admin/api/Observation/11890?_format=json&_pretty=true

All FHIR specifications regarding the API's were applied, and the system can now communicate with the other systems by FHIR API's as it is shown in table 2, which shows all API's in the system.

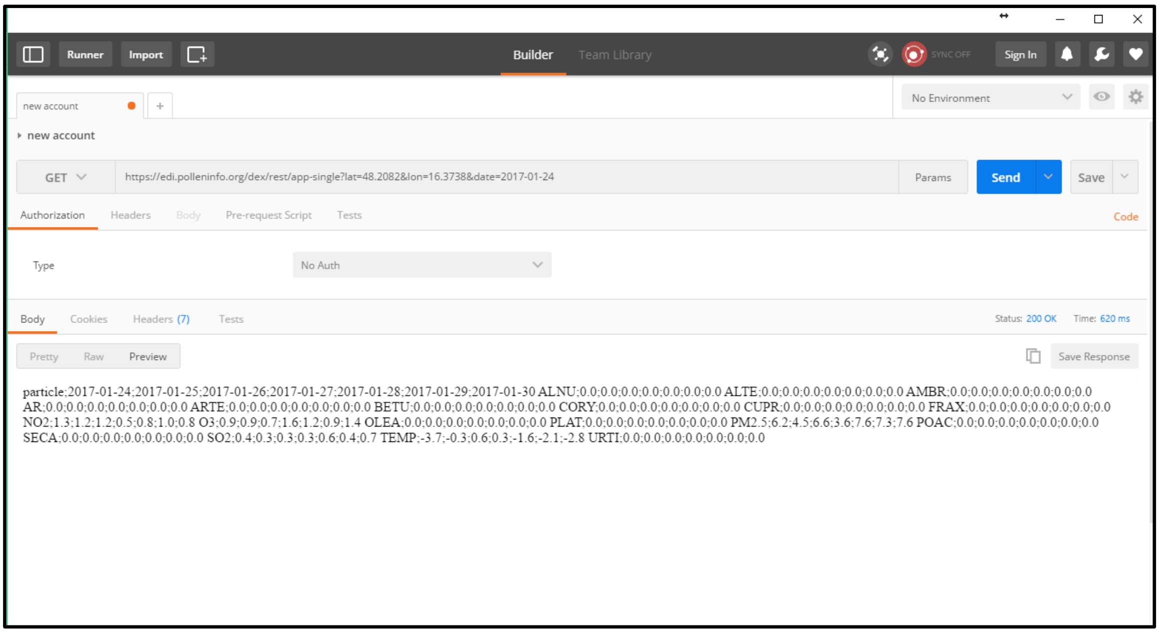
Patient Resource	
Creating	http://localhost/fhir/admin/api/Patient?_format=ison&_pretty=true
Deleting	http://localhost/fhir/admin/api/Patient/27944?_format=json&_pretty=true
Updating	http://localhost/fhir/admin/api/Patient/31807?_format=json&_pretty=true
Reading	http://localhost/fhir/admin/api/ Patient/27944?_format=json&_pretty=true
History	http://localhost/fhir/admin/api/Patient/27944/_history?_format=json&_pretty=true
Practitioner Resource	
Creating	http://localhost/fhir/admin/api/ Practitioner?_format=json&_pretty=true
Deleting	http://localhost/fhir/admin/api/Practitioner/27944?_format=json&_pretty=true
Updating	http://localhost/fhir/admin/api/Practitioner/31807?_format=json&_pretty=true
Reading	http://localhost/fhir/admin/api /Practitioner/3178?_format=json&_pretty=true
History	http://localhost/fhir/admin/api/Practitioner/27944/_history?_format=json&_pretty=true
Organization Resource	
Creating	http://localhost/fhir/admin/api/ Organization?_format=json&_pretty=true
Deleting	http://localhost/fhir/admin/api/ Organization/27944?_format=json&_pretty=true
Updating	http://localhost/fhir/admin/api/ Organization /31807?_format=json&_pretty=true
Reading	http://localhost/fhir/admin/api /Organization/13404?_format=json&_pretty=true
History	http://localhost/fhir/admin/api/Organization/27944/_history?_format=json&_pretty=true

Observation Resource	
Creating	http://localhost/fhir/admin/api/observation?_format=json&_pretty=true
Deleting	http://localhost/fhir/admin/api/Observation/27944?_format=json&_pretty=true
Updating	http://localhost/fhir/admin/api/Observation/11890?_format=json&_pretty=true
Reading	http://localhost/fhir/admin/api/Observation/11890?_format=json&_pretty=true
History	http://localhost/fhir/admin/api/Observation/11890/_history?_format=json&_pretty=true
Diagnostic Resource	
Creating	http://localhost/fhir/admin/api/DiagnosticReport/3565?_format=json&_pretty=true
Deleting	http://localhost/fhir/admin/api /DiagnosticReport/3565?_format=json&_pretty=true
Updating	http://localhost/fhir/admin/api/ DiagnosticReport /27944?_format=json&_pretty=true
Reading	http://localhost/fhir/admin/api/ DiagnosticReport/27944?_format=json&_pretty=true
History	http://localhost/fhir/admin/api/ DiagnosticReport /11890/_history?_format=json&_pretty=true

Table 2: Project API's

Analysis Tool

As mentioned before, in this part, pollen records were retrieved from the Medical University of Vienna API URL, which was integrated in the written code. Pollen data was retrieved in CSV form (see figure 37). After that, the data was stored as an extension in the FHIR resources, and was analyzed by calling it each time.



No Environment

GET https://edi.polleninfo.org/dex/rest/app-single?lat=48.2082&lon=16.3738&date=2017-01-24

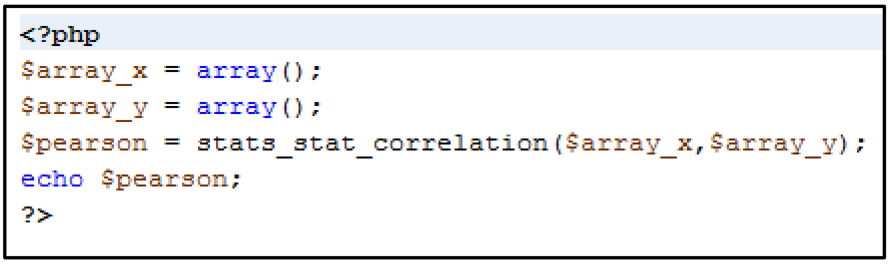
Type: No Auth

Status: 200 OK Time: 620 ms

```
particle;2017-01-24;2017-01-25;2017-01-26;2017-01-27;2017-01-28;2017-01-29;2017-01-30 ALNU;0.0;0.0;0.0;0.0;0.0;0.0;0.0 ALTE;0.0;0.0;0.0;0.0;0.0;0.0;0.0 AMBR;0.0;0.0;0.0;0.0;0.0;0.0;0.0
AR;0.0;0.0;0.0;0.0;0.0;0.0;0.0 ARTE;0.0;0.0;0.0;0.0;0.0;0.0;0.0 BETU;0.0;0.0;0.0;0.0;0.0;0.0;0.0 CORY;0.0;0.0;0.0;0.0;0.0;0.0;0.0 CUPR;0.0;0.0;0.0;0.0;0.0;0.0;0.0 FRAX;0.0;0.0;0.0;0.0;0.0;0.0;0.0
NO2;1.3;1.2;1.2;0.5;0.8;1.0;0.8 O3;0.9;0.9;0.7;1.6;1.2;0.9;1.4 OLEA;0.0;0.0;0.0;0.0;0.0;0.0;0.0 PLAT;0.0;0.0;0.0;0.0;0.0;0.0;0.0 PM2.5;6.2;4.5;6.6;3.6;7.6;7.3;7.6 POAC;0.0;0.0;0.0;0.0;0.0;0.0;0.0
SECA;0.0;0.0;0.0;0.0;0.0;0.0;0.0 SO2;0.4;0.3;0.3;0.3;0.6;0.4;0.7 TEMP;-3.7;-0.3;0.6;0.3;-1.6;-2.1;-2.8 URTI;0.0;0.0;0.0;0.0;0.0;0.0;0.0
```

Figure 37: Pollen API response

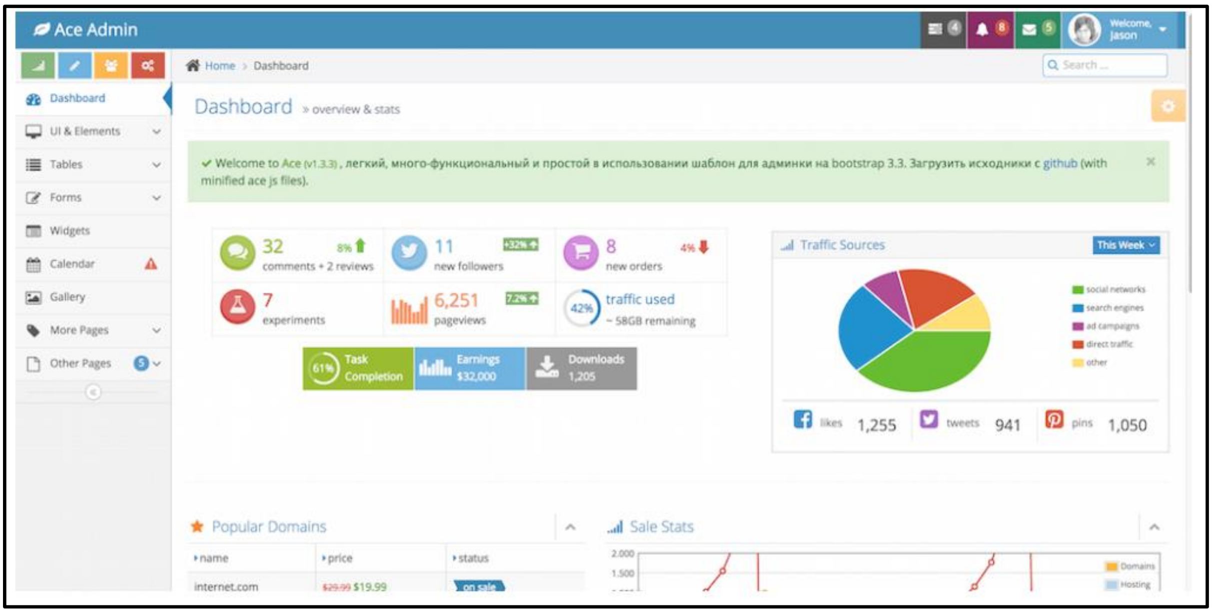
After that, the correlation coefficient was calculated between the data and blood pressure measurements by using PHP correlation function (see figure 38).



```php
<?php
$array_x = array();
$array_y = array();
$pearson = stats_stat_correlation($array_x,$array_y);
echo $pearson;
?>
```

Figure 38: PHP correlation function

PHP visualization tool was used to visualize the results in the graphs beside an HTML5 admin platform called ACE (see figure 39).

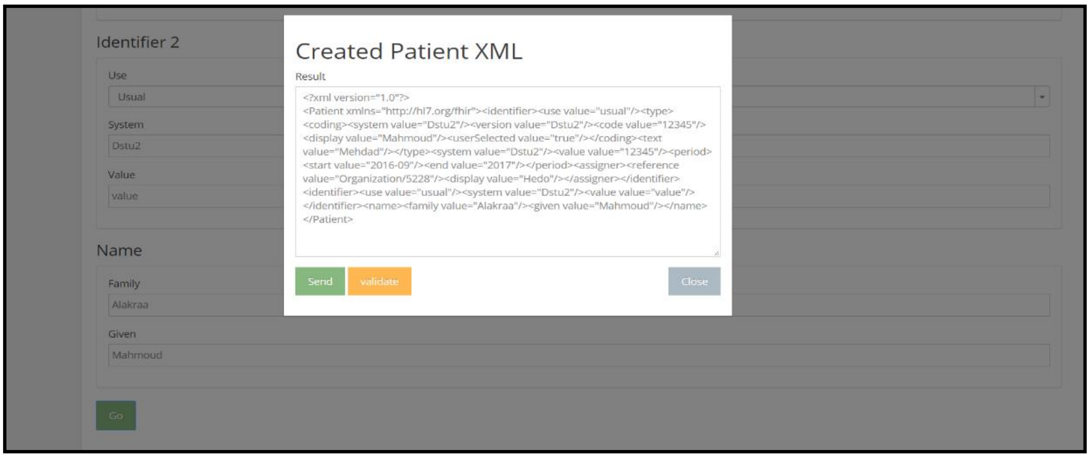


✓ Welcome to Ace (v1.3.3) , легкий, много-функциональный и простой в использовании шаблон для админки на bootstrap 3.3. Загрузить исходники с github (with minified ace js files).

Figure 39: HTML ACE panel [52]

3.2.3 Testing and Verification

All system parts were tested after the implementation, and everything worked without any problem. HAPIFHIR validation tool (see figure 40) was used to check the resource's structures before exchanging them between system parts.



Identifier 2

Use

Usual

System

Dstu2

Value

value

Name

Family

Alakraa

Given

Mahmoud

Created Patient XML

Result

```
<?xml version="1.0"?>
<Patient xmlns="http://hl7.org/fhir"><identifier><use value="usual"/><type>
<coding><system value="Dstu2"/><version value="Dstu2"/><code value="12345"/>
<display value="Mahmoud"/><userSelected value="true"/></coding><text
value="Mehdad"/></type><system value="Dstu2"/><value value="12345"/><period>
<start value="2016-09"/><end value="2017"/></period><assigner><reference
value="Organization/5228"/><display value="Hedo"/></assigner></identifier>
<identifier><use value="usual"/><system value="Dstu2"/><value value="value"/>
</identifier><name><family value="Alakraa"/><given value="Mahmoud"/></name>
</Patient>
```

Figure 40: Validation step

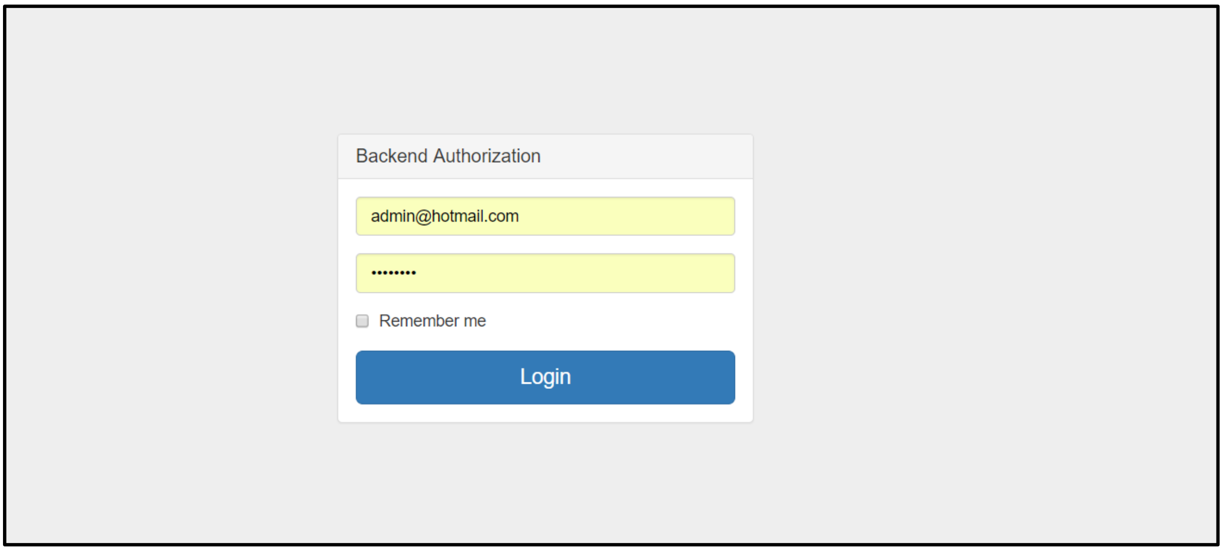
Also, many helping tools were implemented into the system, like supporting interfaces, which allowed users to contact the developers if anything went wrong.

3.3 The visible results

The system provides an access control management tool, which YII framework provided. It is an action filter. In each logging time, it will check its rules to find the first rule that matches the current context variables (such as user IP address, user role). The matching rule will dictate whether to allow access to the requested controller action. If no rule matches, the access will be denied

The first time the user opens the system, they must access as one of three options:

- As admin (see figure 41): in this case, the admin can access to all parts in the system and use all tools in the platform
- As user (see figure 42): in this case, the user (the patient) can only log into their records and view them without any possibility to edit them
- As researcher: in this case, the researcher can only log in to the analysis tool and start it (see figure 43)



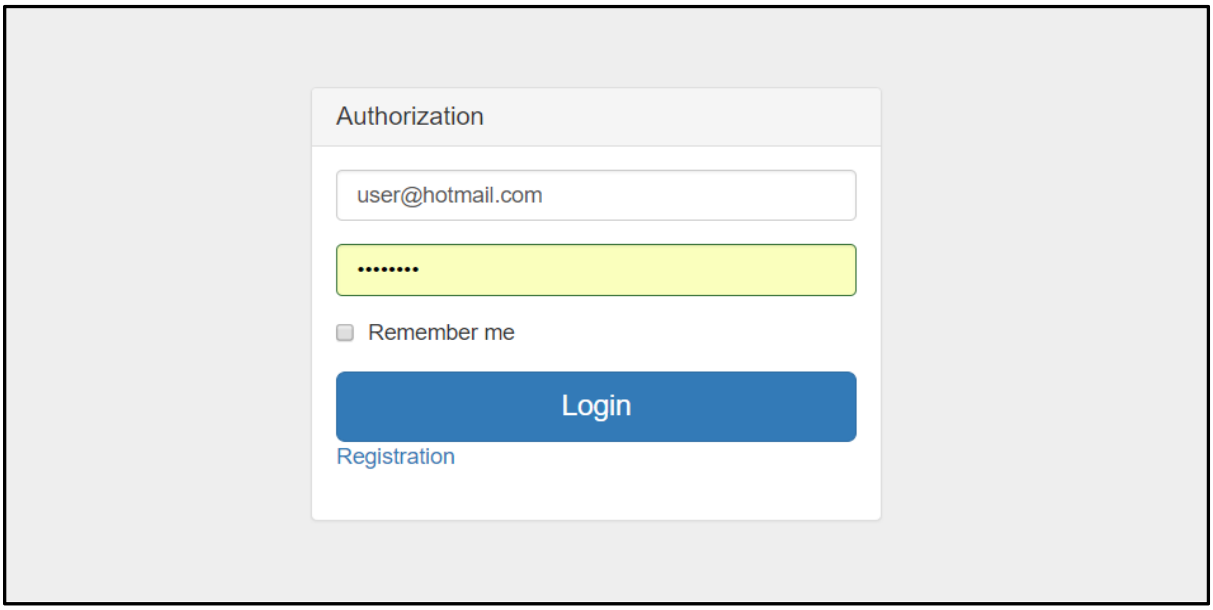
Backend Authorization

admin@hotmail.com

••••••••

□ Remember me

Figure 41: Admin access



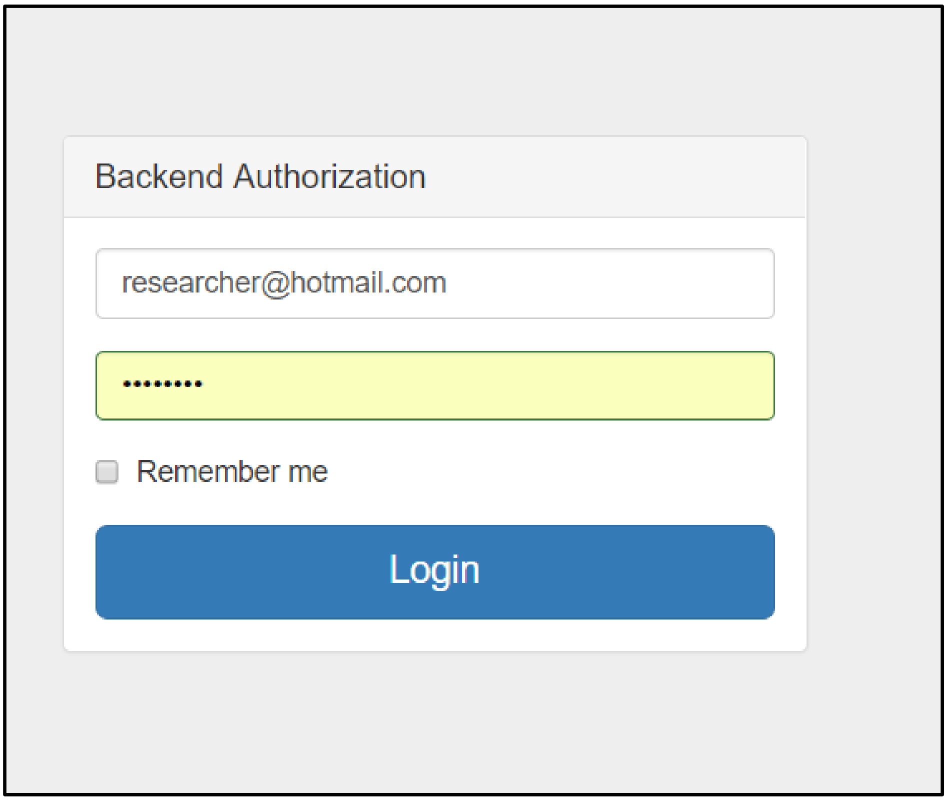
Authorization

user@hotmail.com

••••••••

□ Remember me

Figure 42: User access



Backend Authorization

researcher@hotmail.com

••••••••

□ Remember me

Login

Figure 43: Researcher access

After the login step, the user finds the home site (see figure 44), which contains a pie chart that shows the system status, number of resources in the server, users information, and the last analysis graph. This site gave an example for applying the ACE panel.

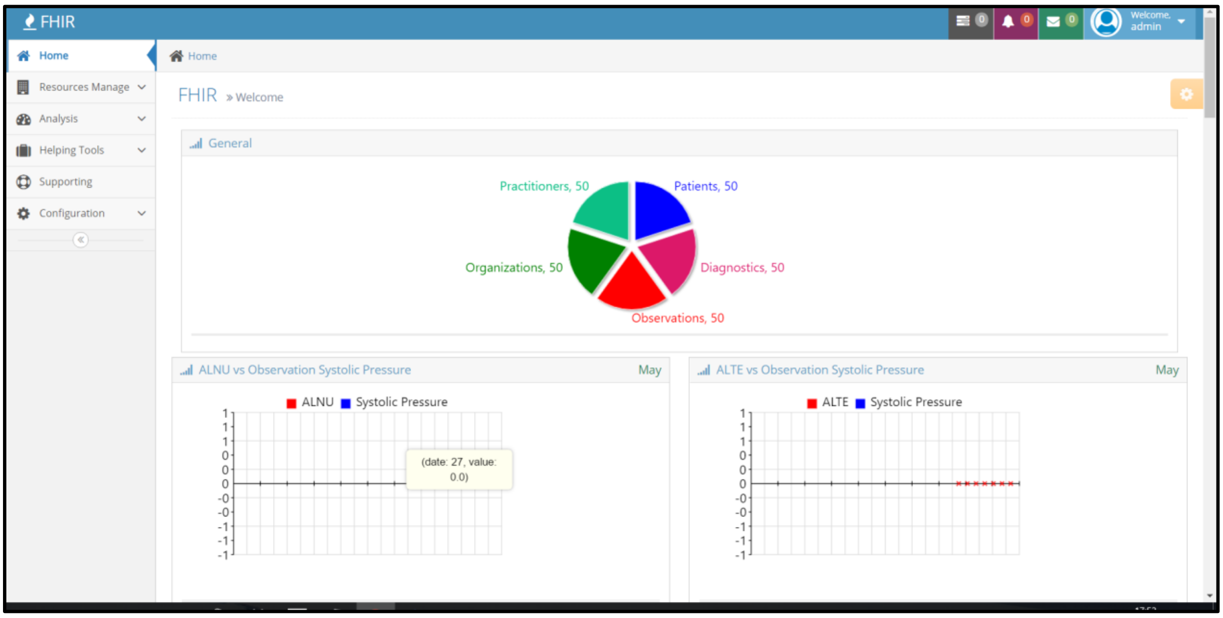
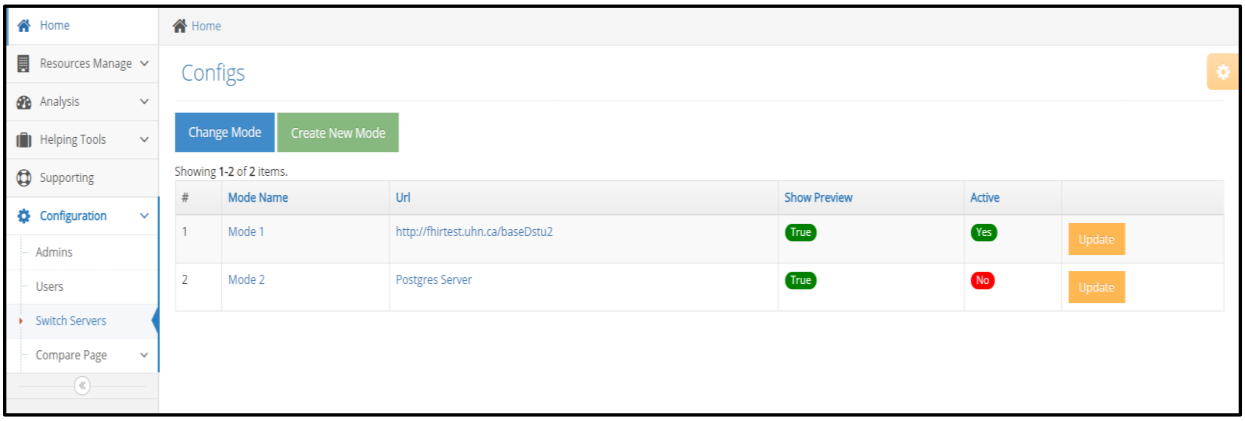


Figure 44: Home page in the application

All methods were applied and worked as supposed, and both FHIR servers (HAPIFHIR and FHIRBASE) supported the system. There is a possibility to switch between HAPIFHIR and FHIRBASE servers (see figure 45), keeping the same performance and interoperability.



Configs

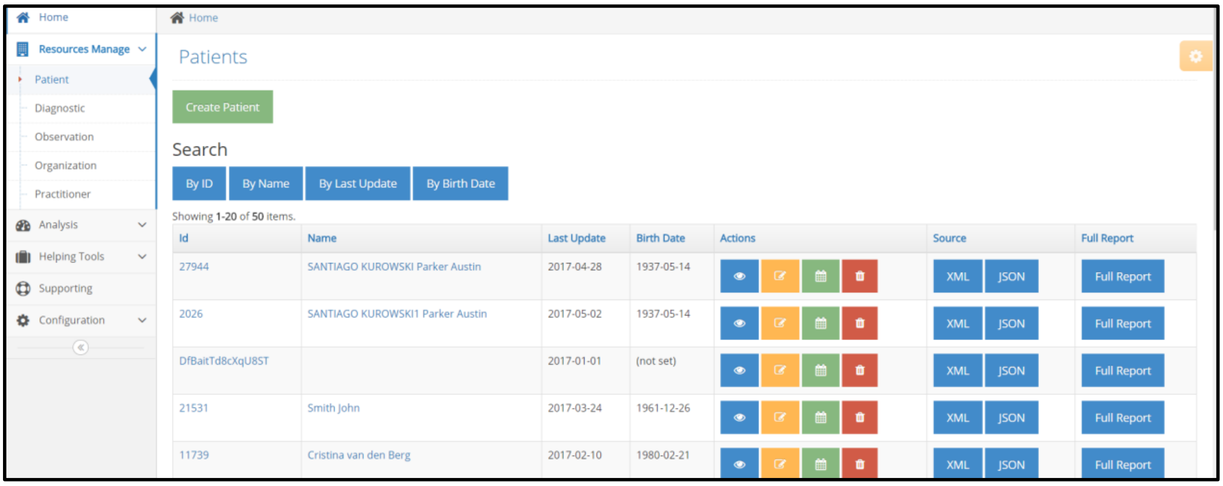
Showing **1-2** of **2** items.

#	Mode Name	Url	Show Preview	Active	
1	Mode 1	http://fhirtest.uhn.ca/baseDstu2	True	Yes	Update
2	Mode 2	Postgres Server	True	No	Update

Figure 45: Switching between servers

The resource management tool supports creating, searching, deleting, archiving, and validating transactions for patient, observation, diagnostic, organization, and practitioner resources. In searching transaction, the user can search for a specific resource by many parameters. These parameters depend on the kind of resource as follows:

- By ID, By Name, By Last Update, and By Birth Date for the patient resource (see figure 46).
- By ID, By Last Update, and By Status for the diagnostic resource (see figure 47).
- By ID, By Last Update, By Status, and By Code for the observation resource (see figure 48).
- By ID, By Last Update, and By Type for the organization resource (see figure 49).
- By ID and By Last Update for the practitioner resource (see figure 50).



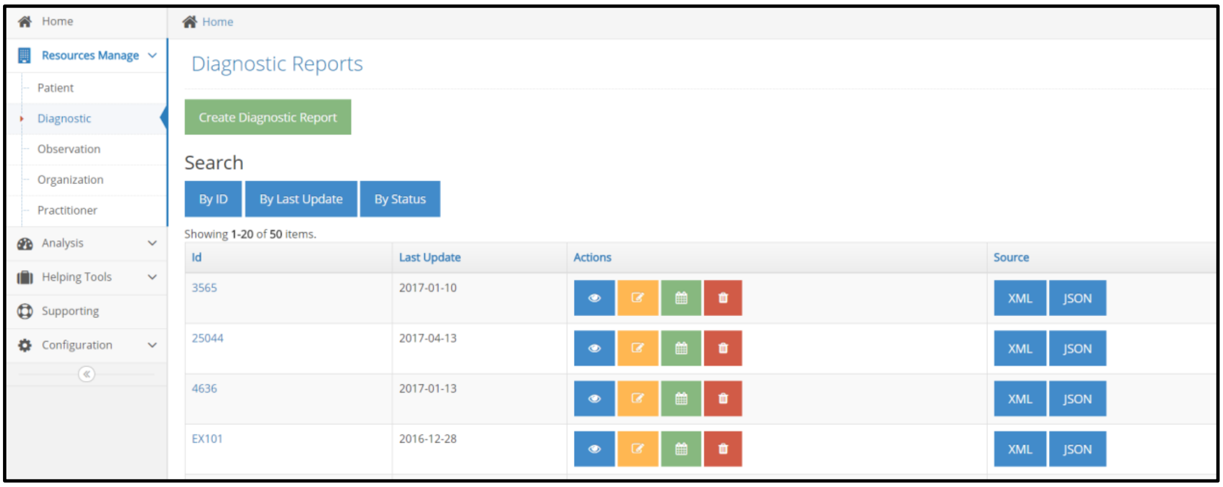
Patients

Search

Showing **1-20** of **50** items.

Id	Name	Last Update	Birth Date	Actions	Source	Full Report
27944	SANTIAGO KUROWSKI Parker Austin	2017-04-28	1937-05-14		XML JSON	Full Report
2026	SANTIAGO KUROWSKI1 Parker Austin	2017-05-02	1937-05-14		XML JSON	Full Report
DfBaitTd8cXqU8ST		2017-01-01	(not set)		XML JSON	Full Report
21531	Smith John	2017-03-24	1961-12-26		XML JSON	Full Report
11739	Cristina van den Berg	2017-02-10	1980-02-21		XML JSON	Full Report

Figure 46: Patient resource searching possibilities



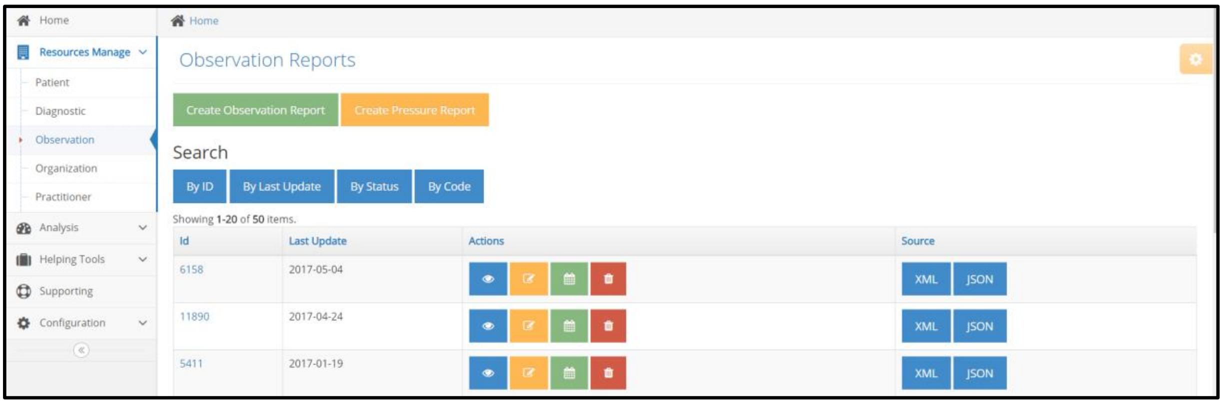
Diagnostic Reports

Search

Showing **1-20** of **50** items.

Id	Last Update	Actions	Source
3565	2017-01-10		XML JSON
25044	2017-04-13		XML JSON
4636	2017-01-13		XML JSON
EX101	2016-12-28		XML JSON

Figure 47: Diagnostic resource searching possibilities



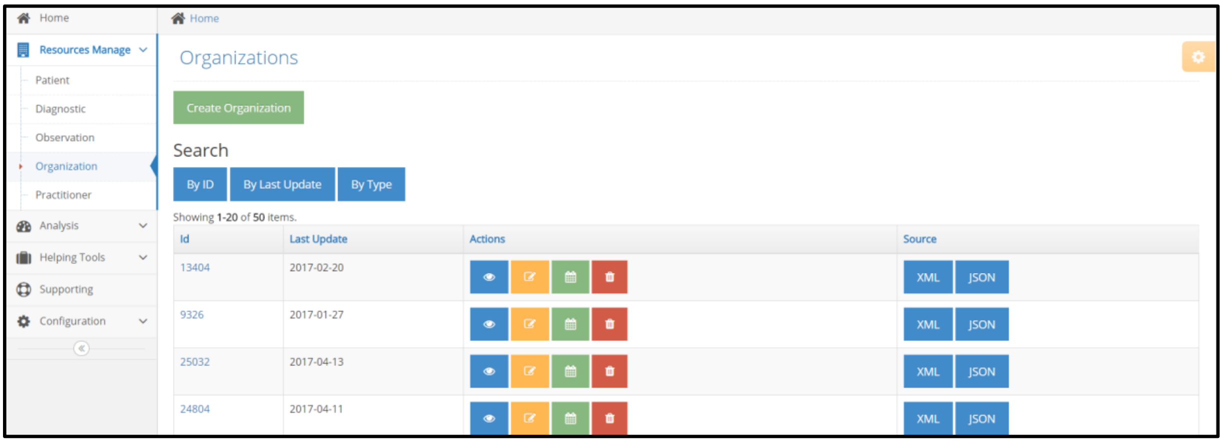
Observation Reports

Search

Showing **1-20** of **50** items.

Id	Last Update	Actions	Source
6158	2017-05-04		XML JSON
11890	2017-04-24		XML JSON
5411	2017-01-19		XML JSON

Figure 48: Observation resource searching possibilities



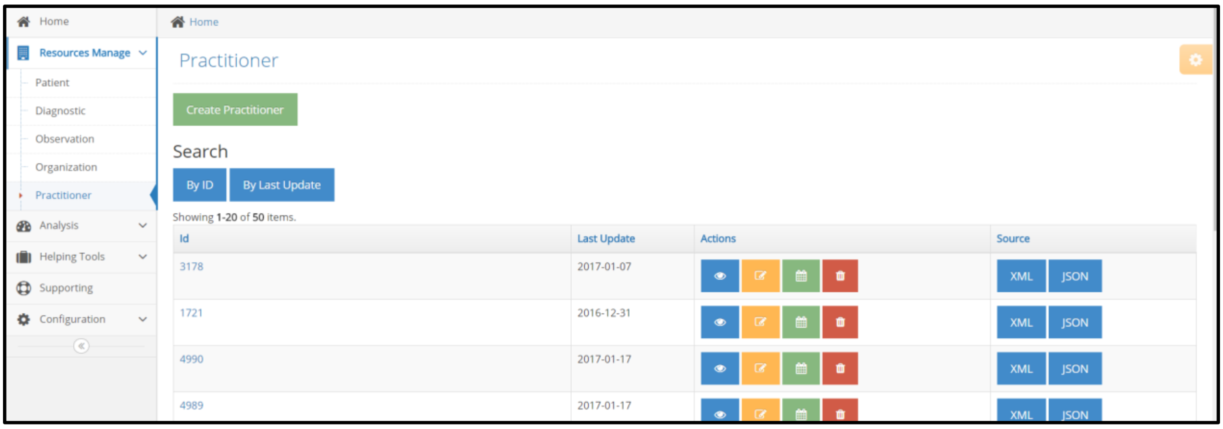
Organizations

Search

Showing **1-20** of **50** items.

Id	Last Update	Actions	Source
13404	2017-02-20		XML JSON
9326	2017-01-27		XML JSON
25032	2017-04-13		XML JSON
24804	2017-04-11		XML JSON

Figure 49: Organization resource searching possibilities

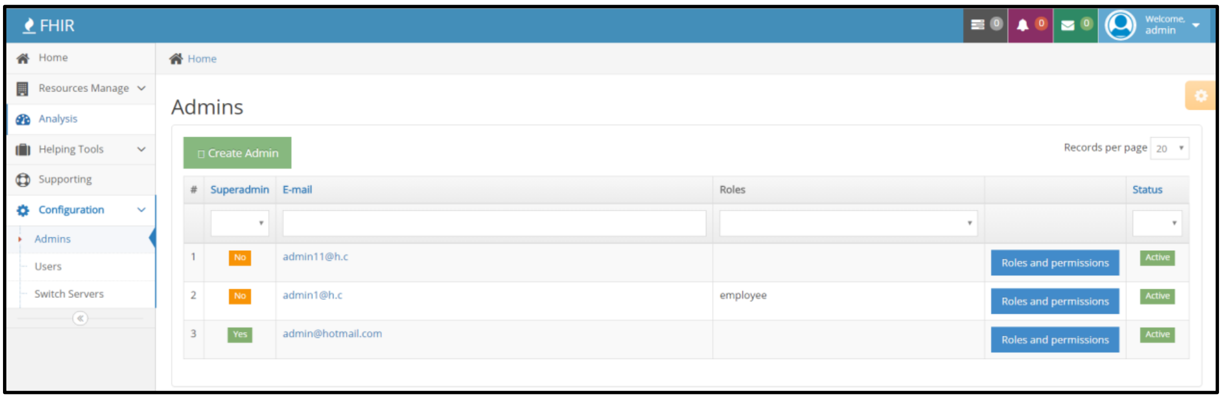


Showing 1-20 of 50 items.

Id	Last Update	Actions	Source
3178	2017-01-07		XML JSON
1721	2016-12-31		XML JSON
4990	2017-01-17		XML JSON
4989	2017-01-17		XML JSON

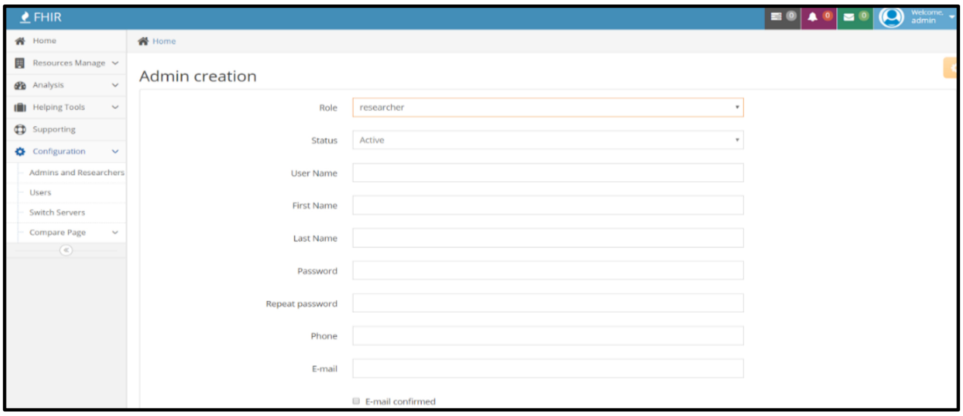
Figure 50: practitioner resource searching possibilities

The system supports an access control list, which gives the patient the ability to access their records and resources (see figure 51), review them, and manage them by using their national number. The admin creates the patient account in the system by using their national number, which is included in the observation resource that was received from the mobile application. Also, the researcher can log-in to the system and make analysis research without violation of the patient's privacy (see figure 52).



#	Superadmin	E-mail	Roles		Status
1	No	admin11@h.c		Roles and permissions	Active
2	No	admin1@h.c	employee	Roles and permissions	Active
3	Yes	admin@hotmail.com		Roles and permissions	Active

Figure 51: The configuration tool to manage access control



Admin creation

Role	researcher
Status	Active
User Name	
First Name	
Last Name	
Password	
Repeat password	
Phone	
E-mail	

□ E-mail confirmed

Figure 52: The configuration tool to manage researchers accounts

As mentioned before, the system has an analysis tool to find the hidden relationship between pollen values in the air and the blood pressure of the patients. The system receives the blood pressure values from the Android application (for 7 participates who do blood pressure test every day for one month). It stores them in the FHIR server as FHIR format, and then finds the correlation values between them and the pollen values (and other particles) coming from the Medical University Interface (DEX). The correlation method was used between the blood pressure and 10 kinds of pollen. Each kind of pollen showed different correlation values depending on the pollen ratio in the air, because the pollen values vary according to their concentration in the air.

In figures 53 and 54, a scatterplot of blood pressure and two kinds of particles (O3, NO2) are shown.

The correlation coefficient was 0,00156 between blood pressure and O3, and 0,000418 between blood pressure and NO2. There is a small relationship between blood pressure and both particles kinds, because at the chosen time, the concentration of the O3 and NO2 in the air was small. This means that when the O3 and NO2 concentration in the air increase so will allergies for some people [58], which in turn increase the blood pressure of those individuals [59].

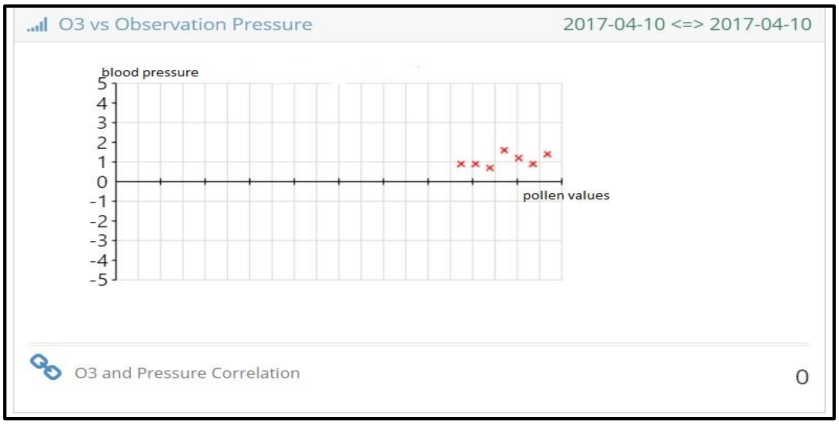


Figure 53: The correlation between blood pressure and O3

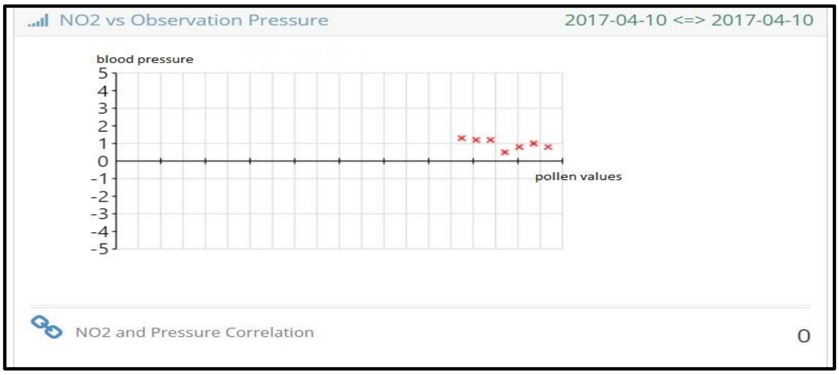
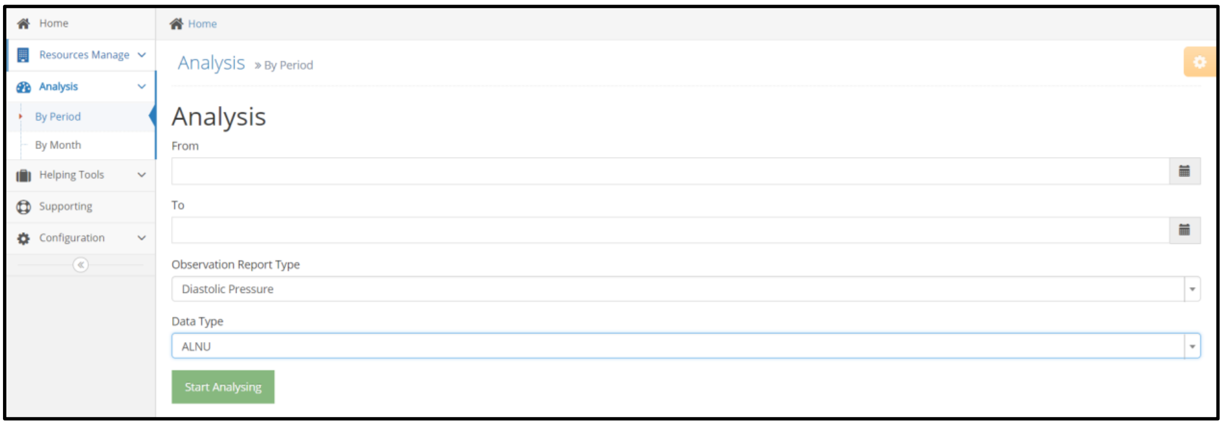


Figure 54: The correlation between blood pressure
and NO2

In the analysis tool, the researcher can choose parameters as follows:

- By period
- By month

By choosing the first possibility, the researcher can choose time ranges for the pollen values (see figure 55). They can choose systolic pressure, diastolic pressure, and heart rate. On the other side, they can choose one of the pollen kinds.



Analysis

From

To

Observation Report Type

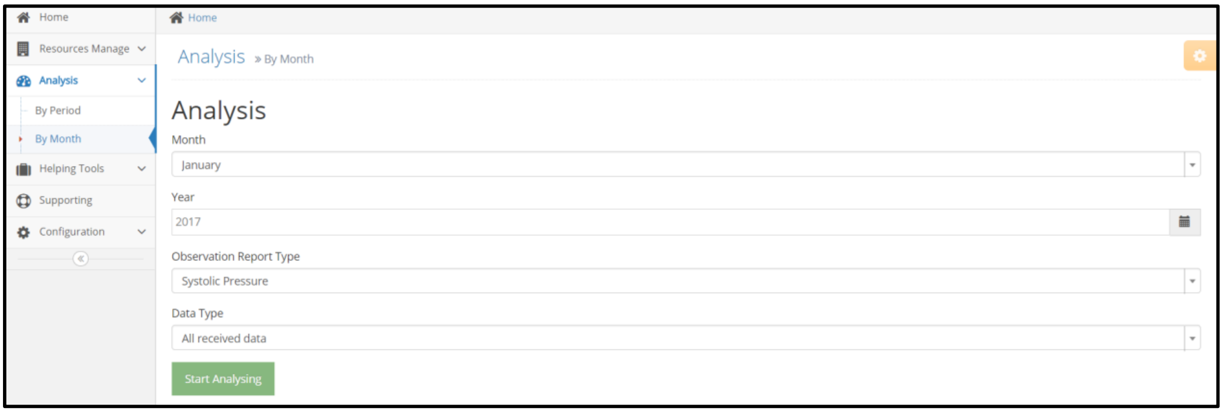
Diastolic Pressure

Data Type

ALNU

Figure 55: Starting the analyzing step for specific period of time

By choosing the second possibility (see figure 56), the researcher can choose the same parameters as the first one, but here they can make the analysis process by choosing a specific month.



Analysis

Month

January

Year

2017

Observation Report Type

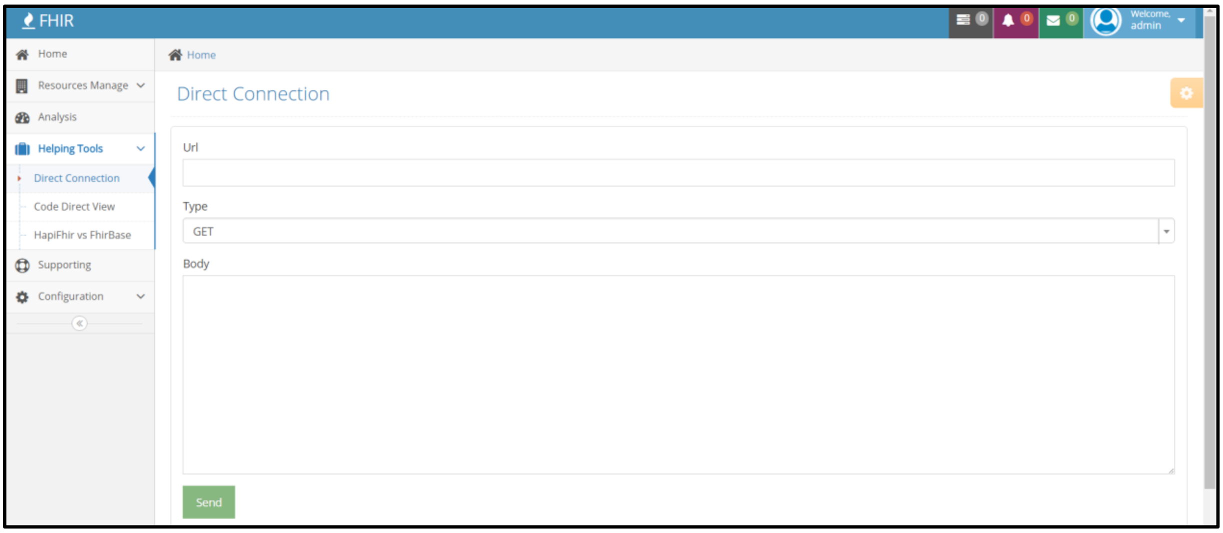
Systolic Pressure

Data Type

All received data

Figure 56: Starting the Analyzing step for specific month

There are some tools that help users understand the process and the FHIR specification, like direct connection tools (see figure 57) to connect to any other FHIR server and code direct view to parse any FHIR format file (see figure 58).



Type: GET

Figure 57: The direct connection tool

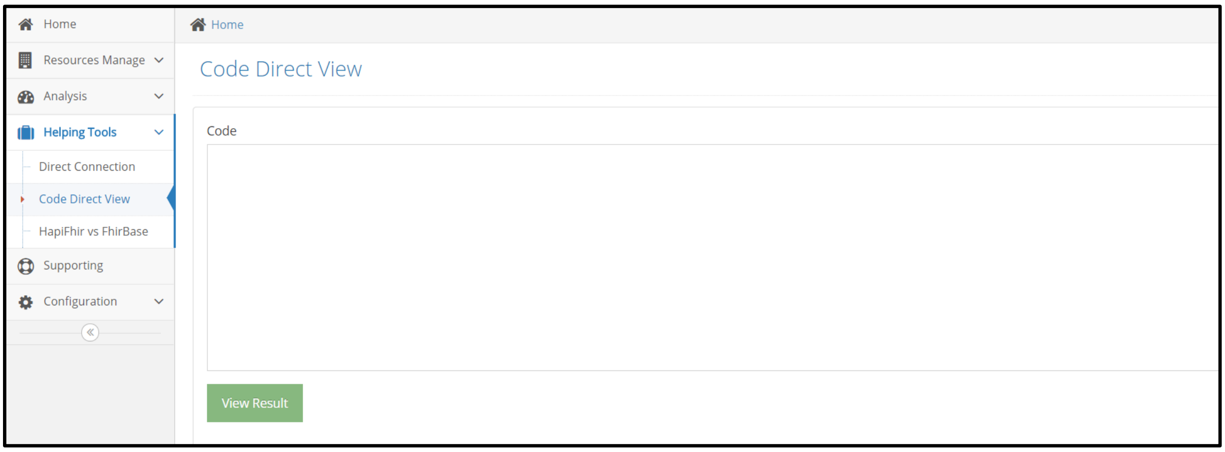


Figure 58: Code direct viewer

A support page was needed in case the users had any problems in the system and needed assistance (see figure 59).

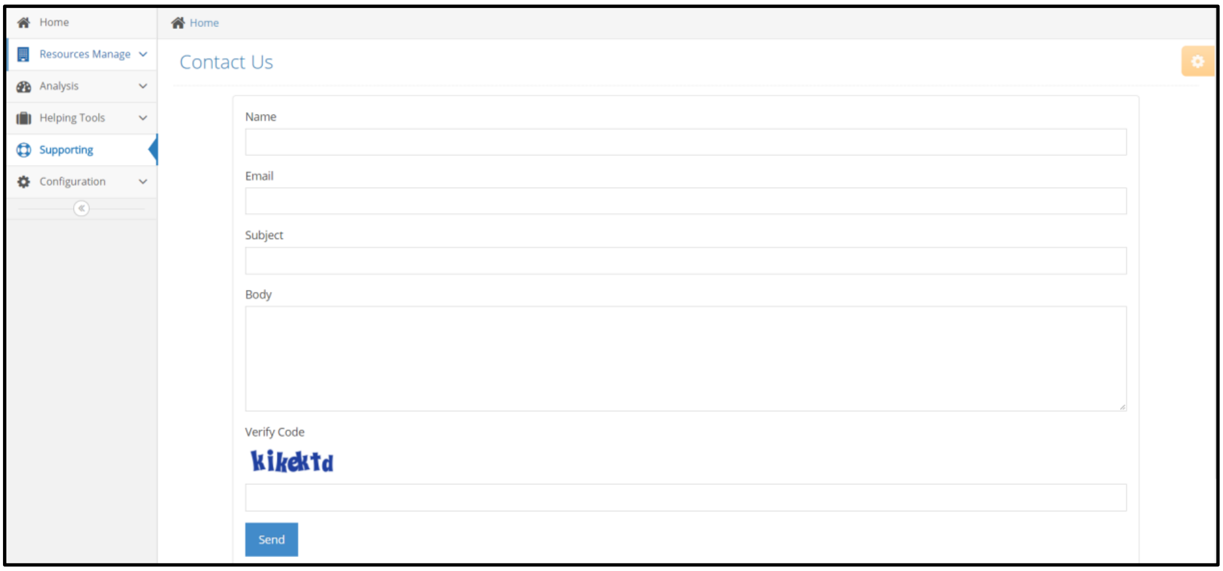


Figure 59: The supporting interface in the system

4 Discussion

FHIR Draft Standard for Trial Use (DSTU2) version was used because this version was the latest version of the FHIR when the system development started. Also, it contains all the necessary resources. FHIR Standard for Trial Use release 3 (STU) was not published, but it is possible to move to the FHIR release 3 STU by changing the XML Schema Definition (XSD) files and choosing HAPIFHIR from system configuration, because HAPIFHIR supports FHIR version 3 STU.

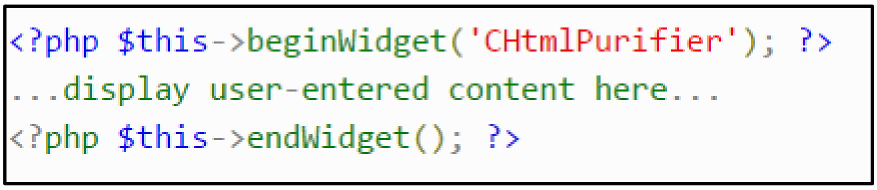
The resource management part works as supposed. The creating, reading, updating, and deleting transactions work without any problems.

In the analysis aspect, the correlation function gave inaccurate results, because at the time of the year there are no high pollen values in the air. Maybe in the future, there will be a high pollen concentration in the air, which will give applicable results. But generally, some pollen kinds gave a high correlation value, which means that there is a relationship between blood pressure and pollen, and it is a linear relationship. When pollen values are high blood pressure is high. A solution for each challenge was found as follows:

- For the interoperability challenge: the system provides a high level of interoperability between system parts, which are: mobile application, server side, and big data interface. By using RESTFULL API service, all system parts communicate with each other consistently, and because all APIs were done according to the FHIR specification, the system can communicate with any other system that uses FHIR specifications, including sending and receiving different resources. An example for API to create new patient resource is:
  POST http://localhost/fhir/admin/api/Patient? Format=json&_pretty=true
  By comparing between this URL and HAPIFHIR URL, which is considered a valid example for FHIR specifications, it is the same as it is shown in the example below [60]:
  POST http://fhirtest.uhn.ca/baseDstu2/Patient?_format=json&_pretty=true
- The big data challenge: FHIR servers were used as a storage method to standardize all data and store it as an extension in the FHIR resources. Also, the analyzing process can start and extract the hidden relationship between the pollen values and any vital measurements
- The long stay in the hospital challenge: this part was solved by using telemonitoring systems that contain the mobile application, monitoring devices, and telemedicine part
- The patient privacy challenge: the system has an access control management that applies a high level of authorization. The system has three accessing layers: one for the admin, who can see everything in the system; one for the researcher, who can only run an analysis without any possibility to see patient’s data; and one for the patient, who can see their records and give the permission to doctors or anyone else

to see their records. These advantages were achieved by using Authentication, Authorization, and Access Level Control features in the YII framework

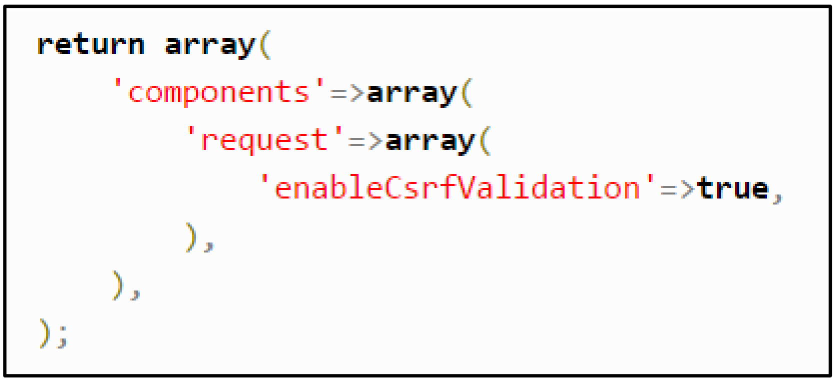
- In the system security challenge: Cross-site scripting (also known as XSS) prevention was used to prevent hackers from gathering data from a user. The implementation uses a useful component called CHtmlPurifier [61] (see figure 60), which can remove all malicious code with a thorough audit.



```
<?php $this->beginWidget('CHtmlPurifier'); ?>
...display user-entered content here...
<?php $this->endWidget(); ?>
```

Figure 60: The YII CHtmlPurifier component

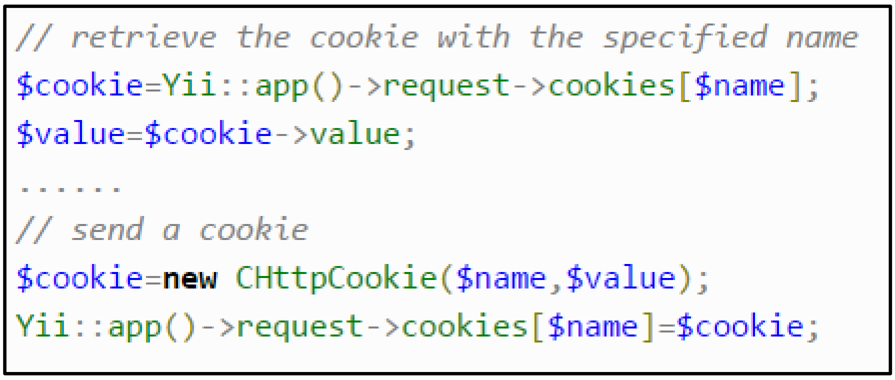
The CHttpRequest (see figure 61) component was used in YII to prevent a malicious web site for causing a user's web browser to perform an unwanted action. This is called Cross-site Request Forgery Prevention, and this is important to keep the patients' data safe [36].



```
return array(
    'components'=>array(
        'request'=>array(
            'enableCsrfValidation'=>true,
        ),
    ),
);
```

Figure 61: The YII CHttpRequest component

The cookie validation scheme in the YII was implemented to prevent cookies from being attacked, which validate cookie data and if it discovers any modifying in this data, it will delete it. This is done by using CookieValidation tool in the CHttpRequest as it is shown in figure 62 below [36].



```
// retrieve the cookie with the specified name
$cookie=Yii::app()->request->cookies[$name];
$value=$cookie->value;
......
// send a cookie
$cookie=new CHttpCookie($name,$value);
Yii::app()->request->cookies[$name]=$cookie;
```

Figure 62: The YII CookieValidation tool

In these tools, patient's data was protected and keep the system secure and safe, given that all data which were used in this thesis is a testing data.

Two FHIR servers were used in this project. Both servers worked as supposed, but from the performance aspect, a performance test was done for both servers. A high number of queries were applied in both servers using JMETER and the following was observed:

Transaction	HAPIFHIR (ms)	FHIRBASE(ms)	Queries number
Creating	3000	4100	10000
Reading	11000	10000	10000
Deleting	7000	7500	10000
Updating	9000	12000	10000

Table 3: Comparison between FHIR servers

This result was enough to prove that the system can process a huge number of queries at the same time.
HAPIFHIR server was faster in the creating, updating, and deleting steps for 10000 queries, and generally HAPIFHIR had better results according to the performance test.
HAPIFHIR has some disadvantages, which were noticed during the implementation. One of them was that the reading and searching quires in HAPIFHIR are done in many independently steps. This will slow queries where there are multiple criteria, and it will be weak in a huge database. Furthermore, the resources are stored as blobs in HAPIFHIR, so it is not possible to call it directly.

FHIRBASE gave somewhat similar results in the performance test, but it was used in this project because its ability to extend, and maybe in the future, it will be possible to extend this server to include more functions. But as with that HAPIFHIR server, there are some things that should be considered in the FHIRBASE. The first thing was that users should expect that FHIRBASE is a bit slower in CRUD operations than general-purpose PostgreSQL setup, because it stores additional meta-data for each resource and uses Stored Procedures instead of vanilla SQL statements. Also, the resources stored in FHIRBASE will consume a bit more disk space than its raw JSON representation - about 1.3 of its original size.

The ACE panel made the system understandable for all users, and all charts and graphs were visually understandable, but ACE had some restrictions in its functions and designs. In the future, the development of a panel that provides more functions is recommended.

This system could integrate to the existing projects, which deals with the telemonitoring systems and interoperability approaches like telemonitoring of diabetes mellitus in Austria, which aims to improve the healthcare for people with diabetes [2]. The developed platform can receive the diabetics' measurements from the telemonitoring system, store them in the FHIR server, and then manage them as FHIR resources to give the patients the ability to view their records. Also, in this way it would be possible to use these records for the analysis process.

5 Conclusion

All the wanted goals were achieved in an acceptable level. As mentioned before, the analysis results are somewhat not suitable, but this was because of the concentration of the pollen in the air at the time of the year, but the main goal was to deal with this kind of non-standardizing data and integrate it to the FHIR environment, at this point, the system succeeded to store it in the FHIR resources as an extension, and then analyzed it by comparing it with the vital signs. As mentioned before, the system detected that, when the pollen concentration increases in the air, it causes the allergies of some people to also increase, which leads to an increase in the blood pressure of those people.

The system could be considered as a health management system, because it has many functions that allow users to control all patient's health records and connect with other systems without any interoperability problems, because the using of FHIR as a core for this system gives the system the ability to provide enough level of the interoperability with other systems. As mentioned before, all FHIR specifications regarding the API's were applied successfully to allow the systems to communicate with each other and with other systems without interoperability problems.

The system now provides a tool for resources management, including: reading, creating, deleting, and updating transactions. Also, the system provides a levels of access control, which gives the patients the ability to see their records, gives the admin the ability to control in the system, and provides the authorization to the users to access the system and set the necessary configuration for the system. It also gives the researchers the ability to access the system and use the analysis process to extract some useful information.

The system applied the HAPIFHIR and FHIRBASE servers, which indicates the strength and the weaknesses for each one by making performance test for each one.

The system gives an acceptable solution for all challenges. The visualization tools provide clear charts and graphs to make the results clear and useful. Furthermore, the system could be considered an example of applying the FHIR specification and test medical applications against deferent FHIR servers.

5.1 Future work

At this time, the system can only deal with pollen data, but it can be extended to deal with any kind of big data, and it can extract a lot of hidden relationships between vital signals and environmental data to understand more about diseases and how they develop.

The system now provides a management tool for the patient, practitioner, organization, observation, and diagnostic resources, but FHIR has a lot of resources that cover many aspects, like healthcare and administration aspects. Because of that, in the future extend the implementation to include more FHIR resources and more functions will be possible, because this system was developed in the developable way.

The system used two servers HAPIFHIR and FHIRBASE, but because of that, the system became restricted to the functions that these two servers provide. In the future, it would be beneficial to develop a special FHIR server to meet the desired requirements without any restrictions.

This system is a part of INNOVATE project [62], which is running in the “Fachhochschule Technikum Wien”. In the future, it would be effective to extend the project to receive vital signs from many sources and many monitoring health devices, like EKGs and ECGs. After that, handling these measurements and storing them as FHIR resources in the server, and then compare them with deferent kinds of environment data to extract more information about the relations between this data. This also could include handling these vital signs as DICOM reports and provide an appropriate viewer for these reports. This will give the system the ability to provide a lot of analyzing tools and handles different aspects.

Bibliography

[1] Corepoint Health, “The HL7 Evolution,” Corepoint Health, Plano, Texas, 2009.

[2] S. Sauermann and I. Weik, “Telemonitoring in Österreich,” Zeitschrift für Gesundheitspolitik, Vienna, 2016.

[3] The Bluetooth SIG, “Health Device Profile,” The Bluetooth SIG, [Online]. Available: https://www.bluetooth.com/specifications/assigned-numbers/health-device-profile. [Accessed 15 May 2017].

[4] Bluetooth SIG, “BLOOD PRESSURE PROFILE,” 25 10 2011. [Online]. Available: https://www.bluetooth.org/docman/handlers/downloaddoc.ashx?doc_id=243125 BLOOD PRESSURE PROFILE. [Accessed 15 5 2017].

[5] “boso medicus system,” [Online]. Available: http://www.boso.de/en/products/blood-pressure-instruments-for-personal-use/upper-arm-measurement.html. [Accessed 15 May 2017].

[6] HL7 Organization, "FHIR Documentation," HL7 Organization, 15 10 2015. [Online]. Available: https://www.hl7.org/fhir/DSTU2/patient.html. [Accessed 2 1 2017].

[7] Medical University of Vienna, “Data Interface Dex / App Info,” Medical University of Vienna, Vienna, 2016.

[8] O. Iroju, A. Soriyan and I. Gambo, “Interoperability in Healthcare: Benefits, Challenges and Resolutions,” *International Journal of Innovation and Applied Studies,* vol. 3, no. 2028-9324, pp. 262 - 270, 1 May 2013.

[9] A. Pfuntner and L. Wier, “Costs for Hospital Stays in the United,” *STATISTICAL BRIEF #146,* pp. 1-11, 7 January 2013.

[10] G. Pare and P. Poba, “Home Telemonitoring for Chronic Disease Management: An Economic Assessment,” *International Journal of Technology Assessment in Health Care,* vol. 29:2, no. 0266462313000111, p. 155–161, 2013.

[11] T. Cooper and J. Collman, “MANAGING INFORMATION SECURITY AND PRIVACY IN HEALTHCARE DATA MINING,” in *Medical informatics*, vol. 8, California,, Springer US, 2005, pp. 95-137.

[12] D. Agrawal, E. Bernstein, E. Bertino and S. Davidson, “Challenges and Opportunities with Big Data,” Computing Community Consortium, Washington, D.C., USA., 1012.

[13] F. Matthias, “CDA –Clinical DocumentArchitecture,” Fachhochschule Technikum Wien, Vienna, 2015.

[14] D. Boerner, “WHAT IS HL7 FHIR AND WHY YOU SHOULD CARE,” Orion Health™ group of companies, 2014.

[15] J. Quinn, “Health Level Seven International (HL7),” HL7 International CTO, Atlanta, GA, USA, 2015.

[16] B. Dolin, "HL7/documentcente," HL7, 2009. [Online]. Available: https://www.hl7.org/documentcenter/public_temp_1192E9A1-1C23-BA17-0CF72CAEC4500D15/calendarofevents/himss/2010/presentations/HIMSS2010%20cda.pdf. [Accessed 20 1 2017].

[17] R. Dolin, L. Alschuler and S. Boyer, “HL7 Clinical Document Architecture, Release 2.0,” Health Level Seven International (HL7), 2004.

[18] HL7 Organazation, "Introducing HL7 FHIR," 2017. [Online]. Available: https://www.hl7.org/fhir/summary.html. [Accessed 20 1 2017].

[19] HL7 Organization, “Resource Index,” HL7, 19 April 2017. [Online]. Available: https://www.hl7.org/fhir/resourcelist.html. [Accessed 4 2017].

[20] L. McKenzie, "FHIR for Architects," Health Level Seven International (HL7), 2016.

[21] HL7 organization, "Resource Practitioner," HL7 organization, 24 10 2015. [Online]. Available: https://www.hl7.org/fhir/DSTU2/practitioner.html. [Accessed 12 10 2016].

[22] HL7 Organization, "Resource Organization - Content," HL7 Organization, 24 10 2015. [Online]. Available: https://www.hl7.org/fhir/DSTU2/organization.html. [Accessed 22 2 2017].

[23] HL7 Organization, "Resource Observation - Content," HL7 Organization, 24 10 2015. [Online]. Available: https://www.hl7.org/fhir/DSTU2/observation.html. [Accessed 11 1 2017].

[24] HL7 Organization, "Resource DiagnosticReport - Content," HL7 Organization, 24 10 2015. [Online]. Available: https://www.hl7.org/fhir/DSTU2/diagnosticreport.html. [Accessed 2 11 2016].

[25] Z. Miloservice and A. Bond, "Services, processes and policies for digital health: FHIR® case study," IEEE, Australia, Canberra, 2016.

[26] HL7 Organization, "Extensibility," HL7 Organization, 19 4 2017. [Online]. Available: https://www.hl7.org/fhir/extensibility.html. [Accessed 4 5 2017].

[27] D. Bender and K. Sartipi, "HL7 FHIR: An Agile and RESTful Approach to," IEEE, Canada, Oshawa,, 2013.

[28] M. Fowler, "Richardson Maturity Model," martinfowle, 18 3 2010. [Online]. Available: https://martinfowler.com/articles/richardsonMaturityModel.html. [Accessed 14 5 2017].

[29] HL7 Organization , "RESTful API," HL7 Organization , 19 4 2017. [Online]. Available: https://www.hl7.org/fhir/http.html#2.21.0. [Accessed 5 5 2017].

[30] HSPC , "The Healthcare Innovation Ecosystem," HSPC , 2017. [Online]. Available: https://sandbox.hspconsortium.org/#/start. [Accessed 24 1 2017].

[31] Furore, "Vonk server documentation," Simplifier’s, 2016. [Online]. Available: http://docs.simplifier.net/simplifier/index.html. [Accessed 10 5 2017].

[32] Furore, "SPARK FHIR server," SPARK, 2017. [Online]. Available: http://spark.furore.com/. [Accessed 15 5 2017].

[33] Health Samurai Team, “Vision of FHIRbase,” Health Samurai Team, 2014. [Online]. Available: http://fhirbase.github.io/index.html. [Accessed 4 1 2017].

[34] University Health Network, “Introduction to HAPI FHIR,” Smile CDR, 20 4 2014. [Online]. Available: http://hapifhir.io/doc_intro.html. [Accessed 22 4 2017].

[35] Yii Software LLC, “The Fast, Secure and Professional PHP Framework,” Yii Software LLC, Washington DC, USA, 2014.

[36] O. Xue, A. Makarov and C. Brandt, The Definitive Guide to Yii 2.0, Washington DC: Yii Software LLC, 2014.

[37] Intersystems, "HL7, FHIR, and other Healthcare Standards," Intersystems, 2017. [Online]. Available: http://www.intersystems.com/our-products/healthshare/hl7-and-other-healthcare-standards/#IHE. [Accessed 11 5 2017].

[38] R. Dobson, "Interoperability Toolkit (ITK)," 2017. [Online]. Available: https://developer.nhs.uk/wp-content/uploads/2013/03/ITK-Overview-Pack-for-initial-workshop.pdf. [Accessed 13 5 2017].

[39] openEHR community, “What is openEHR?,” openEHR, 2017. [Online]. Available: http://www.openehr.org/what_is_openehr#. [Accessed 20 5 2017].

[40] P. Schloeffel, S. Heard, D. Kalra and D. Lioyd, “Introducing openEHR,” openEHR, London, 2006.

[41] The EN 13606 Association, “The CEN/ISO EN13606 standard,” The EN 13606 Association, 2009. [Online]. Available: http://www.en13606.org/the-ceniso-en13606-standard. [Accessed 21 5 2017].

[42] International Organization for Standardization, “ISO 13606-1:2008,” ISO, 2 2008. [Online]. Available: https://www.iso.org/standard/40784.html. [Accessed 22 5 2017].

[43] Continua, “Continua Health Alliance,” Continua, 2016. [Online]. Available: http://www.pchalliance.org/. [Accessed 22 5 2017].

[44] Integrating the Healthcare Enterprise (IHE) , "Profiles," Integrating the Healthcare Enterprise (IHE) , 2016. [Online]. Available: https://www.ihe.net/Profiles/. [Accessed 20 4 2017].

[45] Integrating the Healthcare Enterprise (IHE), "Cross-Enterprise Document Sharing," Integrating the Healthcare Enterprise (IHE), 2016. [Online]. Available: http://wiki.ihe.net/index.php/Cross-Enterprise_Document_Sharing. [Accessed 16 5 2017].

[46] Integrating the Healthcare Enterprise (IHE), "Publication and Discovery XDS and DSUB," 2010. [Online]. Available: https://www.ihe.net/WorkArea/DownloadAsset.aspx?id=357. [Accessed 7 5 2017].

[47] IHE organization , “Mobile access to Health Documents (MHD),” IHE, 2015. [Online]. Available: http://wiki.ihe.net/index.php/Mobile_access_to_Health_Documents_(MHD). [Accessed 20 5 2017].

[48] D. Hay, "FHIR and XDS – an Overview," Hay on FHIR, 2016. [Online]. Available: https://fhirblog.com/2013/11/05/fhir-and-xds-an-overview/. [Accessed 10 5 2017].

[49] G. Wood, “HL7 Basic Overview,” HL7 Organization, Washtenaw, USA, 2012.

[50] K. Menetelmäpankki, "ADOPTING WEB FRAMEWORK IN WEB-APPLICATION DEVELOPMENT," Lahti University of Applied Sciences, Nguyen Minh Thanh, 2012.

[51] HL7 Organization, "Publicly Available FHIR Servers for testing," HL7 Organization, 4 5 2017. [Online]. Available: http://wiki.hl7.org/index.php?title=Publicly_Available_FHIR_Servers_for_testing. [Accessed 22 4 2016].

[52] EasyMind, "WrapBootstrap," wrapmarket., 2017. [Online]. Available: https://wrapbootstrap.com/theme/ace-responsive-admin-template-WB0B30DGR. [Accessed 8 12 2016].

[53] ELGA, “Meine elektronische Gesundheitsakte.,” ELGA, [Online]. Available: https://www.elga.gv.at/index.html. [Accessed 22 5 2017].

[54] HL7 Organization , "Clinical Document Architecture (CDA)," HL7 Organization , 19 4 2017. [Online]. Available: https://www.hl7.org/fhir/comparison-cda.html. [Accessed 12 5 2017].

[55] M. Smits, E. Kramer and M. Harthoorn, "A comparison of two Detailed Clinical Model representations: FHIR and CDA," *EJBI,* vol. 11, no. 2, p. 11, 2015.

[56] HEALTH SAMURAI, “Relational storage for FHIRresources,” HL7, 2015. [Online]. Available: https://www.hl7.org/documentcenter/public_temp_CDEB4F47-1C23-BA17-0C51F91CFFFEC323/wg/java/20150510_AID_fhirbase.pdf. [Accessed 20 4 2017].

[57] Yii Software LLC, "Model-View-Controller (MVC)," Yii Software LLC, 29 5 2009. [Online]. Available: http://www.yiiframework.com/doc/guide/1.1/en/basics.mvc. [Accessed 20 2 2017].

[58] United States Environmental Protection Agency, “Nitrogen Dioxide (NO2) Pollution,” United States Environmental Protection Agency, 9 2016. [Online]. Available: https://www.epa.gov/no2-pollution/basic-information-about-no2. [Accessed 27 5 2017].

[59] S. Mohapatra, "Allergies Across America," Quest Diagnostics, USA, 2011.

[60] University Health Network, “RESTful Client,” 20 4 2017. [Online]. Available: http://hapifhir.io/doc_rest_client.html. [Accessed 1 5 2017].

[61] Yii Software LLC, “CHtmlPurifier,” 2017. [Online]. Available: http://www.yiiframework.com/doc/api/1.1/CHtmlPurifier. [Accessed 4 2 2017].

[62] FH Technikum Wien, “Secure Services, eHealth & Mobility,” 9 2016. [Online]. Available: https://www.technikum-wien.at/forschung/forschungsschwerpunkte/ehealth/. [Accessed 26 5 2017].

List of Figures

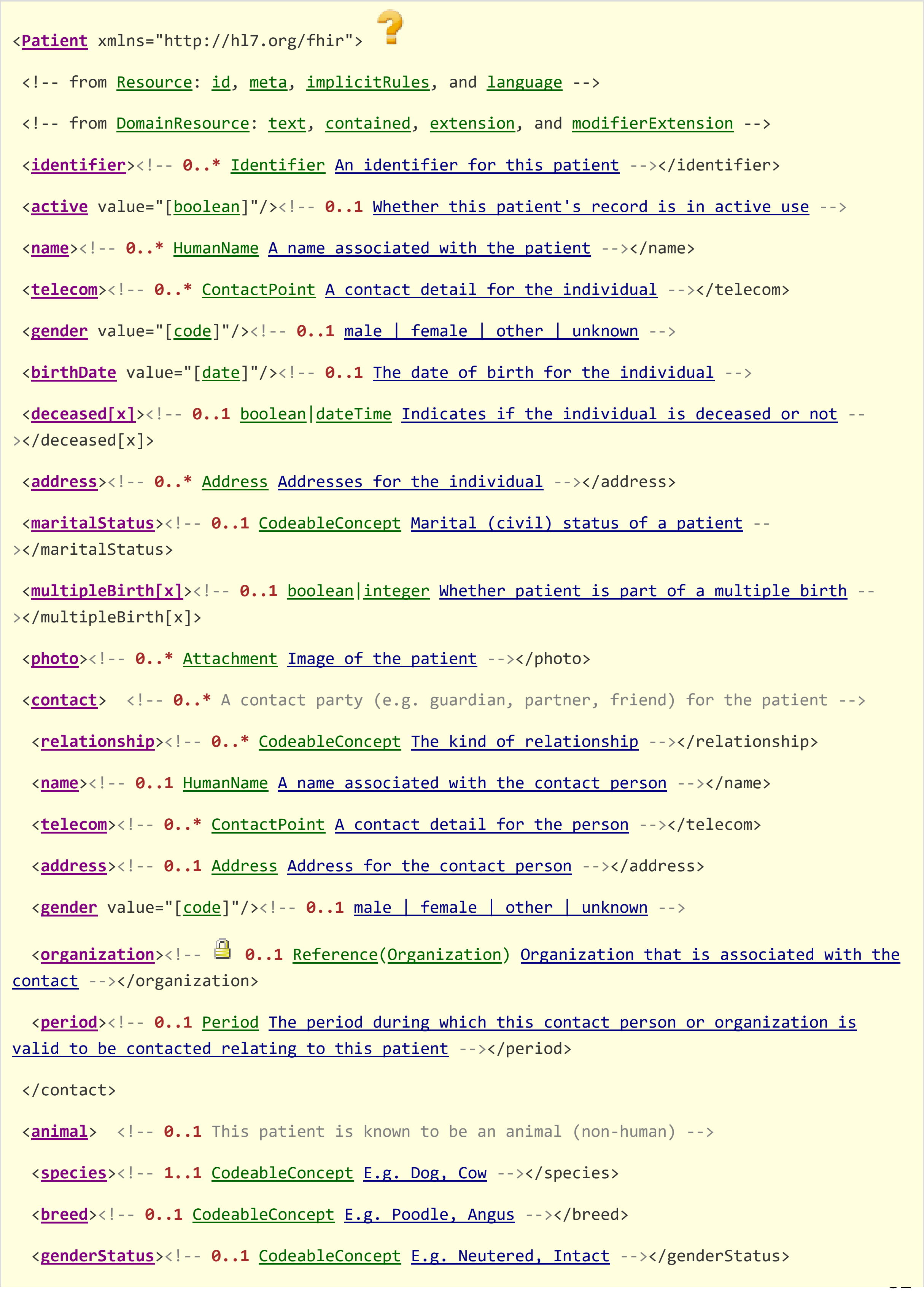
List of Tables

List of Abbreviations

FHIR	Fast Healthcare Interoperability Resources
HL7	Health Level 7
BLP	Blood Pressure Profile
HTP	Health Thermometer Profile
GLP	Glucose Profile
CGMP	Continuous Glucose Monitor Profile
BCS	Body Composition System
CSCP	Cycling Speed and Cadence Profile
CPP	Cycling Power Profile
HRP	Heart Rate Profile
LNP	Location and Navigation Profile
RSCP	Running Speed and Cadence Profile
WSP	Weight Scale Profile
IPSP	Internet Protocol Support Profile
ESP	Environmental Sensing Profile
UDS	User Data Service
PXP	Proximity Profile
API	Application Programming Interface
PHDs	Personal Health Devices
RIM	Reference Information Model
CDA	Clinical Document Architecture
XML	Extensible Markup Language
SS-MIX	Standard Structured Medical Information Exchange
NHS	National Health Service
IHE	Integrating Healthcare Enterprise
HER	Electronic Health Records
JPQL	Java Persistence Query Language
MVC	Model, View and Controller
DAO	Data Access Object
ORM	Object-Relational Mapping
XSD	XML Schema Definition
YII	Yes, IT Is Framework
HTTP	Hypertext Transfer Protocol
PDP	PHP Data Object
EKG	Electrocardiogram
DICOM	Digital Imaging and Communications in Medicine
SQL	Structured Query Language

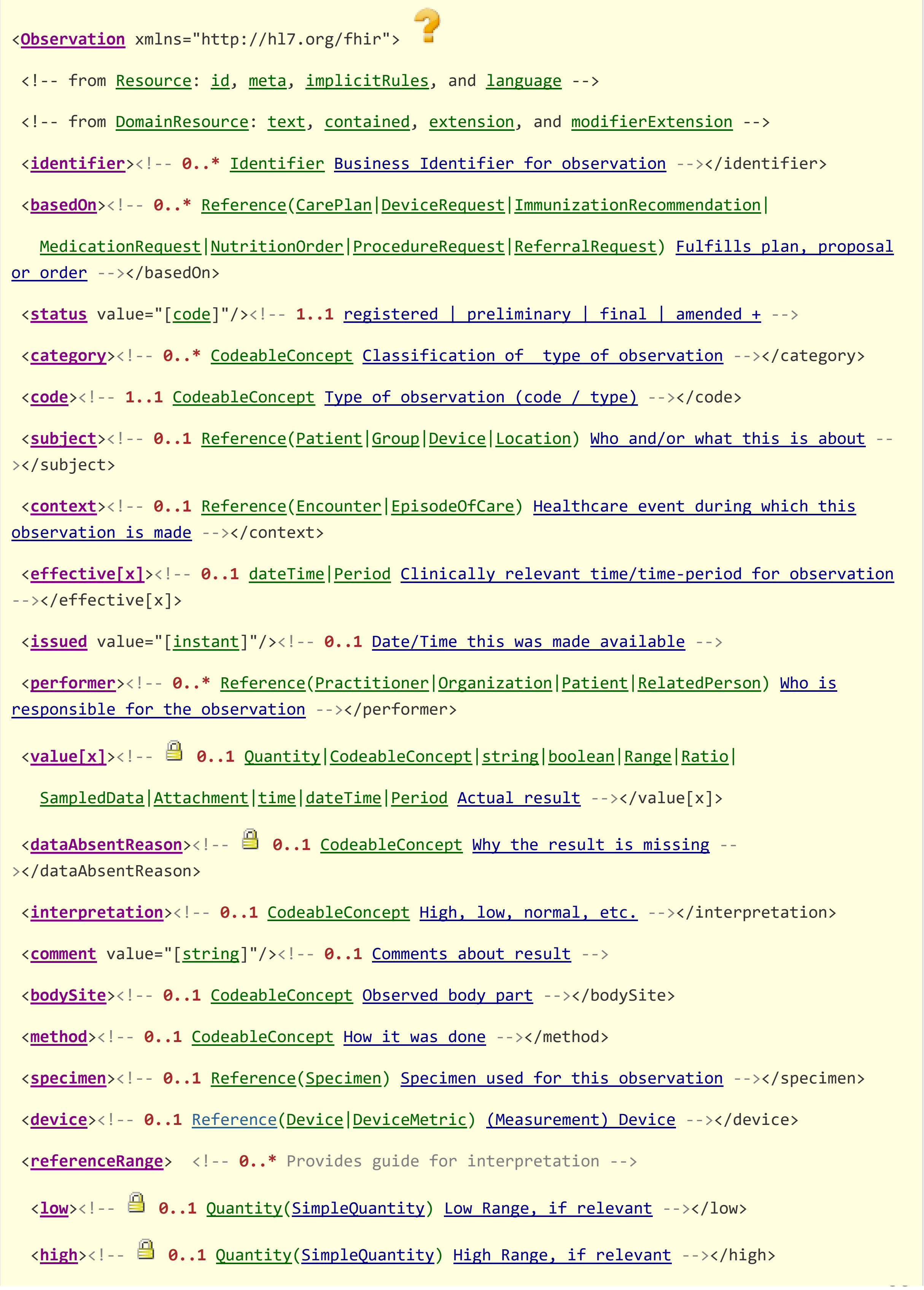
PHP	Personal Home Page
MySQL	My Structured Query Language
O3	Ozone
NO2	Nitrogen Dioxide.
DSTU 2	Draft Standard for Trial Use
JSON	JavaScript Object Notation

Appendix A: patient resource structure



```
<Patient xmlns="http://hl7.org/fhir">
 <!-- from Resource: id, meta, implicitRules, and language -->
 <!-- from DomainResource: text, contained, extension, and modifierExtension -->
 <identifier><!-- 0..* Identifier An identifier for this patient --></identifier>
 <active value="[boolean]"/><!-- 0..1 Whether this patient's record is in active use -->
 <name><!-- 0..* HumanName A name associated with the patient --></name>
 <telecom><!-- 0..* ContactPoint A contact detail for the individual --></telecom>
 <gender value="[code]"/><!-- 0..1 male | female | other | unknown -->
 <birthDate value="[date]"/><!-- 0..1 The date of birth for the individual -->
 <deceased[x]><!-- 0..1 boolean|dateTime Indicates if the individual is deceased or not --></deceased[x]>
 <address><!-- 0..* Address Addresses for the individual --></address>
 <maritalStatus><!-- 0..1 CodeableConcept Marital (civil) status of a patient --></maritalStatus>
 <multipleBirth[x]><!-- 0..1 boolean|integer Whether patient is part of a multiple birth --></multipleBirth[x]>
 <photo><!-- 0..* Attachment Image of the patient --></photo>
 <contact>  <!-- 0..* A contact party (e.g. guardian, partner, friend) for the patient -->
  <relationship><!-- 0..* CodeableConcept The kind of relationship --></relationship>
  <name><!-- 0..1 HumanName A name associated with the contact person --></name>
  <telecom><!-- 0..* ContactPoint A contact detail for the person --></telecom>
  <address><!-- 0..1 Address Address for the contact person --></address>
  <gender value="[code]"/><!-- 0..1 male | female | other | unknown -->
  <organization><!--  0..1 Reference(Organization) Organization that is associated with the contact --></organization>
  <period><!-- 0..1 Period The period during which this contact person or organization is valid to be contacted relating to this patient --></period>
 </contact>
 <animal>  <!-- 0..1 This patient is known to be an animal (non-human) -->
  <species><!-- 1..1 CodeableConcept E.g. Dog, Cow --></species>
  <breed><!-- 0..1 CodeableConcept E.g. Poodle, Angus --></breed>
  <genderStatus><!-- 0..1 CodeableConcept E.g. Neutered, Intact --></genderStatus>
 </animal>

 <communication>  <!-- 0..* A list of Languages which may be used to communicate with the
patient about his or her health -->

  <language><!-- 1..1 CodeableConcept The language which can be used to communicate with the
patient about his or her health --></language>

  <preferred value="[boolean]"/><!-- 0..1 Language preference indicator -->

 </communication>

 <generalPractitioner><!-- 0..* Reference(Organization|Practitioner) Patient's nominated
primary care provider --></generalPractitioner>

 <managingOrganization><!-- 0..1 Reference(Organization) Organization that is the custodian of
the patient record --></managingOrganization>

 <link>  <!-- 0..* Link to another patient resource that concerns the same actual person -->

  <other><!-- 1..1 Reference(Patient|RelatedPerson) The other patient or related person
resource that the link refers to --></other>

  <type value="[code]"/><!-- 1..1 replaced-by | replaces | refer | seealso - type of link -->

 </link>

</Patient>
```

Appendix B: observation resource structure



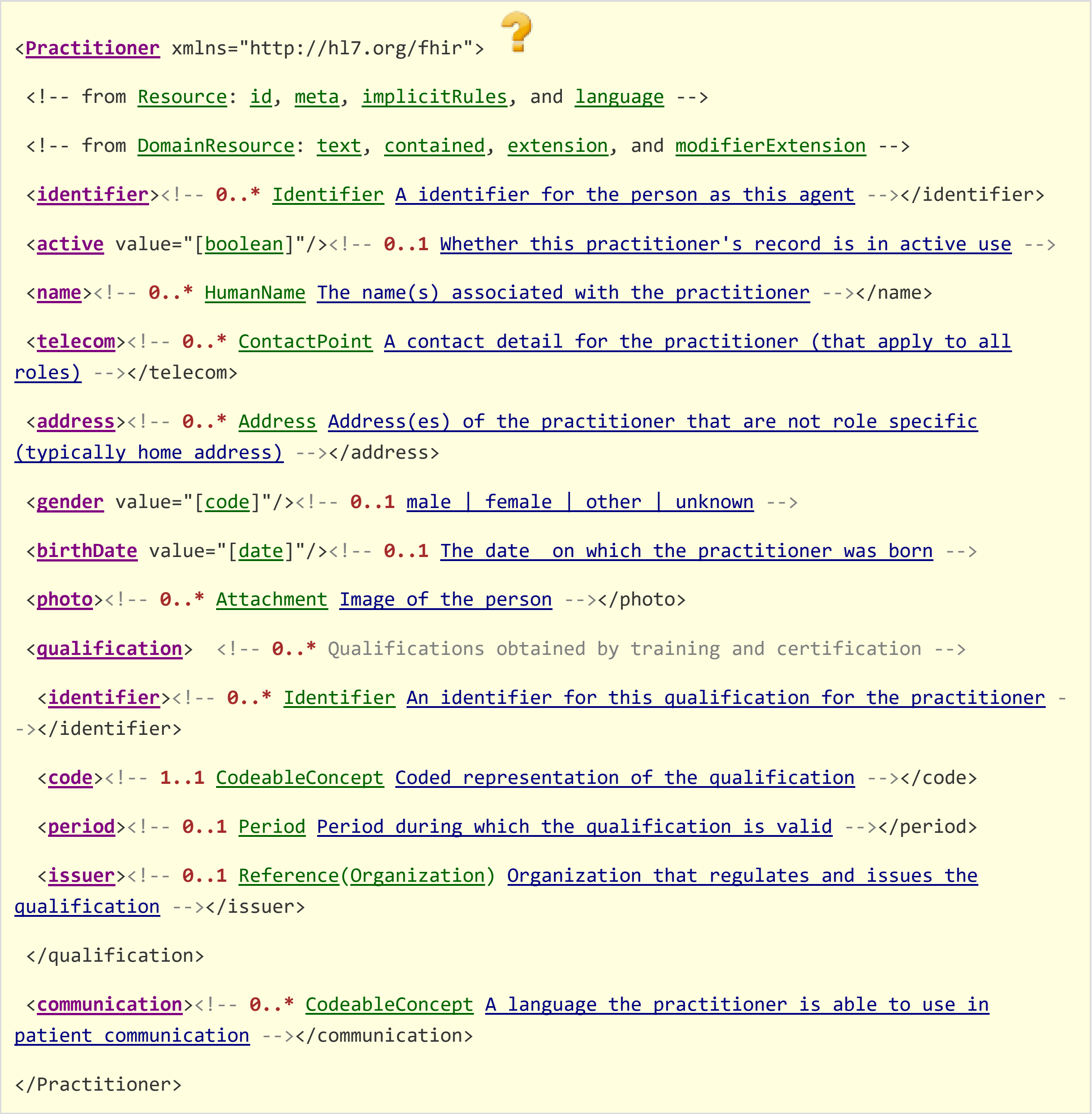
```
<Observation xmlns="http://hl7.org/fhir">
 <!-- from Resource: id, meta, implicitRules, and language -->
 <!-- from DomainResource: text, contained, extension, and modifierExtension -->
 <identifier><!-- 0..* Identifier Business Identifier for observation --></identifier>
 <basedOn><!-- 0..* Reference(CarePlan|DeviceRequest|ImmunizationRecommendation|
   MedicationRequest|NutritionOrder|ProcedureRequest|ReferralRequest) Fulfills plan, proposal
or order --></basedOn>
 <status value="[code]"/><!-- 1..1 registered | preliminary | final | amended + -->
 <category><!-- 0..* CodeableConcept Classification of  type of observation --></category>
 <code><!-- 1..1 CodeableConcept Type of observation (code / type) --></code>
 <subject><!-- 0..1 Reference(Patient|Group|Device|Location) Who and/or what this is about --
></subject>
 <context><!-- 0..1 Reference(Encounter|EpisodeOfCare) Healthcare event during which this
observation is made --></context>
 <effective[x]><!-- 0..1 dateTime|Period Clinically relevant time/time-period for observation
--></effective[x]>
 <issued value="[instant]"/><!-- 0..1 Date/Time this was made available -->
 <performer><!-- 0..* Reference(Practitioner|Organization|Patient|RelatedPerson) Who is
responsible for the observation --></performer>
 <value[x]><!-- 🔒 0..1 Quantity|CodeableConcept|string|boolean|Range|Ratio|
   SampledData|Attachment|time|dateTime|Period Actual result --></value[x]>
 <dataAbsentReason><!-- 🔒 0..1 CodeableConcept Why the result is missing --
></dataAbsentReason>
 <interpretation><!-- 0..1 CodeableConcept High, low, normal, etc. --></interpretation>
 <comment value="[string]"/><!-- 0..1 Comments about result -->
 <bodySite><!-- 0..1 CodeableConcept Observed body part --></bodySite>
 <method><!-- 0..1 CodeableConcept How it was done --></method>
 <specimen><!-- 0..1 Reference(Specimen) Specimen used for this observation --></specimen>
 <device><!-- 0..1 Reference(Device|DeviceMetric) (Measurement) Device --></device>
 <referenceRange>  <!-- 0..* Provides guide for interpretation -->
  <low><!-- 🔒 0..1 Quantity(SimpleQuantity) Low Range, if relevant --></low>
  <high><!-- 🔒 0..1 Quantity(SimpleQuantity) High Range, if relevant --></high>
```
]

```
  <type><!-- 0..1 CodeableConcept Reference range qualifier --></type>

  <appliesTo><!-- 0..* CodeableConcept Reference range population --></appliesTo>

  <age><!-- 0..1 Range Applicable age range, if relevant --></age>

  <text value="[string]"/><!-- 0..1 Text based reference range in an observation -->

 </referenceRange>

 <related>  <!-- 0..* Resource related to this observation -->

  <type value="[code]"/><!-- 0..1 has-member | derived-from | sequel-to | replaces |
qualified-by | interfered-by -->

  <target><!-- 1..1 Reference(Observation|QuestionnaireResponse|Sequence) Resource that is
related to this one --></target>

 </related>

 <component>  <!-- 0..* Component results -->

  <code><!-- 1..1 CodeableConcept Type of component observation (code / type) --></code>

  <value[x]><!-- 0..1 Quantity|CodeableConcept|string|Range|Ratio|SampledData|

    Attachment|time|dateTime|Period Actual component result --></value[x]>

  <dataAbsentReason><!--  0..1 CodeableConcept Why the component result is missing --
></dataAbsentReason>

  <interpretation><!-- 0..1 CodeableConcept High, low, normal, etc. --></interpretation>

  <referenceRange><!-- 0..* Content as for Observation.referenceRange Provides guide for
interpretation of component result --></referenceRange>

 </component>

</Observation>
```

Appendix C: diagnostic resource structure

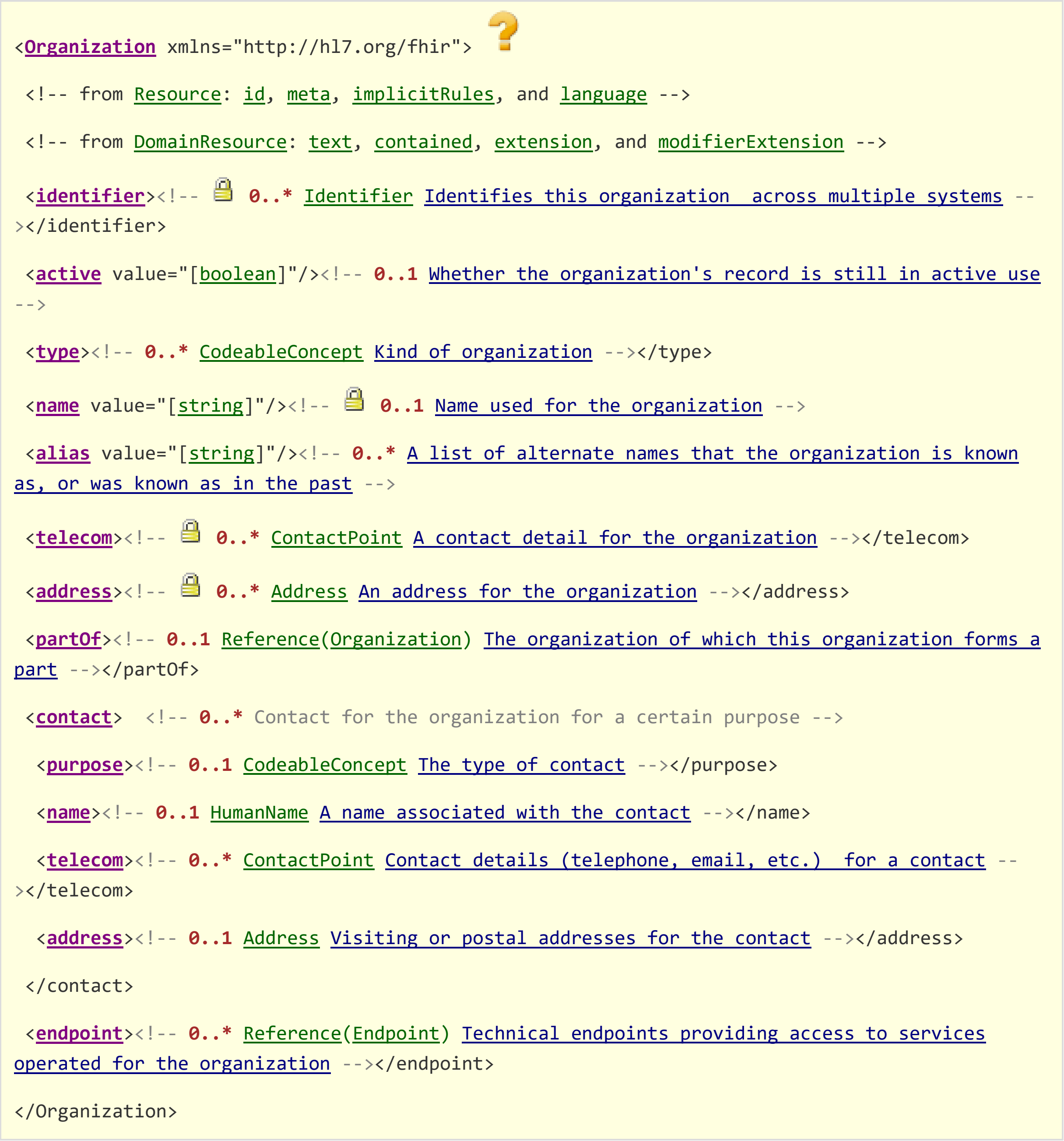
```
<DiagnosticReport xmlns="http://hl7.org/fhir">

 <!-- from Resource: id, meta, implicitRules, and language -->

 <!-- from DomainResource: text, contained, extension, and modifierExtension -->

 <identifier><!-- 0..* Identifier Business identifier for report --></identifier>

 <basedOn><!-- 0..* Reference(CarePlan|ImmunizationRecommendation|

   MedicationRequest|NutritionOrder|ProcedureRequest|ReferralRequest) What was requested --
></basedOn>

 <status value="[code]"/><!-- 1..1 registered | partial | preliminary | final + -->

 <category><!-- 0..1 CodeableConcept Service category --></category>

 <code><!-- 1..1 CodeableConcept Name/Code for this diagnostic report --></code>

 <subject><!-- 0..1 Reference(Patient|Group|Device|Location) The subject of the report -
usually, but not always, the patient --></subject>

 <context><!-- 0..1 Reference(Encounter|EpisodeOfCare) Health care event when test ordered --
></context>

 <effective[x]><!-- 0..1 dateTime|Period Clinically relevant time/time-period for report --
></effective[x]>

 <issued value="[instant]"/><!-- 0..1 DateTime this version was released -->

 <performer>  <!-- 0..* Participants in producing the report -->

  <role><!-- 0..1 CodeableConcept Type of performer --></role>

  <actor><!-- 1..1 Reference(Practitioner|Organization) Practitioner or Organization
participant --></actor>

 </performer>

 <specimen><!-- 0..* Reference(Specimen) Specimens this report is based on --></specimen>

 <result><!-- 0..* Reference(Observation) Observations - simple, or complex nested groups --
></result>

 <imagingStudy><!-- 0..* Reference(ImagingStudy|ImagingManifest) Reference to full details of
imaging associated with the diagnostic report --></imagingStudy>

 <image>  <!-- 0..* Key images associated with this report -->

  <comment value="[string]"/><!-- 0..1 Comment about the image (e.g. explanation) -->

  <link><!-- 1..1 Reference(Media) Reference to the image source --></link>

 </image>

 <conclusion value="[string]"/><!-- 0..1 Clinical Interpretation of test results -->
 <codedDiagnosis><!-- 0..* CodeableConcept Codes for the conclusion --></codedDiagnosis>

 <presentedForm><!-- 0..* Attachment Entire report as issued --></presentedForm>

</DiagnosticReport>
```

Appendix D: practitioner resource structure



```
<Practitioner xmlns="http://hl7.org/fhir">
 <!-- from Resource: id, meta, implicitRules, and language -->
 <!-- from DomainResource: text, contained, extension, and modifierExtension -->
 <identifier><!-- 0..* Identifier A identifier for the person as this agent --></identifier>
 <active value="[boolean]"/><!-- 0..1 Whether this practitioner's record is in active use -->
 <name><!-- 0..* HumanName The name(s) associated with the practitioner --></name>
 <telecom><!-- 0..* ContactPoint A contact detail for the practitioner (that apply to all
roles) --></telecom>
 <address><!-- 0..* Address Address(es) of the practitioner that are not role specific
(typically home address) --></address>
 <gender value="[code]"/><!-- 0..1 male | female | other | unknown -->
 <birthDate value="[date]"/><!-- 0..1 The date  on which the practitioner was born -->
 <photo><!-- 0..* Attachment Image of the person --></photo>
 <qualification>  <!-- 0..* Qualifications obtained by training and certification -->
  <identifier><!-- 0..* Identifier An identifier for this qualification for the practitioner -
-></identifier>
  <code><!-- 1..1 CodeableConcept Coded representation of the qualification --></code>
  <period><!-- 0..1 Period Period during which the qualification is valid --></period>
  <issuer><!-- 0..1 Reference(Organization) Organization that regulates and issues the
qualification --></issuer>
 </qualification>
 <communication><!-- 0..* CodeableConcept A language the practitioner is able to use in
patient communication --></communication>
</Practitioner>
```

Appendix E: organization resource structure



```
<Organization xmlns="http://hl7.org/fhir"> ?
 <!-- from Resource: id, meta, implicitRules, and language -->
 <!-- from DomainResource: text, contained, extension, and modifierExtension -->
 <identifier><!-- 🔒 0..* Identifier Identifies this organization  across multiple systems --></identifier>
 <active value="[boolean]"/><!-- 0..1 Whether the organization's record is still in active use -->
 <type><!-- 0..* CodeableConcept Kind of organization --></type>
 <name value="[string]"/><!-- 🔒 0..1 Name used for the organization -->
 <alias value="[string]"/><!-- 0..* A list of alternate names that the organization is known as, or was known as in the past -->
 <telecom><!-- 🔒 0..* ContactPoint A contact detail for the organization --></telecom>
 <address><!-- 🔒 0..* Address An address for the organization --></address>
 <partOf><!-- 0..1 Reference(Organization) The organization of which this organization forms a part --></partOf>
 <contact>  <!-- 0..* Contact for the organization for a certain purpose -->
  <purpose><!-- 0..1 CodeableConcept The type of contact --></purpose>
  <name><!-- 0..1 HumanName A name associated with the contact --></name>
  <telecom><!-- 0..* ContactPoint Contact details (telephone, email, etc.)  for a contact --></telecom>
  <address><!-- 0..1 Address Visiting or postal addresses for the contact --></address>
 </contact>
 <endpoint><!-- 0..* Reference(Endpoint) Technical endpoints providing access to services operated for the organization --></endpoint>
</Organization>
```