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Linking Health Web Services as Resource Graph by Semantic REST Resource Tagging

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Abstract

Various health Web services host a huge amount of health data about patients. The heterogeneity of the services hinders the collaborative utilization of these health data, which can provide a valuable support for the self-management of chronic diseases. The combination of REST Web services and Semantic Web technologies has proven to be a viable approach to address the problem. This paper proposes a method to add semantic annotations to the REST Web services. The service descriptions and the resource representations with semantic annotations can be transformed into a resource graph. It integrates health data from different services, and can link to the health-domain ontologies and Linked Open Health Data to support health management and imaginative applications. The feasibility of our method is demonstrated by realizing with OpenAPI service description and JSON-LD representation in an example use case.

Keywords: health data integration; eHealth; Web service description; Semantic Web; REST

1. Introduction

With the wide use of personal smart devices and portable medical equipment, self-management of chronic disease is getting much more desirable than before [1]. In the meantime, various emerging health-related applications have made this self-management feasible for the patients [2]. The many applications and devices record a huge amount of valuable health data about a patient. The collaborative utilization of various health data across data sources has the potential to support chronic disease patients having more effective and convenient self-management [3].

However, the services holding these health data are heterogeneously built. Currently, the access of these health data services is usually provided by programming language specified Software Development Kits (SDKs) or platform-independent Web APIs. Thanks to the development of Web services technologies, which has promoted the interoperability of various software applications running on distributed and diversified systems, the Web APIs have become the preferred way of accessing data across different services.

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The method of Web APIs, however, is still facing the problem of heterogeneity of exchange data model, and it is also becoming a tediously repetitive work to consume different Web services. Without an effective way to connect the health Web services, the health data within each service will be restricted to be utilized only in their own places with very limited outside collaboration. Thus it makes these health data become in fact data silos. This situation is hindering these high volume valuable health data to have more imaginative potential collaborative utilization.

The application of Semantic Web technologies aims to address these problems [3], but much of the previous work comes with the problems of lacking connection to the actual Web development technology stack, high complexity and expertise requirement on Semantic Web, which hinders the wide application of these solutions.

In this paper, we propose the upgraded Semantic REST Resource Tagging (SemREST), with extensions from a previous work [4], to apply it in eHealth domain to support the collaborative utilization of health data across heterogeneous Web services. The SemREST is another approach to add semantic annotations to the REST Web services, but in a simple and lightweight way. The semantic resource graph, which is generated from the service description and resource representation, integrates health data from different health Web services. The annotated semantics can also support the resource graph to link with the Web of health data.

2. Related work

Aggregating and integrating health data from various sources is always a need for better health management. Works have been done on this front though there are challenges. The approach of mobile application was demonstrated by V. Gay et al. in [1]. Their Android application aggregated health and fitness data in one place by connecting to wearable devices, electronic health record systems and other applications to enable interoperability. A. Garai et al. presented the idea of interconnection among hospital information system, telemedicine instrument and eHealth wearable devices by their hybrid cloud-based Open Telemedicine Interoperability Hub [5]. H. Honko et al. proposed a Wellness Warehouse Engine to exchange health data from different services [6]. Its *Unifier* engine transforms data into reusable generic units for connected services.

Commercial service providers have also attempted to provide solutions to aggregate user health data together into their services. Solutions include Microsoft HealthVault, Apple HealthKit, Google Fit and Samsung Health provide SDKs or APIs for third-party services to store and access data to their backend platforms.

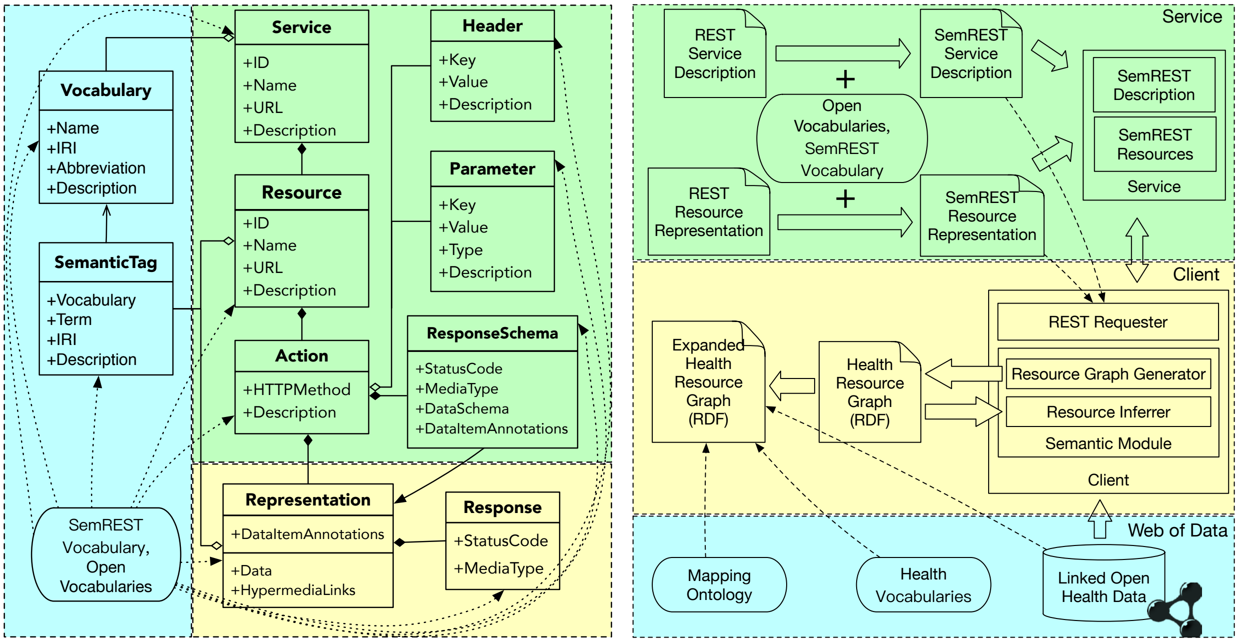
Semantic Web technologies have been applied in the eHealth domain as they can integrate data in semantic level by using common vocabularies and ontologies to define the entities and their relationships. The HL7 organization is working on the supporting of Linked Data, which is for connecting data with semantics on the Web by using Semantic Web technologies [7], to the Fast Healthcare Interoperability Resources (FHIR) standard[1]. N. Arch-int et al. proposed a graph-based Semantic Web Services (SWS) composition system to integrate healthcare data from heterogeneous Web services [8]. It uses the proposed SWS composition ontology to construct the input and output parameters relationships as a dependency graph. An ontology-based framework was proposed by W. Passornpakorn to make various REST eHealth Web services work together [9]. It applies Hydra vocabulary [10] and REST principles [11] to decouple services, and combines OWL-DL and SPARQL rules to implement the decision-making module.

Due to the high demand for data standardization, integration and reuse, there have been a lot of works done on using Semantic Web technologies to support data integration from various sources in the Bioinformatics domain. One of the recent influencing attempts is the FAIR data principles [12]. It intends to utilize already available techniques and standards including RDF Mapping Language (RML) [13], Triple Pattern Fragments [14], common vocabularies and ontologies to make data Findable, Accessible, Interoperable and Reusable.

3. SemREST on Integrating Health Web Service Data

In this section, we firstly present an extended SemREST model to support the semantic integration of health data across different Web services. And then we introduce the semantic health resource graph generating with the connection to the Web of health data and health-domain ontologies.

[1] https://www.hl7.org/fhir/linked-data-module.html



(a) SemREST service description model.

(b) SemREST health resource integration framework.

Fig. 1: (a) SemREST service description model, separated into 3 conceptual domains of service (top right), representation (bottom right) and semantic (left). Each object's elements in the model are identified by terms in SemREST vocabulary and other open vocabularies; (b) SemREST health resource integration framework. The client retrieves the semantically annotated service description and resource representation to generate a resource graph, which can link to the Web of Data.

3.1. SemREST Model

As mentioned, the initial version of SemREST was proposed in [4]. In this paper, we extract the model for a potential wider application with other service description standards. The service description model in Fig. 1a is depicted based on the nature of REST Web service, and inspired by different service description standards include WADL, OpenAPI, RAML, etc. This bottom-up approach can achieve a more adaptable and integrated solution with the actual development technology stack.

In addition, we extend SemREST to include actual data from the representation of a resource. The existing work on SemREST only adds semantic tags to the service description. The resource graph generated from a service description contains only the semantic annotations tagged on a resource. In this model, semantic annotation is added to the REST resource representation. It can expand the resource graph to have health data items. The resource graph is then able to integrate with health domain ontologies and Linked Health Data to enhance the health management outcome.

The SemREST model can be separated into 3 conceptual domains, service domain, representation domain and semantic domain. On the top right is the service domain. *Service* is the root object of the model, it stands for a REST service and contains one or more resources. A *Resource* is the unit of information in a REST Web service. Certain actions, which are HTTP methods in this case, can be performed on a resource. To perform an action on a resource, it requires objects of *Header* and *Parameter*. Multiple response schemas can be defined on an action to a resource, which can be used as hints for actual responses or to validate the response data.

On the bottom right is the representation domain, which contains objects of *Response* and *Representation*. A response object is an actual response of an action performed on a resource (sending an HTTP request) and returned by the service. Along with a status code is a representation object in a certain media type. SemREST requires only Resource Description Framework (RDF) serializable media types such as JSON-LD, RDF/XML and Turtle. A representation, if the action succeeds, contains the data requested. Data item annotations could be added to the metadata of a representation, which will be used to map the data from the representation to the resource graph.

On the left is the semantic domain, which contains the objects of *SemanticTag* with used *Vocabulary*. The SemREST and other used open vocabularies also belong to the semantic domain. *SemanticTag* is used to annotate resources and response representations to make them capable of semantic meaning. A semantic tag is equivalent to the Internationalized Resource Identifier (IRI) [15] of a term in a vocabulary. In the SemREST model, we follow the abbreviation mechanism of OWL (Web Ontology Language)[2] to express a semantic tag as two parts, which are the abbreviation of the used vocabulary and the term in this vocabulary. The abbreviation of a vocabulary is expressed in the *Vocabulary* object.

In addition, in order to transform the description model into an RDF compatible graph, we will have vocabularies to map all the elements in the description model to the graph. For reusing existing open vocabularies as much as possible, we use vocabularies that are available in the Linked Open Vocabularies (LOV)[3] such as Hydra [10], and to link them with the SemREST vocabulary.

3.2. Semantic Health Resource Graph Generation

Fig. 1b shows the framework of SemREST along with the generation process of a health resource graph. On the service aspect, the SemREST semantic annotation is not meant to break the compatibility to the normal service description and resource representation. The semantically annotated elements of service description and resource representation could be generated on the fly, which also makes the service to be able to serve different responses based on the content negotiation of a request.

We propose to add an HTTP *OPTIONS* method under the service's root path "/" of each service to serve the service description for the client. A service description describes all the resources under the service. It makes it natural for a client to discover all the resources' communication options by retrieving the service description via *OPTIONS* method [16] since its purpose is similar to what is described in HTTP/1.1 specification [17]. There are also other ways proposed to retrieve a service description. For example, a special HTTP link header is used by Hydra [10] to return the URL of API documentation.

The purpose of making a service description along with semantics is to empower a generic client to achieve a more autonomous client service interaction, include service discovery, invocation and composition. The semantically annotated service description can be transformed into an RDF document by the client, which is then a semantic resource graph.

A client can retrieve multiple semantic service descriptions from different health services. Then a larger resource graph can be generated. As shown in the description model, a resource will be annotated by one or more semantic tags. So the client can semantically query resources from different health services in the graph by the semantic tags. The functional metadata with semantics in the graph can be used by the client to retrieve the representations of resources.

With a successful request, the representation returned by a service will contain the required actual data with semantic annotations indicate which field in the representation is the data items. The resource graph will then expand to include the representation with the actual data. So eventually the client could have access to the resource graph that contains the aggregated health data from different health Web services.

3.3. Connecting Health Domain Ontologies/Vocabularies

RDF is able to describe entities and their relationships with explicit semantic meanings, which are defined in vocabularies or ontologies. As a resource graph is actually an RDF document, it makes the health resource graph have the same ability to be expanded to link to the concepts defined in healthcare vocabularies, such as SNOMED-CT and ICD-10, besides the ones used in the semantic tags annotation. In order to achieve the link from the resource graph to other healthcare vocabularies, certain ontology mapping is required, which could be created on demand or found on LOV for reuse.

RDF's expressing entities and relationships in a standardized compatible way also enables the resource graph to be able to integrate with the large-scale Linked Data [7]. Fig. 2 shows the relative levels of a conceptual resource graph.

[2] https://www.w3.org/TR/2012/REC-owl2-syntax-20121211/#IRIs
[3] http://lov.okfn.org/dataset/lov/

It is generated from a service description, then expanded with the retrieved resource representation with a data item, and eventually expanded to link with Linked Open Data (LOD)[4]. Currently, there have been 9960 datasets that include over 149 billion triples (according to the LODStats project[5]) published and interlinked with other datasets in the LOD project. Out of these datasets, about 1/3 are healthcare and life science domain datasets, making the linked health data cloud a valuable source for mining unknown knowledge. The W3C Health Care and Life Sciences working group also promoted it further by works such as the Translational Medicine Ontology. Making all these data available on the Web results in the Web of Data.

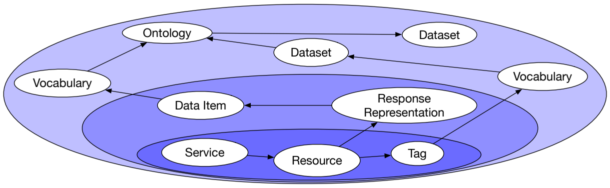


Fig. 2: Levels of conceptual resource graph from service description to Linked Open Data

When the health resource graph is linked to the Linked Open Health Data Cloud, there could be imaginative potential benefits, such as health data visualization with semantic meaning, health decision support, and mining health data with the massive linked health data.

4. Feasibility and case study

In this section, we will demonstrate how this extended SemREST could be realized with the OpenAPI service description and JSON-LD resource representation. This is followed by a use case to demonstrate the usability of SemREST to support the self-management of a patient's health. Since this is only for the purpose of testifying the feasibility of the approach, so we only demonstrate the working process without any performance evaluation.

```yaml
tags:
  - name: schema
    description: the schema.org vocabulary
    externalDocs:
      url: http://schema.org
paths:
  # fitbit:resource1
  /user/activities/calories/date/{base-date}/{end-date}.json:
    get:
      description: Returns activity time series data in the specified range for a given resource.
      tags:
        - schema:calories
        - schema:activities
        - schema:ConsumeAction
      parameters:
        ...
      responses:
        ...
  # fitbit:resource2
  /user/foods/log/caloriesIn/date/{baseDate}/{endDate}:
    get:
      tags:
        - schema:calories
        - schema:FoodEvent
      parameters:
        ...
      responses:
        ...
```

Listing 1: Fragment of annotated OpenAPI service description in YAML format, contains *fitbit:resource1* and *fitbit:resource2* with semantic tags

4.1. Realization with OpenAPI and JSON-LD

The semantic tag is annotated as the OpenAPI built-in field *tags*, and expressed in the way as *vocab:term*, which follows the OWL's abbreviation mechanism[2]. Listing 1 shows an example OpenAPI service description fragment that contains two resources with semantic tags. One of these resources is tagged with the semantics of calories consumed by activities. Another resource is tagged with the semantics of calories intake by food. All the semantic tags in this description are annotated by using the terms in the open vocabulary Schema.org.

[4] http://lod-cloud.net/
[5] http://stats.lod2.eu/

JSON-LD is a lightweight serialization syntax to express RDF in JSON format. A normal JSON document with incremental JSON-LD objects such as *@context* and *@id* can then be used as an RDF document. With the features of JSON-LD, we can add the data item annotations to the *@context* to indicate the actual data object of a resource.

Listing 2 shows an example of how a data item annotation could be added to a JSON-LD representation. It is the representation of the *fitbit:resource1* in Listing 1. We defined a term *dataItem* in the *semrest* vocabulary. We use it to indicate which object is the actual data in the JSON body. So here the object *activities-calories* is indicated by *semrest:dataItem* as the actual data. This JSON-LD document can then be transformed as an RDF and be merged to the resource graph of the service description, under a *Response* object of a resource. The Turtle serialization of this RDF is shown in Listing 3. With a few other annotations, the value and dateTime in the data item will be able to be merged to the resource graph as well.

4.2. Use Case Demonstration

Here we will demonstrate an example on how a resource graph is generated from two different health Web services' OpenAPI service descriptions and the corresponding resources' JSON-LD representations, and how will it link to the Linked Open Health Data.

The scenario of this example case is the same as the one in [4], where Alice manages her health by herself. She uses Fitbit service to record her activities and food intake, which are represented as *calories consume Action* and *FoodEvent* respectively. The resources are shown in Listing 1 as *fitbit:resource1* and *fitbit:resource2*. She also uses a heart rate monitor, the data of which can be retrieved from Human API. The resource is shown in Listing 4 as *humanapi:resource1*.

```
{
    "@context": {
        "semrest": "http://semrest.org/",
        "activities-calories": "semrest:dataItem"
    },
    "@id": "http://fitbit.com/namespace#representation1",
    "activities-calories": [{
        "dateTime": "2017-11-11",
        "value": "1568"
    }]
}
```

Listing 2: JSON-LD representation fragment of *fitbit:representation1* that represents *fitbit:resource1*

```
@prefix fitbit: <http://fitbit.com/namespace#> .
@prefix schema: <http://schema.org/> .
@prefix semrest: <http://semrest.org/vocab#> .

<http://api.fitbit.com/> a semrest:Description ;
    semrest:hasResource fitbit:resource1.
fitbit:resource1 a semrest:Resource ;
    semrest:hasResponse fitbit:response1 ;
    semrest:hasMethod semrest:get ;
    semrest:hasTag schema:ConsumeAction,
        schema:calories ,
        schema:activities;
    semrest:urlTemplate "/user/activities/calories/date/
    ↪ {base-date}/{end-date}.json"
    ↪ .
fitbit:response1 a semrest:Response;
    semrest:hasRepresentation fitbit:representation1 .
fitbit:representation1 a semrest:Representation ;
    semrest:dataItem [ schema:calories "1568" ;
            schema:dateTime "2017-11-11" ] .
```

Listing 3: Simplified resource graph of resource *fitbit:resource1* with Representation *fitbit:representation1* in RDF/Turtle format

After Alice's health agent client retrieved the two service descriptions, a resource graph is generated (as darkest blue in Fig. 3). The required resources will be identified by the semantic tags. Then it will send HTTP requests based on the functional metadata to get the resources' JSON-LD representations. The fragments of JSON-LD representation from the services' responses are shown in Listing 2 and Listing 5. Since JSON-LD is a serialization format of RDF, these two representations can be merged to Alice's resource graph (as slightly lighter blue in Fig. 3).

To expand the resource graph to link with other health ontology and linked open health data, we can add a triple "*schema:calories owl:sameAs dbr:Calorie*" in the mapping ontology to indicate that the calories in the Schema.org vocabulary has the same meaning to the Calorie in the DBpedia. So that we can link the resource tagged with *schema:calories* to the entities with either *dbr:Calorie* or *schema:calories* in the linked open health data. Similarly, we can link *m3lite:HeartBeat* to *snomedct:364075005*[6] , which is the term of heart rate under the clinical ontol-

[6] http://purl.bioontology.org/ontology/SNOMEDCT/364075005

ogy SNOMED-CT (available under the BioPortal project). Thus we expanded the resource graph being linked with other health ontology and linked open health data. The entire Fig. 3 shows the health resource graph (simplified for readability) generated so far.

```yaml
tags:
  - name: m3lite
    description: The M3-lite Taxonomy
    externalDocs:
      url: http://purl.org/iot/vocab/m3-lite#
paths:
  # humanapi:resource1
  /v1/human/heart_rate:
    get:
      description: The latest heart rate measurement
      tags:
        - m3lite:HeartBeat
      ...
```

Listing 4: Annotated service description of Human API's heart rate resource *humanapi:resource1*

```json
{
    "@context": {
        "semrest": "http://semrest.org/",
        "value": "semrest:dataItem"
    },
    "@id":
      ↪  "http://humanapi.co/namespace#representation1",
    "userId": "52e20cb2fff56aac62000001",
    "timestamp": "2015-03-19T22:48:26.000Z",
    "value": 66,
    "unit": "bpm",
    "source": "ihealth"
}
```

Listing 5: JSON-LD representation fragment of *humanapi:representation1* that represents *humanapi:resource1*

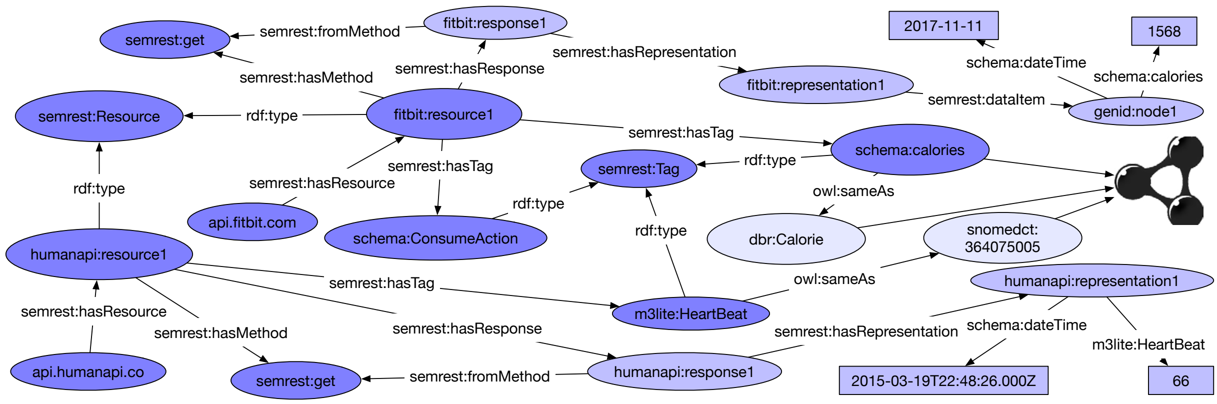


Fig. 3: Alice's simplified health resource graph, contains two resources with data in representations from different services, and being linked to other ontologies to eventually link to the Linked Open Health Data

In this health resource graph, Alice's health data from different services are integrated together. It can help Alice to have a comprehensive view of her health status without restriction of service boundary. The semantic annotations of the data contained in the resource graph can empower third-party services to provide imaginative applications on the integrated health data without concern on the heterogeneity of data models.

5. Conclusion and future work

In this paper, we presented the upgraded REST Web service description model SemREST, which is a comparably simple approach to semantically annotate REST health services. Compare with the previous work [4], this extended SemREST model is extracted as a conceptual model to work with various service description standards. More importantly, the extended model is able to integrate actual resource data by including resource representations. The service description and the retrieved resource representation can be transformed into a semantic resource graph expressed in RDF document. This method can integrate health data from different services into one semantic resource graph, which can be further linked to healthcare ontologies and linked open health data. The integrated health data with semantic meanings in the resource graph can promote some potential imaginative third-party applications such as health data mining [18, 19] and health decision support [20], to assist health self-monitoring and management.

In the current stage, though we have extracted the description model, it has only realized on the widely used OpenAPI description and JSON-LD representation. As a health data aggregator, realizing only the *GET* HTTP method is sufficient. But it will certainly need other HTTP methods to be a fully functional service description method. The resource representation has to be an RDF serialization format for being merged into the resource graph. Since JSON is used by majority Web services as the data exchange format, the fully JSON compatible RDF serializable format JSON-LD could reduce much supporting work. However, for some of the data models, it might not be straightforward to annotate the data items.

For future works, we plan to evaluate the effectiveness of identifying resources by using semantic tags, and to perform surveys with Web service providers and consumers for the usability. Also, the costs of annotation and resource graph generation will be measured on different factors such as data size and processing time increment, which will be used to evaluate if the health data integration worth the performance reduction. Since the HL7 FHIR specification is working on supporting Linked Data format, we will explore the integration with HL7 FHIR and the possibility of promoting the work further.

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