An architectural design for self-reporting e-health systems

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***Abstract*—Worldwide, public healthcare is challenged to deliver consistent and cost-efficient services. The cost of healthcare is increasing primarily due to growing populations and more expensive treatment. Health facilities in many countries are reaching their full operational capacity, and the resources of these hospitals are less than what is required to deliver the expected quality of care. Under these circumstances, ICT has a major role to play in mitigating the growing need for hospital care. In this paper, we present a cloud-based interoperable architecture built on the top of Service-Oriented Architecture (SOA) for Internet-based treatment where patients can directly interact with underlying healthcare systems such as Electronic Health Record (EHR). Based on this architecture, we also present a prototype for screening and monitoring of mental and neurological health morbidities. The proposed solution is based on healthcare interoperability standard, HL7 FHIR, that enables healthcare providers to assess and monitor patients condition in a secure environment.**

***Index Terms*—service-oriented architecture, healthcare, self-screening, HL7 FHIR, SMART on FHIR, Internet-based Treatments**

I. Introduction

E-health is an emerging field of medical informatics which refers to the use of information and communications technologies in healthcare. According to World Health Organization (WHO), e-health is the cost-effective and secure use of information and communications technologies to support health and health-related fields, including healthcare services, health surveillance, health literature, health education, knowledge and research [42]. Today e-Health infrastructures and systems are being considered as central to the provision of high quality, citizen-centered healthcare. A very common requirement for e-health applications is to exchange information between healthcare systems and to support patients while they are staying at home. Although there exist many techniques such as electronic surveys to get data from patients for screening and monitoring, they are not integrated with existing electronic health record systems (EHRs), the data are not standardized, not interoperable and not easily accessible to researchers and clinicians [7]. As a result, healthcare providers are in general unable to use any standardized system for collecting and analyzing information from patients while they are not inside a hospital and cannot share the information with other care providers if needed. To resolve these issues, we propose an architectural design for a self-reporting e-health system that uses healthcare standards for interoperability.

WHO states that one in four people in the world will be affected by mental or neurological disorders at some point in their lives and around 450 million people currently suffer from such conditions [42]. People suffering from mental health problems may have difficulty in comprehending, acting or processing the experiences and information appropriately. This is due to the illness which can affect the mental or neurological functioning including concentration, memory, initiative, ability to plan, summing up the information, experience of time, and generalization [36]. Lack of such cognitive functioning can have a serious impact on patients, families, friends, and society. Dealing with such mental health patients can be economically [13], [33], [44], physically and emotionally challenging. Several types of research have been carried out to facilitate automated and personalized screening and treatment to such mental health patients. Human Brain Project[1], eMEN [15], and INTROMAT [25] are among the European projects that address such mental health problems. In particular, the goal of INTROMAT is to offer *personalized* treatment for patients suffering from mental and neurological disorders.

In this paper, we focus on the mental healthcare domain and envision developing an adaptive system for the mental healthcare domain which can support citizen-centered mental healthcare. We focus on the assessment and monitoring process in order to develop a patient-centered healthcare solution. As part of the INTROMAT project, we are developing core services that will be made available to research projects through the Internet of Things (IoT) and application platforms. Examples of such services are data processing services, data storage, security and privacy services, artificial intelligence (cognitive computing, machine learning, deep learning), event processing, analytical services, and others. We provide an overview of the proposed solution which includes: (i) a cloud-based interoperable architecture built on the top of SOA, named as INTROMAT Core, for self-assessment and evaluation of mental or neurological morbidity, (ii) HL7 FHIR standard questionnaire, (iii) a working prototype of self-assessment and monitoring mobile app, and (iv) a list of research challenges and opportunities in the field.

The paper is structured as follows: Section II outlines the

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[1]https://www.humanbrainproject.eu/en/

main motivation for building a self-reporting e-health system, Section III presents INTROMAT core architecture, its workflow and quality attributes. In Section IV we describe a case study for depression with corresponding domain model for self-reporting system. Section V outlines some of the related works. Section VI concludes the paper with a discussion addressing some challenges and also mentions future work.

II. Motivation

In this paper, we will be addressing the following three challenges:

- heterogeneity of healthcare information across various healthcare service providers
- lack of integrated Internet-based treatment that is accessible for patients and healthcare providers
- lack of adaptiveness in patient-centered care

Healthcare ICT technologies have substantial contributions in uplifting the quality of life and reducing socioeconomic burdens. Technology provides a variety of promising approaches to mental health and neurological practices, training, and supervision in several ways including therapeutic intervention [19] and Cognitive Behavioral therapy [40]. Despite this high prevalence of ICT system in healthcare, the inadequacy provision of interventions for the prevention and treatment of mental or neurological problems has become a global challenge. This is mainly due to lack of standardization in data collection and data preparation methodologies, and heterogeneity of the data [24]. This limits the sharing of data among different healthcare providers. The limitation in sharing health data is detrimental to patient care, provider satisfaction, and healthcare cost [20]. Moreover, providing access to and sharing of health data have been shown to benefit and empower the patients [43]. The complexity of heterogeneity in data and restriction in sharing patient data have hindered standardization and interoperability in the healthcare industry [1]. In this project, we propose to overcome these problems of data collection and interoperability by following a common health standard HL7 FHIR (Fast Healthcare Interoperability Resource) [2], [10]. HL7 FHIR solutions are designed for web standards like XML, JSON, HTTP, and OAuth, are constructed from a set of modular components called Resources which can be grouped into working healthcare systems. HL7 FHIR specification component terminology is supported by the coding system that defines the content being exchanged. This coding system is established by external organizations including SNOMED-CT, LOINC, RxNorm, ICD family and others [2]. OpenEHR[2] is an alternative to HL7 FHIR, which is maintained by the openEHR foundation. Both HL7 FHIR and OpenEHR have open-standard and data interoperability as the main vision. HL7 FHIR is created to exchange data using REST API using the block of around 100 FHIR resources. In contrast to HL7 FHIR resources, openEHR uses over 300 more complex Archetypes which are designed to provide a maximal set of data elements.

[2]https://www.openehr.org

People suffering from mental health require continuous monitoring and treatment. It is not only costly to provide the continuous monitoring and treatment using hospital facilities but it also has a social burden for patients and families. Internet-based psychotherapy treatments play a major role to resolve these issues and evidence illustrates that some forms of Internet-based treatments have comparable outcomes as conventional face-to-face psychotherapy [11]. Moreover, these Internet-based interventions can be presented to a large population flexibly and inexpensively. Internet-based psychotherapy includes treatments programs that are delivered via the Internet such as CBT, CRT, and Mindfulness. Self-assessment is a major component of these Internet-based treatments. Self-assessment provides a possible way such that people suffering from such morbidity can self-evaluate and manage their illness. The concept of self-assessment is not new in the healthcare domain and dates early back to 1977 where Alert Bandura published a theory of self-assessment process incorporating self-observation, self-judgment, and self-evaluation [29]. This is to say, self-assessment comprises behavior observation, behavior evaluation and a response to the evaluation or progress performance. Self-assessment can be a convenient and economical tool for understanding areas for improvement, accelerating self-esteem and enhancing self-awareness [12]. A self-reporting mobile application can provide a virtual therapist in everyone's pocket and help overcome the issue of stigma. Such stigma towards neurological or mental disorders is one of the main causes why some ethnic minority group does not seek and adhere to clinical treatments [18]. Moreover, the study done in [41] shows people suffering from mental health issues undergoes a fear of discomfort in facing a practitioner or choosing services, fear of community and psychosis. However, there is a need for self-assessment tool that a therapist can access in situations where the patients require the involvement of therapist in their treatment program. We address this issue by providing a prototype application for self-assessment and monitoring which is accessible by therapists.

People with different mental or neurological health problems require various types of screening, monitoring, and treatment. Based on the patients monitoring condition, the intervention should be adapted accordingly. But the current Internet-based treatment programs are not flexible enough to support such customization of the treatment plan based on patients need. In INTROMAT project, we envision an architecture where we continuously monitor the mental health conditions and provide a personalized intervention. In this paper, we mainly focus on self-reporting part and leave the discussion of adaptive treatment for future work.

III. Architecture

In this section, we outline the cloud-based INTROMAT core architecture which is based on Service-Oriented Architecture (SOA). The proposed architecture is built around the healthcare process model as shown in Fig. 1. The process model is based on evidence-based treatment where the healthcare provider optimizes patient outcomes through a series of in-

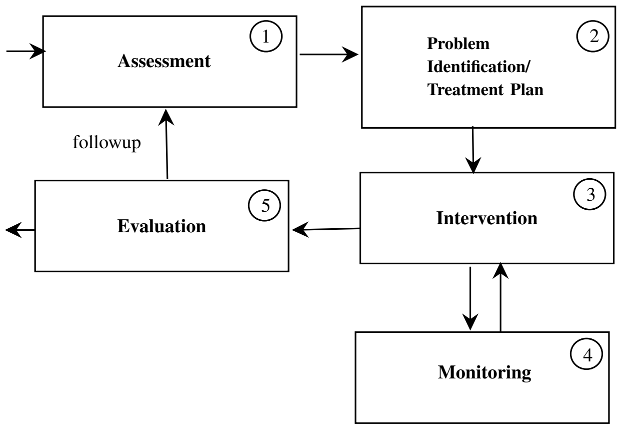

Fig. 1. Work-flow Model for mental or neurological clinical interventions

teractions during which they (1) obtain and examine patients' perspectives and clinical information (assessment); (2) identify the problem and create a treatment plant (problem identification/treatment plan); (3) administer clinical and behavioural interventions; (4) monitor patient progress; and (5) evaluate the progress and ensure follow-up if required. Clinical and behavioral intervention includes evidence-based treatments including Cognitive Based Therapy (CBT), Cognitive Remedial Therapy (CRT) and mindfulness.

Our SOA based solution is centered on the exchange of information using HL7 FHIR resources. The architecture uses services that are given by application components through some communication protocol over a network [6]. The reference model for SOA [30] is an abstract framework that illustrates how significant entities communicate within a service-oriented environment. SOA is a standard for creating and using distributed components as services that may be maintained by different ownership domain.

In the rest of the section we outline the main components of INTROMAT core architecture (Section III-A), discuss communication between different components (Section III-B), and discuss its quality attributes (Section III-C).

A. Components

Fig. 2 is a reference model [30] illustrating significant components and relationship between them with their relevant environments. As illustrated in the figure, the service provider component will reside in the cloud to perceive the benefits of distributed architecture. In this section, we outline the most significant entities in the architecture and discuss the communication between them.

1) Mobile Client: Mobile client facilitates data acquisition, data transmission from wearable sensors. Moreover, mobile apps can be used to provide evidence based treatments.

2) Web Client: A web client provides interfaces for login, authentication, and authorization for practitioners, abilities to create evidence-based treatments for patients and provide a comprehensive dashboard to visualize lists of patients, associated interventions, progress, and their activities. Both mobile and web clients form the service requester/consumer components of the architecture.

3) Authorization Server: The authorization server is an OpenID connect [38] compliant web server with an ability to authenticate users and grant authorization access tokens. Moreover, authorization server manages scopes and permission of the clients, introspects token and requests for the resource server.

4) SMART on FHIR: SMART on FHIR [34] performs the role of service broker [6] and provides identity and access management, access to data and launch sequence management. SMART on FHIR incorporates OAuth2 [21] for authorization, OpenID connect [38] for authentication, data models from FHIR, and supports EHR UI integration through SMART launch specification like EHR context and UI embedding for web apps [32].

5) Resource Server: Resource server is an FHIR [2] compliant web server with an ability to respond to FHIR REST requests consuming access tokens granted by Authorization Server. This component performs the role of service provider [6] in the SOA architecture.

6) Health Provider Clients: Health Provider clients can be external tools and applications, national resources, regional clinical and core systems, as well as legacy systems. While external EHRs following FHIR standards can communicate with Resource Server inside INTROMAT Core using web services, the legacy systems require a middleware, that transcribes legacy standard into FHIR standard.

7) Data Analysis: Data Analysis is one of the important aspects of INTROMAT Core Infrastructure. Data collected and stored in the core will be available to researchers for analysis and to practitioners for medical interventions. The core will provide services through IoT and application platforms enforcing research services including data processing, artificial intelligence, event processing and analytical services. Explaining such research services and how it will be implemented is not within the scope of this paper.

B. Communication Flow

SMART on FHIR specifies three different workflows including contextless flow, EHR launch flow, SMART application launch flow [34]. Our architecture supports all three types of workflows, but for building self-reporting technology, we adopt contextless workflow and is explained in Fig. 3. Development and support for other workflows are entitled to the extension of this work and further development.

The contextless communication between different components is illustrated by the sequence diagram in Fig. 3 and the steps involved as follows.

1) SMART applications (mobile/web clients) makes conformance request to the Resource Server.
2) The Resource Server responds back with valid conformance endpoints (/token, /authorize, /manage).
3) The end users generate an OAuth 2.0 authorization grant request (with valid scopes and headers) and redirect the end users to the authorization server.

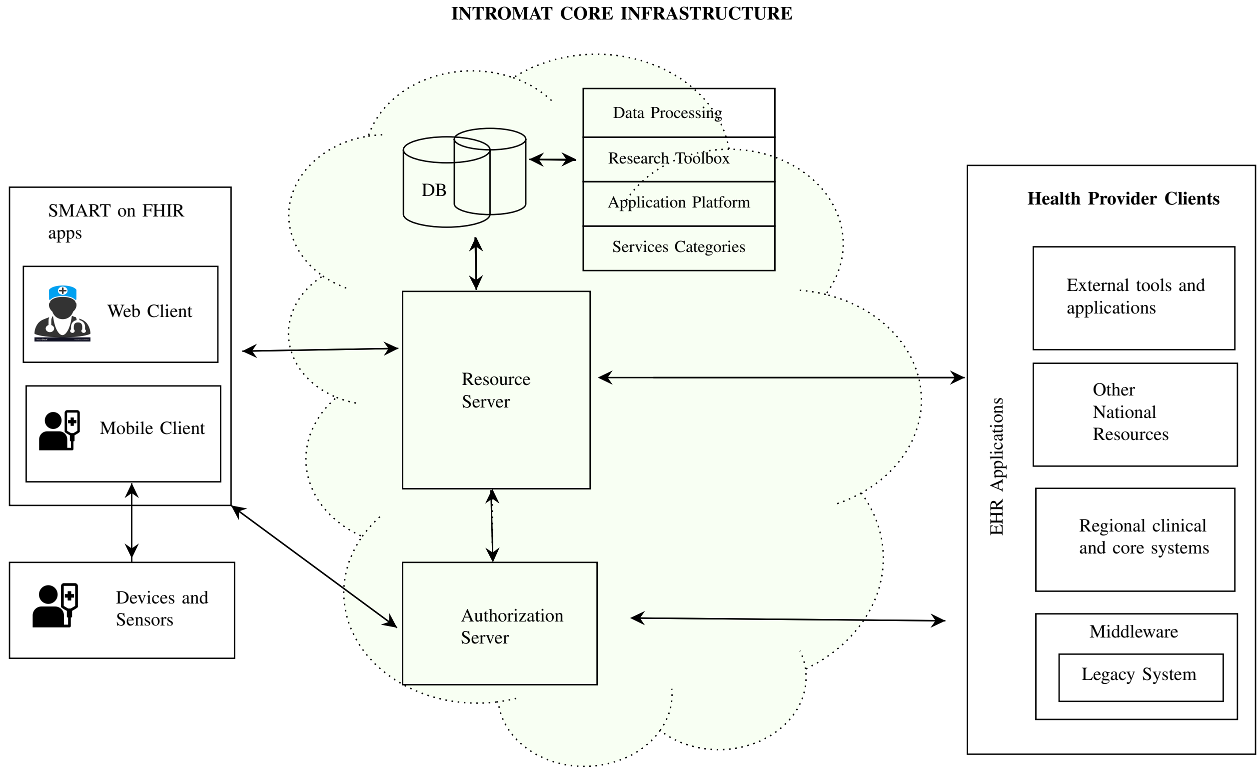

Fig. 2. Service-oriented architecture for adaptive healthcare system

4) The authorization server validates the identity and creates access tokens for the valid clients.
5) The end user creates a request to the Resource Server with Authorization headers (access token)
6) The Resource Server performs token introspection in order to know more about the user and scopes.
7) The authorization server responds with valid scopes, permissions and other token parameters including the token type and token expiration.
8) The Resource Server makes a DB query with valid requests.
9) The DB responds back with requested resources.
10) The Resource Server then forwards the requested resources to the SMART applications.

C. Quality Attributes

In this section, we present the quality attributes of the proposed INTROMAT architecture to characterize the run-time behavior of the system, its design and user experience. To describe the quality attributes of the architecture, we have adopted the notational convention keywords 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL', 'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'MAY', and 'OPTIONAL' in this section and are to be interpreted as described in RFC 2119 [22].

1) Interoperability: Mandl and Kohane recognized implications of the inflexibility of the contemporary EHR system and proposed a need for health platform with inherent characteristics like liquidity of data, suitability of applications (modularization and interoperability), based on open-standard and supports diverse applications [32]. The same study emphasis interoperability is a key requirement for the success of Healthcare Information Systems. One of the approaches to make system interoperable is to follow open-standard for defining syntactic and semantic meaning of information. We adopt one of such open-standards HL7 FHIR [2], [3], which is based on web standards including XML, JSON, HTTP, OAuth, ontology-based, and OpenID connect. To enforce interoperability, health records SHOULD be stored based on FHIR standards. However, legacy EHR systems MAY choose to utilize middleware that converts legacy data structure into FHIR standard before a successful communication can be established.

2) Security: The authorization server and the resource server MUST be TLS-secured [23] and should be improved using the contemporary practices mentioned in [23]. The authorization server SHOULD issue short-lived tokens and have a mechanism open to administrators and end users to eliminate tokens in the case of a security conflict. Moreover, the authorization servers MUST NOT use the value of the launch code as a mechanism for transferring the authenticated state. Using such a mechanism can lead to a session injection attack and a session fixation attack [27].

3) Modifiability: Modifiability incorporates evolvability, customizability, configurability, and extensibility [16]. SOA-based architecture facilitates modifiability [30] by allowing

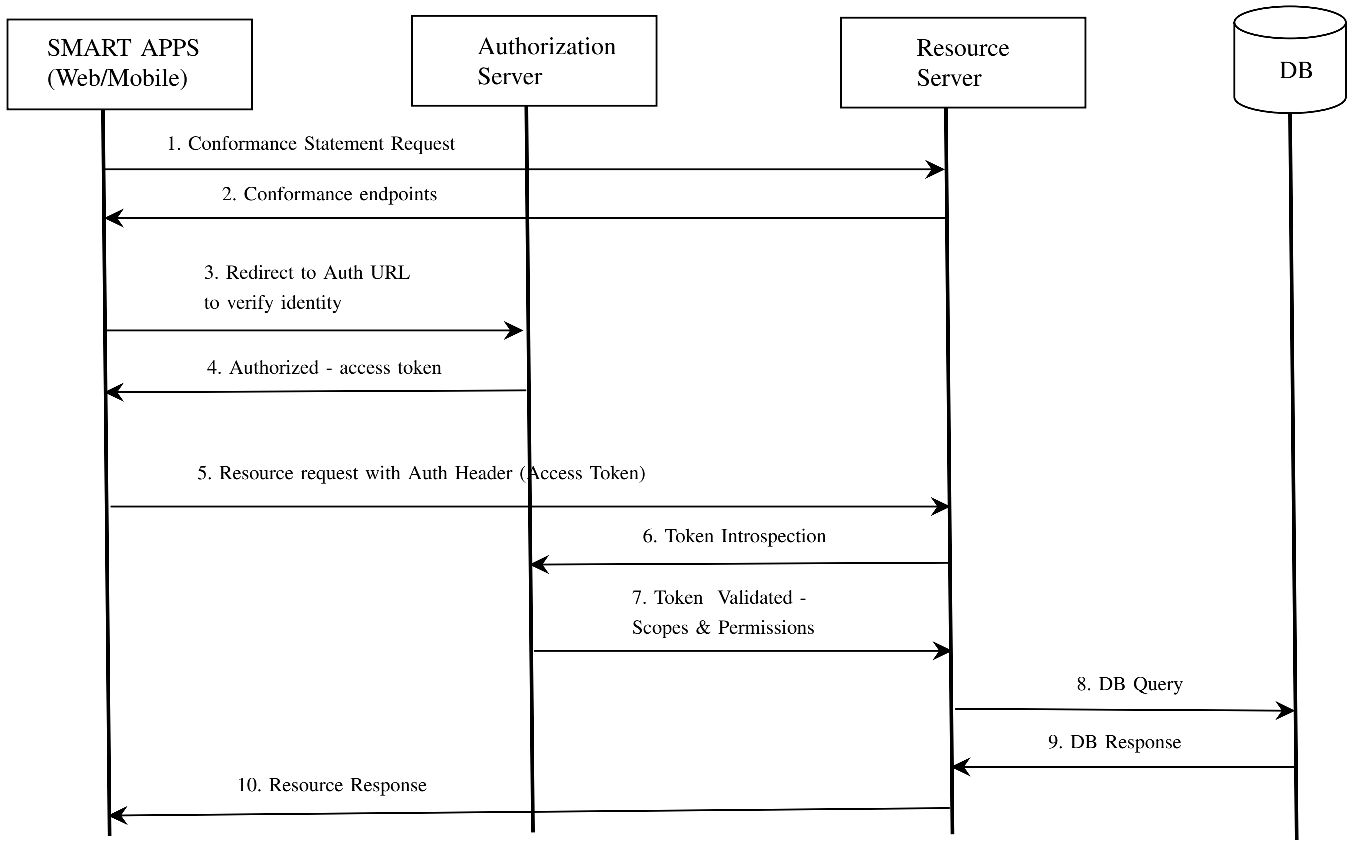

Fig. 3. Communication between different components

manageable growth of large-scale enterprise systems. These enterprise systems or components are independent of vendors, products, and technologies. This makes it easy for individual components to be managed and modified. For example, the Resource server in the architecture (described in Section III-A) MAY update the HL7 FHIR version or create an additional service that consumes the data and performs business intelligence, without affecting other components. Similarly, the authorization server MAY create a customized interface for managing authorized clients, their scopes and permissions without broadcasting its development complexity, structure and patterns, and technological compliances to other components. However, the constituting components MUST follow a common standard for data storage and transmission.

4) Scalability: Scalability can be motivated by simplification of the architectural components, distribution of services across many components [30] and control of configurations and interactions between constituting components [16]. SOA, as mentioned in Section III-A, enforces scalability by organizing services into several components communicating over a network. Each component of the architecture can be updated and evolved in terms of hardware and software independent of other components. For example, the data storage capacity of resource server can be increased or decreased without affecting other components.

5) Testability: As described in Sections III-C3 and III-C4, each component of the architecture is independent and MUST be tested independently to ensure their integral functional components. In addition to unit testing, functional testing and domain testing [17], detailed integration testing MUST be performed in order to ensure different components can communicate with one another.

IV. Case Study

To assess this architecture, we have implemented a prototype based on the proposed architecture for self-assessment and monitoring of mental health problems. We use the prototype for our case study which include depression (MADRAS-S [31], PHQ-9 [28], MDI [9]), anxiety disorder (GAD-7 [39]), ADHD (ASRSV1.1 [14]) and bipolar disorder (ASRM [5]). The self-assessment tool, developed using React Native[3], is in the form of mobile application for both IOS and Android.

In this section, we present the domain model of the self-assessment mobile application and discuss how information from the mobile application is exchanged from the device to Resource Server in INTROMAT core based on FHIR standard.

A. Domain model

We use Diagram Predicate Framework (DPF) [37] for domain modeling. DPF formalizes software development ac-

[3]https://facebook.github.io/react-native/

tivities such as metamodelling [4] and model transformations based on category theory and graph transformations [8]. By applying DPF we can formalize clinical guidelines and clinical domain models at the different abstraction levels in form of diagrammatic specifications. The diagrammatic nature of DPF also facilitates visual representations of guidelines that can be presented at different level of abstraction. A model in DPF is represented by a diagrammatic specification $\mathfrak{S} = (\mathcal{S}, C^{\mathfrak{S}} : \Sigma)$ which consists of a graph $\mathcal{S}$ and a set of constraints $C^{\mathfrak{S}}$ specified by a predicate signature Σ.

The predicate signature is composed of a collection of predicates, each having a name and an arity (shape graph). A constraint consists of a predicate from the signature together with a binding to the subgraph of the models underlying graph which is affected by the constraint. Table I shows a sample DPF predicate signature with three predicates: multiplicity, injective and commutative. The table shows the arity, visualization and the semantic interpretation of the predicates. In Figure 4 we present a portion of the domain model we used for this case study. It illustrates a model M_1 which is typed by metamodel M_0. The model M_1 is constrained with some predicates which specify the following constraints:

1) For each response instance, there exists a source reference and a questionnaire reference.
2) A questionnaire instance may have one or more question items. An example of question item is shown in Listing 1.
3) A question item may have zero or more answer options. FHIR provides two ways to specifies options: *answerValueSet* and *answerOption*. Listing 1 shows an example of *answerValueSet*. In addition, each answer option has a score which is used to get a total score from the response of a user. The score of the options is created by the FHIR concept of extension and StructureDefinition as shown in Listing 2.
4) A question item must have at least one code; An answer option must have at least one code. Listings 1 and 3 shows example of code.
5) A response instance must have the same number of response items as the number of question items the questionnaire instance has.
6) For every response item of a response instance, there exists an answer.

A questionnaire instance has a way to interpret the total score. This can be realized by the concept of extension. Listing 2 shows an example of how a total score should be calculated and interpreted. Moreover, it gives an evaluation expression that can be used to calculate total score by means of a path based navigation and extraction language, fhirpath[4]. The constraints mentioned above are imposed on M_1 by means of three DPF predicates: multiplicity, injective and commutative (see Table I). We transform this DPF model with constraints into an HL7 FHIR profile where Response, Questionnaire, Patient classes are mapped to QuestionnaireResponse, Questionnaire, and Patient FHIR resource type respectively. The purpose of these constraints is to link and validate the responses against the questions being asked by the self-assessment tool. Therefore, the benefits of using an FHIR profile on top of existing HL7 FHIR QuestionnaireResponse is to maintain the validity of the self-assessment tools.

[4]http://hl7.org/fhirpath/

TABLE I
A SAMPLE DPF PREDICATE SIGNATURE

Predicate p, Symbol	Arity, α(p)	Visualization	Semantic Interpretation
Multiplicity, [n..m]	$1 \xrightarrow{f} 2$	$X \xrightarrow{f\ [n..m]} Y$	∀x ∈ X : m ≤ | f(x) | ≤ n, with 0 ≤ m ≤ n
Injective, [inj]	$1 \xrightarrow{f} 2 \xrightarrow{g} 3$	$X \xrightarrow{f} Y \xrightarrow{g} Z$ [inj]	∀y ∈ f(x) where x ∈ X there exists g(y') where y' ∈ y.
Commutative, [=]	$1 \xrightarrow{f} 3$, $1 \xrightarrow{h} 2$, $2 \xrightarrow{k} 4$, $3 \xrightarrow{g} 4$	$X \xrightarrow{f} Y$, $X \xrightarrow{h} W$, $W \xrightarrow{k} Z$, $Y \xrightarrow{g} Z$ [=]	∀x ∈ X : f;g = h;k.

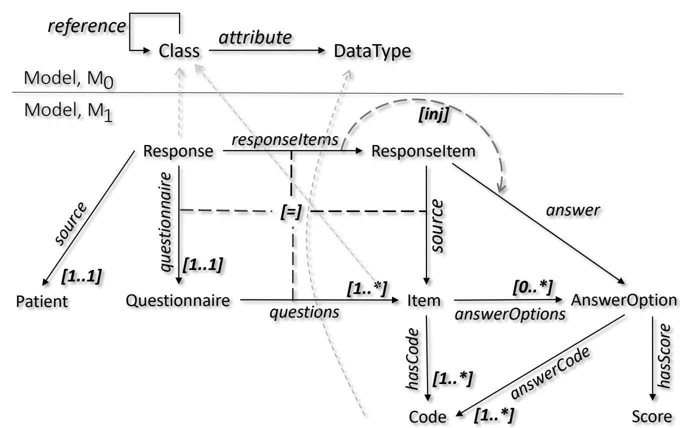

Fig. 4. Example: Diagrammatic model with constraints in DPF

```
{
  "linkId": "LittleInterest",
  "code": [
  {
   "system": "http://loinc.org",
   "code": "44250-9"
  }
  ],
  "text": "Little interest or pleasure in
      doing things",
  "type": "choice",
  "required": true,
  "answerValueSet": "http://loinc.org/vs/LL358
      -3"
}
```

Listing 1. An example question item extracted from PHQ-9

```
"extension": [
 {
  "url" : "http://hl7.org/fhir/
      StructureDefinition/questionnaire-
      calculated-value",
  "valueExpression" : {
```

```
    "description" : "Minimal or none (0-4), Mild
        (5-9), Moderate (10-14), Moderately
        severe (15-19), Severe(20-27)",
    "language" : "text/fhirpath",
    "name" : "score",
    "expression" : "QuestionnaireResponse.item.
        repeat(answer.valueCoding.extension.
        valueDecimal)"
   }
  }
],
```

Listing 2. Specifying scoring criteria using FHIR for PHQ-9

```
{
  "code": "LA6569-3",
  "display": "Several days",
  "extension": [
    {
      "url": "http://hl7.org/fhir/
          StructureDefinition/valueset-
          ordinalValue",
      "valueDecimal": 1
    }
  ],
},
```

Listing 3. Specifying option score for PHQ-9

B. Depression

In this section, we present a self-assessment tool for screening patients with depression and a CBT for managing depression in adults. We implemented MADRS-S [31] using SMART on FHIR. The MADRS-S score is used to evaluate the level of depression of a patient. Based on the level of depression, different CBT modules are created and assigned to patients. One of such CBT training is offered by Helse Bergen, Norway for depression management called eMeistring[5]. Anyone who wants treatment using the eMeisting program must be referred from a General Practitioner, specialist health service, other doctor or psychologist. The patients are offered a CBT to manage mild to moderate depressions. The patients who receive treatment through the eMeistring program are requested to give their consent to use their information for doing research.

A CBT program consists of several modules and each module includes reading, writing, listening or watching tasks. The patients are encouraged to perform these tasks regularly. Moreover, to better understand how patient activities affect the mood, each patient is provided with a mobile client to create a weekly plan consisting of a list of activities. The patients can also annotate the activities with a positive or negative flag to indicate their mood. These activities are shared with their therapist who helps them personalize the CBT based on their activities and mood.

V. Related Work

Balsari and et al. [7] proposed a concept of federated, patient-centric healthcare system after the Government of India announced to provide automated healthcare to 500 million citizens in India. The proposed healthcare system comprises various features including API enabled, authentication and authorization, open-standards (e.g., FHIR), block-chain based and the ability to share the personal health record with researchers and medical practitioner. The concept of transforming collected data into EHR from wearable sensors and using it for medical and research intervention is similar to the INTROMAT project. However, in INTROMAT project we have broader scope focusing on the entire mental health domain. We propose a cloud-based interoperable architecture based on SOA that uses the personal health data in machine learning to get deeper insights and use these insights for creating a personalized Internet-based treatment.

The ALZCARE [35] project developed a mobile application for screening dementia in elderly people. The proposed prototype contains questionnaires tests, whose response could be exported as XML in FHIR format. The proposed system incorporated the web-based clinical Information System for clinical settings and functionality for patient tracking. The system is based on RESTful client-server architecture, while our work is based on SOA. Moreover, we use the latest HL7 FHIR standard, support multiple mental health cases, and provide service for a higher level of cognitive computation.

HABIT [26], funded by the New Zealand Ministry for Business, outlines an IT infrastructure to provide appropriate data management and scalable system for youth mental health intervention. The paper reports the initial design of the platform and intended HABITs platform requirements. While the vision of having identity management, assessment storage, reasoning, usage logging, and consent is similar to INTROMAT project, the approach of implementation, technological eco-system preferences, assessment by a data-driven approach using wearable sensors and cognitive computation, usage of a recent version of the HL7 standard and SMART on FHIR technology are distinct.

VI. Conclusion

This paper presents some results from the INTROMAT project. We give an overview of the proposed solution including a cloud-based SOA for self-assessment and evaluation of mental or neurological morbidity, HL7 FHIR standard questionnaire, a working mobile application prototype for self-assessment and monitoring, a list of research challenges and opportunities in the field. The proposed solution solves the problem of interoperability and stigma on the one hand and provides a self-assessment tool that is accessible and available to patients and healthcare providers on the other. Future work includes the use of mobile applications to collect biological markers using wearable sensors. We will be using these sensors data to perform a cognitive computation to derive useful insights and utilize them to create personalized evidence-based treatments. These treatments will be provided through various types of applications such as mobile, VR application, and voice assistant.

[5]https://helse-bergen.no/emeistring

VII. Acknowledgement

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