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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – Frameworks, architectures and protocols

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Framework to support web of objects ontology based semantic data interoperability of e-health services

Recommendation ITU-T Y.4484

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Recommendation ITU-T Y.4484

Framework to support web of objects ontology based semantic data interoperability of e-health services

Summary

Recommendation ITU-T Y.4484 specifies the framework to support web of objects (WoO) ontology based semantic data interoperability of e-health services in accordance with Recommendations ITU-T Y.4452 and ITU-T Y.4563. Semantic data interoperability enables the various e-health systems to combine received information with other information resources and to process it in a manner that preserves meaning. In order to support the semantic data interoperability functions among e-health systems, this Recommendation applies the WoO framework in Recommendation ITU-T Y.4452 and the semantic data interoperability function in Recommendation ITU-T Y.4563.

History

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Common data model, e-health, ontology semantic data interoperability, web of objects.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Recommendation ITU-T Y.4484

Framework to support web of objects ontology based semantic data interoperability of e-health services

1 Scope

In e-health services, semantic data interoperability will enable the various systems to combine received information with other information resources and to process it in a manner that preserves meaning. The lack of semantic data interoperability between e-health systems is one of the major obstacles in the provision of cross-border and cross-sector e-health systems. [ITU-T Y.4563] identifies the requirements and functional model to support data interoperability in Internet of things (IoT) environments.

In accordance with [ITU-T Y.4452] and [ITU-T Y.4563], this Recommendation describes a framework to support web of objects (WoO) ontology based semantic data interoperability of e-health services by presenting:

– An overview of semantic data interoperability in e-health services;

– Requirements to support WoO based semantic data interoperability in e-health services;

– A functional model to support WoO ontology based semantic data interoperability;

– WoO based semantic data interoperability provisioning in e-health services.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4111] Recommendation ITU-T Y.4111/Y.2076 (2016), *Semantics based requirements and framework of the Internet of things.*

[ITU-T Y.4452] Recommendation ITU-T Y.4552 (2016), *Functional framework of web of objects*.

[ITU-T Y.4563] Recommendation ITU-T Y.4563 (2021), *Requirements and functional model to support data interoperability in Internet of things environments*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 common data model [ITU-T Y.4563]: A data model that allows transformation of data into a single common data format from different formats that are collected from heterogeneous sources. For transformation into a common format or data model, common terminologies, vocabularies, schemes need to be followed.

3.1.2 data interoperability [ITU-T Y.4563]: The ability of two or more systems or components to exchange data and to use the data that has been exchanged.

3.1.3 data model [ITU-T Y.4111]: A representation structure for data that can organize data as elements in the structure and standardize the meaning of data elements and their relationships.

3.1.4 data set [ITU-T Y.4111]: A collection of data that conforms to a particular data model.

3.1.5 ontology [b-ITU-T X.1570]: An explicit specification of a conceptualization.

3.1.6 semantics [b-ITU-T Z.341]: The rules and conventions governing the interpretation and assignment of meaning to constructions in a language.

3.1.7 semantic data interoperability [ITU-T Y.4563]: The ability of two or more computer systems to automatically interpret data exchanged between them meaningfully and accurately in order to produce useful results as defined by the end users of both systems.

3.1.8 semantic data model [ITU-T Y.4563]: A conceptual model that includes the semantic information of instances. Semantic information of data defines the meaning of data based on the context of the data.

3.1.9 web of objects (WoO) [ITU-T Y.4452]: A way to incorporate virtual objects on the world wide web and to facilitate the creation of IoT services.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

API Application Program Interface

BOE Base Ontology Element

BOM Base Ontology Model

CDM Common Data Model

CMO Core Mediation Ontology

CE Composite Element

CVO Composite Virtual Object

DB Database

ICT Information and Communication technologies

ID Identification

IoT Internet of Things

RDF Resource Description Framework

RWO Real World Object

SPARQL SPARQL Protocol and RDF Query Language

SSN Social Services Network

VO Virtual Object

W3C World Wide Web Consortium

WoO Web of Objects

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

The keywords "is not recommended" indicate a requirement which is not recommended but which is not specifically prohibited. Thus, conformance with this specification can still be claimed even if this requirement is present.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview of semantic data interoperability in e-health services

In e-health services, semantic data interoperability is the ability of applications to exchange data between different e-health service environments and the use of exchanged data in a meaningful way in multiple e-health service resources. In general, e-health data interoperability is concerned with the capability of communications between e-health service environments that might have different forms including transfer, exchange, transformation and integration of data.

The semantic data interoperability among e-health applications is concerned with enabling different agents, services, and applications to exchange information, data, and knowledge in a meaningful way. Consensus on meaning is required while exchanging the data across e-health systems. Semantic data interoperability defines the true meaning of the contents that are generated by e-health service resources and are mutually agreed by the different e-health resources that use these contents.

Semantic data interoperability of e-health services provides the ability of computer systems to exchange and understand data with unambiguous, shared meaning among different stakeholders. Thus, semantic data interoperability of e-health services is a requirement to enable machine computable logic, inferencing, knowledge discovery, and data federation between information systems.

Two important concepts in semantic data interoperability provisioning of e-health data can be identified in terms from [ITU-T Y.4111] and [ITU-T Y.4563] as follows:

– Exchange of data between interoperating e-health service environments – implies how the service features will be exchanged;

– Use of exchanged e-health data semantically – implies how the exchanged data can be used in a meaningful and unambiguous way.

Data aggregation and integration in e-health services will be the important processes necessary to achieve intelligent and enhanced e-health service environments. They require well-defined mechanisms for linking semantics such as the automated linking of relevant semantic data sources and the metadata, which enables e-health data integration and reuse of data. As well as mechanisms for the sharing and reusing of data, mechanisms to support the semantic data interoperability in e-health services would also be necessary. The functional model in Figure 6-1 of [ITU-T Y.4563] provides the view to support semantic data interoperability among different e-health service domains. As shown in Figure 1of this Recommendation, three components are necessary to support semantic data interoperability in e-health services:

–	Semantic data interoperability of e-health services;
–	Semantic ontologies to describe its linking and alignment of e-health services;
–	Application program interface (API) request query translation to support the alignment and management of the source and the target semantic schemas of e-health services.

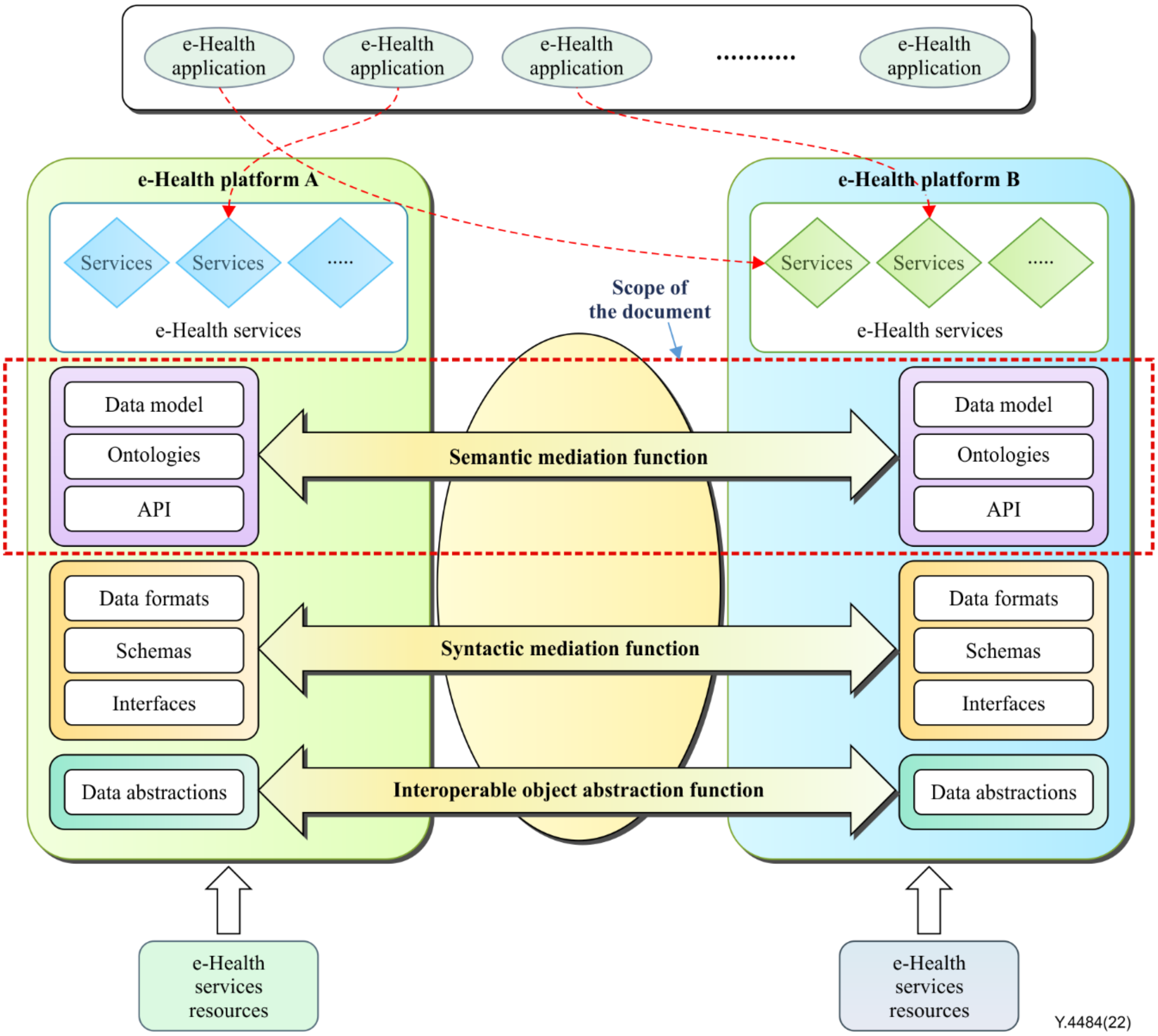

Figure 1 – A view of semantic data interoperability in a heterogeneous e-health platform presented in [ITU-T Y.4563]

7 Requirements to support semantic data interoperability in e-health services

To support semantic data interoperability in e-health services there several requirements to be considered. This clause highlights some of the principal requirements to support data interoperability and some requirements with respect to semantic data interoperability of e-health services.

–	Semantic e-health data modelling: The semantic representation of e-health data is required to express a common understanding across systems. A semantic representation model in e-health services is necessary to provide the conceptual understanding of data as well the relationship among entities.
–	Semantic integration and sharing: Mechanisms for the linking of e-health data based on semantic ontology models are required. The linking mechanisms in e-health are required to be efficient to support dynamic integration and sharing of e-health data.

– Semantic annotation of e-health data: A semantic annotation mechanism is required to support the annotation of e-health data coming from heterogeneous sources. Semantic annotation in e-health services is required to be supported with a well-defined set of metadata to express the features of diverse e-health data.

– Semantic e-health data management: The abstract semantic representations of e-health data are required to be managed through a management service. A suit of well-defined e-health services is required to manage the data allowing its access, retrieval and storage operations.

– Semantic ontology alignment and mapping of e-health services: It is required to provide improved ontology alignment in order to support semantic e-health data interoperability. The ontology alignment techniques with enhanced accuracies can enable and improve interoperability across different e-health service resources.

– Semantic representation of e-health knowledge: Providing rules with e-health knowledge representation supports reasoning on the data which enhances its value. The information model defines the format to contain the e-health information. It is required to be semantically rich and expressive enough to represent the different forms of the objects being maintained. It should also scale well in evolving e-health service technology. An e-health information model should be flexible enough to represent semantic information. Ontologies in e-health service provide an option to exchange the e-health knowledge by giving the semantics required and enhancing the data in the information model.

– Semantic e-health data transformation: A mechanism for the transformation of a semantic format to another is required. In the case of a domain specific e-health service model, it is necessary to provide a transformation service among heterogeneous semantic e-health data models.

– Reference of e-health context: The reference is made to semantic interoperability as the systems' capacity, with the support of information and communication technologies (ICT) applications, to exchange, understand and act upon data related to a citizen/patient and other health data, information and knowledge between clinicians, patients and other actors/systems using diverse languages and information coding systems within and between health systems.

– A key component of operational semantic interoperability: There is a need to differentiate between different types and categories of semantic components although the same semantic components can be classified in different categories:
  - What one means (ontology);
  - How one says it (languages, terminologies and code systems);
  - How one finds it (interface).

8 Functional model to support WoO ontology based semantic data interoperability of e-health services

The functional components to support the semantic data interoperability identified in [ITU-T Y.4563] are applied to provide WoO ontology in accordance with [ITU-T Y.4452] based semantic data interoperability of e-health services. These are six functional components, the registration of the semantic data, semantic translation and query processing, semantic annotation and liking and the validation of semantic alignments as described in [ITU-T Y.4563]. Figure 2 shows core functional components of the semantic data interoperability model of e-health services.

– e-health semantic data registration;

– e-health semantic data translation;

– e-health API request-query translation;

– e-health semantic annotation;

– e-health semantic alignment and linking;
– e-health semantic validation.

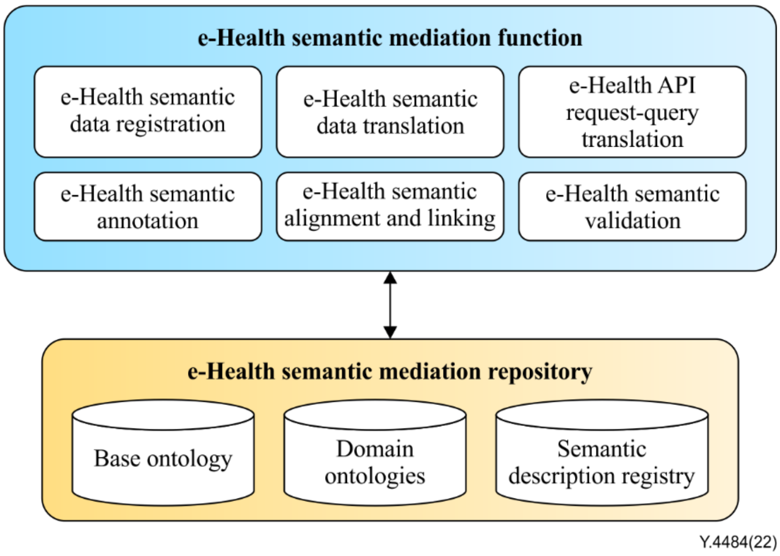

Figure 2 – Functional components of semantic data interoperability model of e-health service in association with [ITU-T Y.4563]

8.1 e-health semantic data registration function

This function enables a record of e-health semantic formats that can be used by a semantic translation function. The e-health semantic registration function performs two core functionalities:

– e-health ontology discovery;
– e-health ontology registration management.

The e-health ontology discovery service provides the search and matching of ontology records in the e-health semantic description registry. In order to perform the e-health ontology discovery function, it will be necessary to define a request interface to query the ontology instances.

The e-health ontology registration management service provides the functional capability to register and manage the semantic ontology models. This registration will be performed in terms of hierarchical terminologies of the e-health ontologies, and the predefined interactions to have registration will be applied during the search in the registry database. The e-health semantic ontology registry will be performed by providing the mapping of semantic IDs and semantic description in resource description framework (RDF) format, and domain ontology endpoints to associate with host domain RDF graphs of e-health service.

8.2 e-health semantic data description translation function

The e-health semantic data description translation function provides the translation of object formats to base semantic data formats of a related e-health service. The functional capabilities of the e-health semantic data translation function are as follows:

– Base ontology translator of an e-health service: delivers the functional capability of translation of concepts from a domain ontology model to the base ontology model of an e-health service;
– Data model: provides the capability to express the semantic data meaning of the exchanged data using the information objects of an e-health service.

8.3 e-health API request-query translation function

The e-health API request-query translation function provides a specialized way to translate the requests into the specific API format of an e-health service through provision of an API request translation, a query formation and format description. The API translation service provides the functional capability to translate the API request to a target request format.

8.4 e-health semantic annotation function

This function enables the annotation of the e-health data based on the WoO ontology and semantic data model indicated in [ITU-T Y.4563]. The e-health semantic data annotation function uses a selected annotation description language and allows attaching or adding additional information by linking machine processing information to a WoO based semantic ontology. This process is used to clarify a WoO based semantic ontology of an e-health service to the existing contents. The e-health semantic annotation function supports the characterization of the relationship between concepts and WoO based e-health ontology, linking information sources to an e-health ontology, and assigning semantic concepts and properties to the target data.

8.5 e-health semantic alignment and linking function

The semantic alignment and linking function enables the alignment and management of the source and the target semantic schemas of e-health services. It takes the source and target ontology models and computes the alignment with the similarity measures and the provided thresholds for each measure, this service returns the alignment results in terms the true mapping achieved through the mapping algorithm.

When WoO based e-health service ontologies are matched they are indeed aligned with the correspondence among different ontologies. The correspondence enables heterogeneous e-health ontologies with different semantics to be interoperable. The identified correspondence among heterogeneous e-health ontologies is a set of rules which transform from one to another ontology to enable the integration of the information. The mapping of matching techniques generates the similarity value of the semantic between e-health services. The higher the value between two entities the more exact match is assumed.

8.6 e-health semantic validation

It is important to evaluate the feasibility of the semantic data interoperability of e-health semantic data with a defined schematic ontology. This function performs the test to validate the semantic data structure of the e-health semantic data in terms of a validation test case defined on the bases of semantic ontology. This function is used to verify the semantic conversion of data with a defined schema. It constitutes the mechanism to validate the semantic structure of the data with validation test case defined on the bases of semantic ontology. The functional capabilities of semantic validation function are as follows:

– e-health ontology validation: provides the validation function on the provided input test case to validate the semantic alignment;

– e-health ontology test execution: provides the execution facility to perform the validation for the alignment function.

9 WoO based semantic data interoperability provisioning in e-health services

This clause provides a functional model to provide a WoO ontology based semantic data interoperability in accordance with [ITU-T Y.4452] and [ITU-T Y.4563] among two or more heterogeneous e-health service domains. As shown in Figure 3, two heterogeneous e-health service domains (e.g., a blue coloured e-health service domain A and a green coloured e-health service domain B) are considered to figure out the provisioning of WoO ontology based e-health service semantic data interoperability.

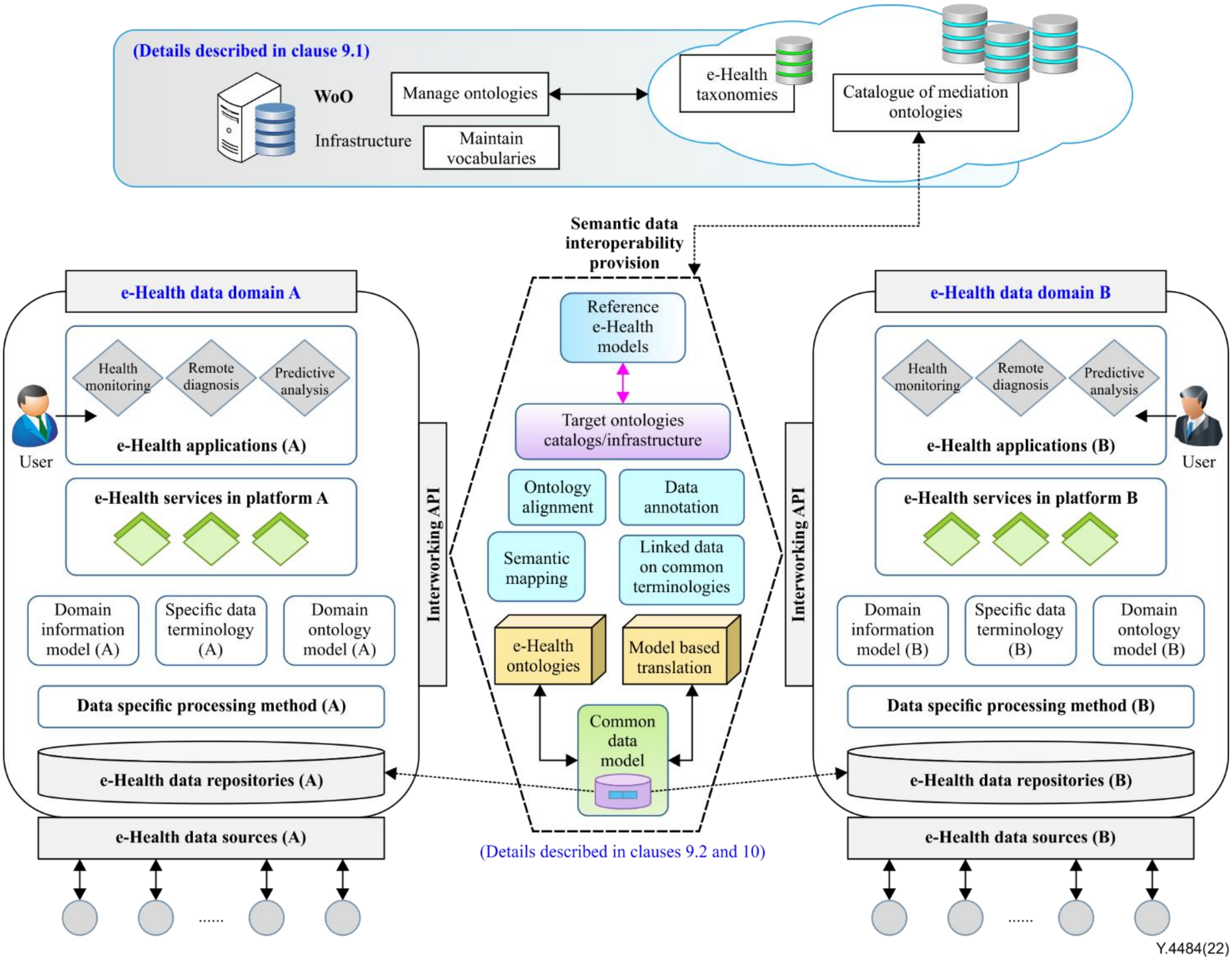

Figure 3 – WoO ontology based semantic data interoperability provisioning model of e-health service

9.1 WoO infrastructure for e-health service ontology based on [ITU-T Y.4452]

The WoO infrastructure of Figure 3 identifies the model of an interoperable WoO e-health service environment. The WoO infrastructure based on [ITU-T Y.4452] is applied to design a WoO ontology based e-health service model to support the following functional capabilities:

– WoO service sub-level functions (based on service sub-level of WoO in [ITU-T Y.4452]) to create and manage e-health service entities;

– WoO composite virtual object (CVO) sub-level functions (based on service sub-level of WoO in [ITU-T Y.4452]) to support control and management of composition of multiple VOs;

– WoO virtual object (VO) sub-level functions (based on service sub-level of WoO in [ITU-T Y.4452]) to provide the functional capabilities responsible for the control and management of VOs;

– The registry DB, template repository, information database in [ITU-T Y.4452], which enable WoO entities to access the WoO resources.

WoO infrastructure of Figure 3 supports four functions to provide a WoO ontology reference model for e-health services, and the model will associate with the semantic data interoperability provisioning function.

– Manage ontologies: manages ontology elements, system and characteristics of e-health service based on WoO framework in accordance with [ITU-T Y.4452].
– Maintain vocabularies: provides functions to efficiently add, delete, search and manage vocabularies created in association with the e-health service.
– e-health taxonomies management: provides a management function to reduce the time, labour, and potential inconsistencies involved in creating, implementing, and maintaining a taxonomy of WoO based e-health service.
– Catalogue management of mediation ontologies: e-health applications with different semantics are expected to use different ontologies for the annotation and interpretation of data on e-health service semantic ontologies. Such differences hamper reuse of data and ontologies across e-health applications. Reuse of data and interoperation between e-health applications on service semantics can be achieved in two principally different ways of ontology mapping or ontology merging. The catalogue management of mediation ontologies manages sequences and procedures of involving WoO semantic ontology entities between e-health applications in terms of semantic ontologies.

9.2 Semantic data interoperability provision of e-health services

It is necessary to define the interoperability interface between WoO based e-health service domain (A) and external e-health service domain (B) to allow access of e-health data and services that are available in any of the e-health domains. The semantic interoperability interface includes the data representation, translation and sharing mechanisms to enable applications for cross-domain data interoperability as identified in [ITU-T Y.4111].

The WoO based interoperability interface enables access to the internal data of the domains and the capabilities for the extraction of e-health data. The interface needs to provide the semantic interoperability that can provide the following functions:

– Semantic information sharing: the semantic information sharing enables access of data and metadata of sensors registered in the domains;
– Semantic data interoperability: the semantic data interoperability enables the translation of the data and the metadata of the information model defined by the domain;
– Semantic object representation: semantic object representation provides the common representation of the sensor observation for the information models defined by the domains.

In semantic data interoperability provision as indicated in Figure 3, the following functional entities keep models, ontologies and related data sets to support semantic data interoperability functions of WoO ontology based e-health services:

– Reference e-health models;
– Target ontologies catalogues/infrastructure;
– e-health ontologies;
– Common data model.

The reference base model of the common data model (CDM) among 4 functional entities will be described in clause 9.3.

The operations to provide WoO ontology based semantic interoperability among heterogeneous e-health services are classified into five functions as indicated in Figure 3. These operational processes are described in clause 10 in detail:

– Ontology alignment;

– Semantic data annotation;
– Semantic mapping;
– Linked data on common terminology;
– Model based translation.

9.3 Common data model for WoO ontology based semantic interoperability provision of e-health services

9.3.1 WoO based semantic base ontology model

The semantic base ontology model (BOM) shown in Figure 4 consists of the generic concepts to support the semantic data interoperability of e-health applications. BoM includes the base object entity which represents a real world object (RWO), which has an operation mode as it may represent any sensor or actuator.

A base object element (BOE) is an entity to hold a base object. The BOE can have input features as well as the output features. Each feature has associated metadata with it which presents the details on the BOEs and the operation that can be supported on this abstraction.

The composite elements (CE) are the entities in the base ontology that will contain the collection of BOE entities. They also have features and the associated metadata.

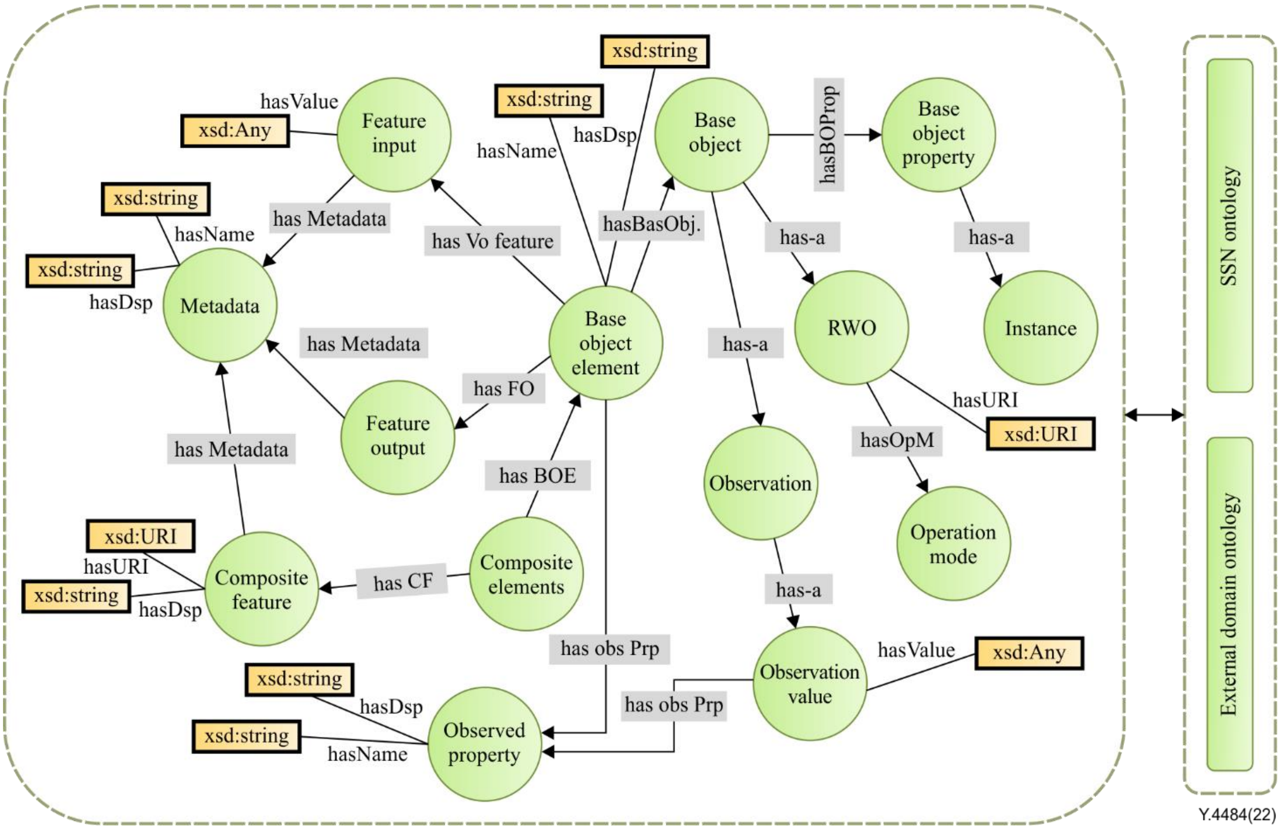

Figure 4 – Semantic base ontology model for e-health service mediation

9.3.2 WoO based core mediation ontology model

Core mediation ontology (CMO) of an e-health service, as shown in Figure 5, is another mediation design pattern that provides an alignment and arbitration for source and target ontologies. The CMO includes a mediation concept which is sub-categorized into core data concepts and structure concepts. The core data mediation concepts include core data mediation, metadata mediation, features mediation, source feature mediation, object mediation, data property mediation, range mediation and domain mediation. These concepts are used to express the alignment through a specific algorithm based on the used formats.

The CMO also contains the concepts related with the structural mediation among the e-health service ontologies to be aligned. From the structural point of view the CMO has mediation concepts such as, structure concept, list of aligned sequence, and list of expected match sequence, core domain list, core range list, source sequence concepts, and target sequence concepts.

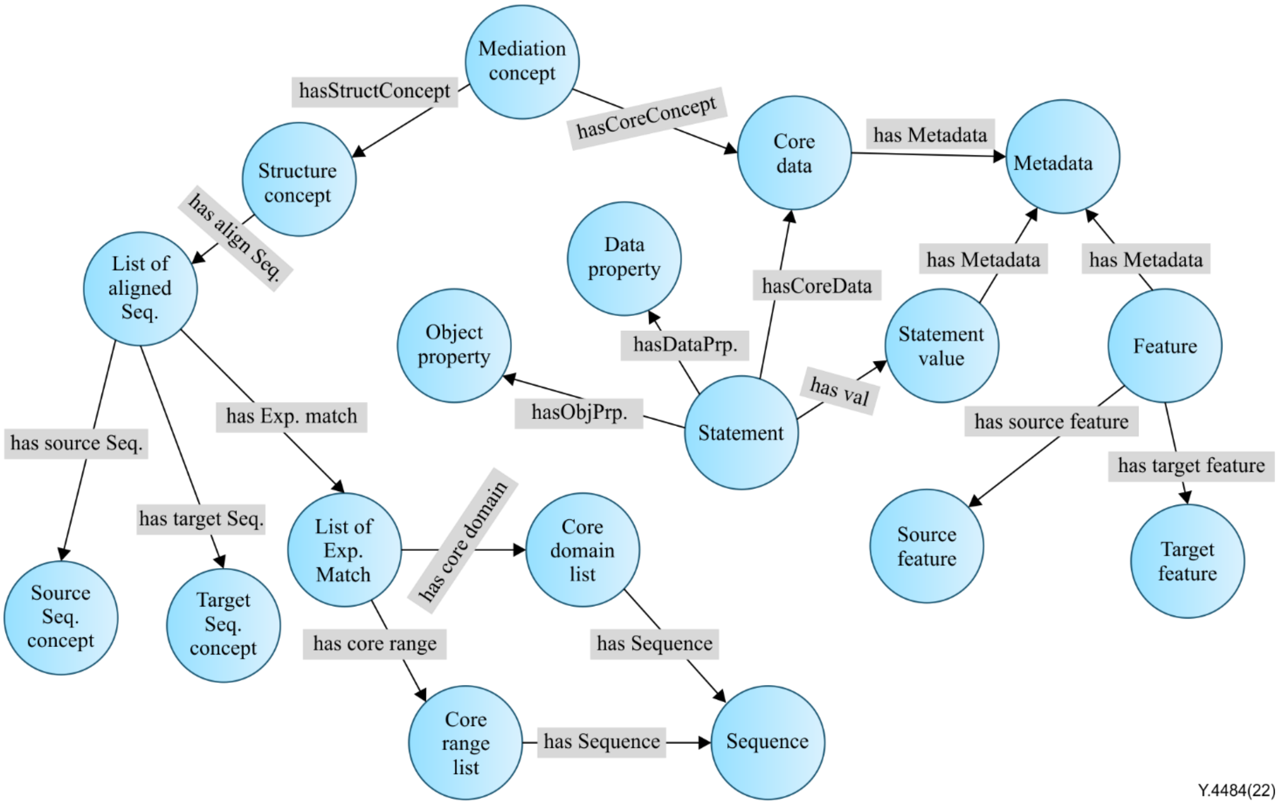

Figure 5 – Core mediation ontology model to express the ontology alignment of e-health services

10 Operational processes to support WoO ontology based semantic data interoperability among heterogeneous e-health services

10.1 Ontology alignment

The semantic ontology alignment function enables the alignment and management of the source and the target semantic schemas of e-health services. The functional capabilities of semantic alignment are illustrated in Figure 9-5 and Figure 9-6 of [ITU-T Y.4563], and these mechanisms include the semantic ontology managing function of e-health services to include the capability to manage the ontology aligner to instantiate the ontology aligner by providing the model of source and semantic target ontology data models. The ontology aligner performs the semantic ontology alignment function. Appendix I provides a use case of ontology alignment in terms of semantic data interoperability provisioning for e-health services based on a deep learning approach.

It takes the source and target ontology models and computes the alignment with the similarity measures and the provided thresholds for each measure, this service returns the alignment results in terms the true mapping achieved through the mapping algorithm.

10.2 Semantic data annotation

The semantic annotation for e-health service provides annotation using the selected annotation description language as identified in [ITU-T Y.4563]. Semantic annotation of e-health service provides enhancement of content by interlinking machine processed data to the mined concepts of a semantic ontology graph. Through the semantic annotation process of an e-health service, additional information can be attached to existing contents based on the concepts of the ontology model. With the semantic annotation an isolated data is transformed into descriptions associated with the ontology that can be inferred, exchanged and reused.

10.3 Semantic mapping

To express the semantic interoperability approach, the following example is provided with semantic alignment and SPARQL query writing. Figure 6 shows two information models, J and K which provide information about two different systems, and both follow the base ontology model. As both models express the arm concept and features in slightly different ways enabling semantic interoperability of e-health services among both systems, semantic alignment is required. The WoO semantic ontology alignment in terms of the defined rules, which is the first to provide the equivalence of the Body arm concept to Arm, and the second describes the relationship hasStatus from the model J is the same as isOnStatus in model k. Following the specified mapping the SPARQL queries are modified in the excerpt.

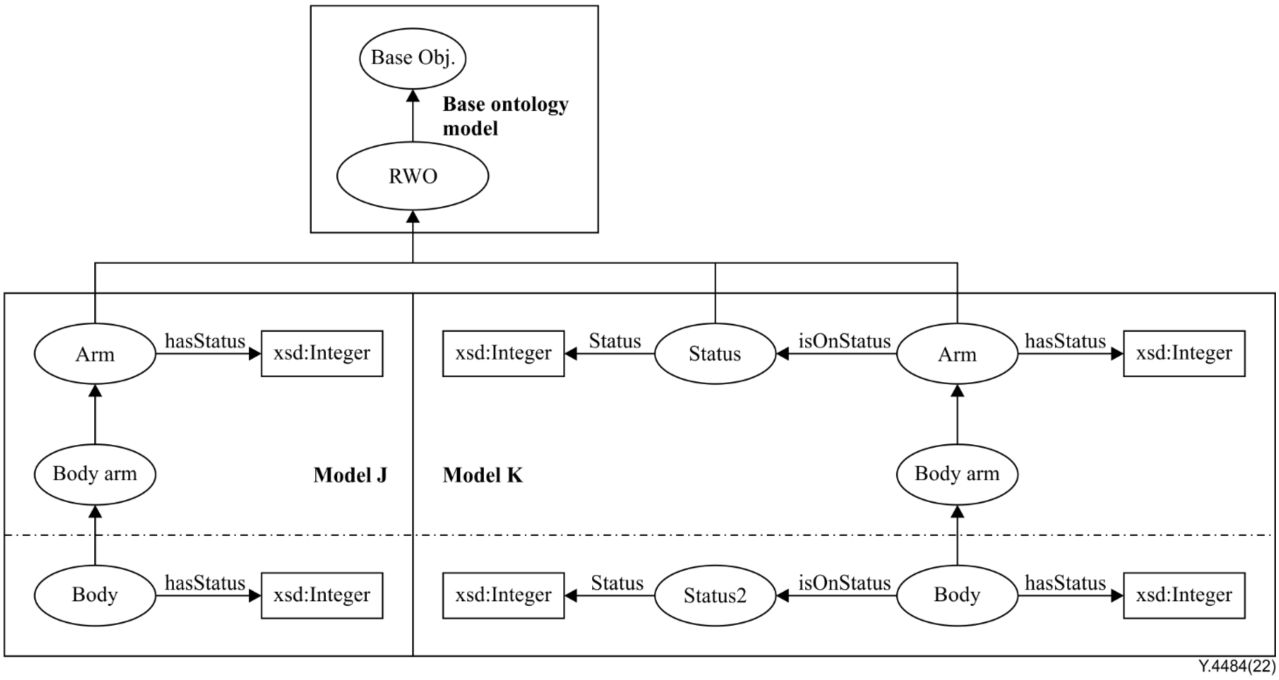

Figure 6 – Semantic mapping using base ontology

10.4 Linked data on common terminology

The WoO ontology based e-health service provides the way to represent shared concepts in diverse domains for sharing of knowledge across different systems. Even though semantic ontologies that describe the same domain, may differ in their diverse elements, as they are designed by different knowledge engineers who provide their own view point while encoding the semantic concepts and relationships on real world concepts in the ontologies.

The semantic matching entries are stored in the base ontology instances. These instances collectively form an interoperable shared data model to provide semantic coherence of multiple data models as shown in Figure 7. The WoO ontology based semantic data interoperability structure described in [ITU-T Y.4452] and [ITU-T Y.4563] will support interoperable and simplified association schemes to handle linked data on WoO ontology based common terminology.

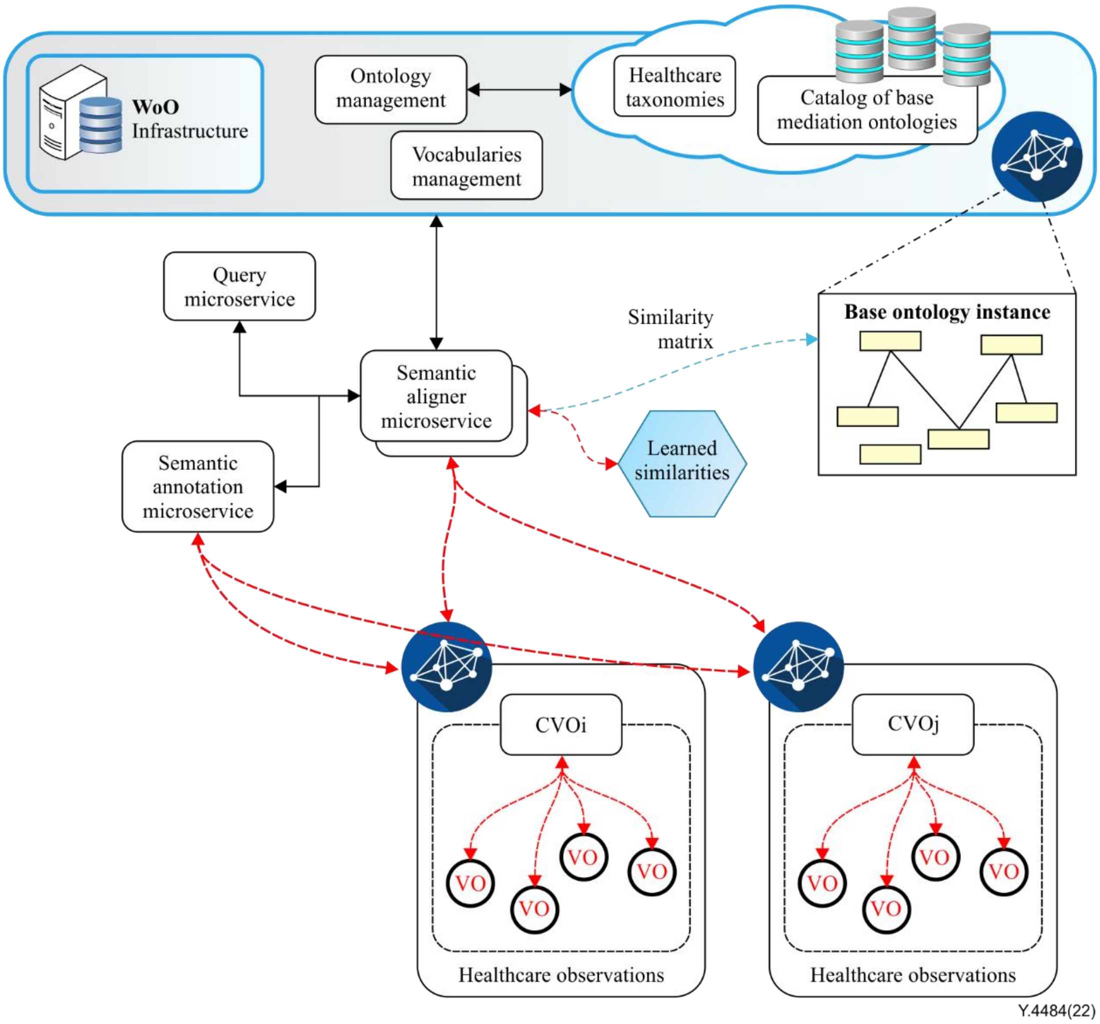

Figure 7 – Semantic data interoperability utilization to provide semantic coherence of multiple data models based on the WoO ontology model

10.5 Model based translation

This model based translation function provides a translation mechanism for the ontology based e-health service model. Different e-health service platforms make use of different ontology models to describe the data semantic. This model based translation function provides the conversion to interoperate the models at the platform level. The framework of the WoO ontology model based translator for e-health service applications will be in accordance with clause 9.2 of [ITU-T Y.4563].

Appendix I

Deep semantic data interoperability provisioning for e-health services

(This appendix does not form an integral part of this Recommendation.)

To overcome the challenges to completely achieve interoperability at data level, this appendix provides a use case of solution for data interoperability provisioning in heterogeneous healthcare applications based on the semantic ontology model. The model involves several features including the semantic annotation of healthcare data collected from different sources, a semantic alignment mechanism involving the deep representation learning, and the integration of healthcare concepts. The work also shows a base ontology model to provide the mapping of healthcare concepts from diverse ontologies. It provides a WoO based ontology catalogue infrastructure to deploy semantic ontologies which could be utilized by diverse healthcare systems to support interoperable data management and processing.

I.1 Semantic ontology association using WoO

In semantic data interoperability provisioning, the semantic alignment and linking function features support the semantic sharing of information in an efficient way. To provision the semantic data interoperability with mechanisms of generalized alignment within source and target ontology models the functional components are developed using composite virtual objects (CVOs) and microservices based on Figure I.1.

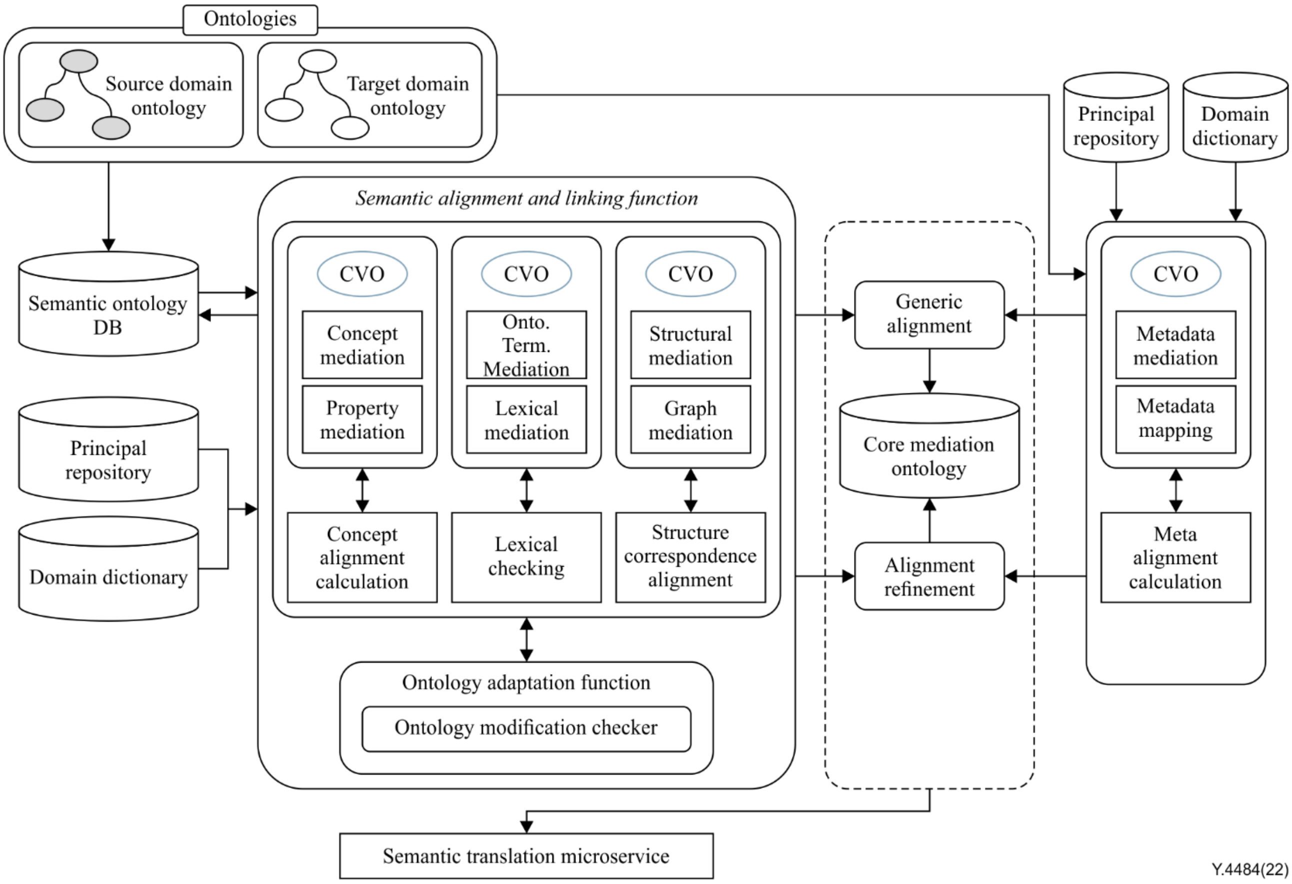

Figure I.1 – Semantic association flow with functional features interaction

As indicated in Figure I.1, the semantic ontology association function manages the change over the ontologies in the association process. It maintains the initial status of ontologies and the later algorithm modified ontology model. In addition, semantic data interoperability requires the interoperable machine readable format to retrieve and process the ontology information and for this purpose a semantic ontology repository has been considered. The domain dictionaries such as the WordNet dictionary have been considered to provide a lexical resource in the alignment process. In addition to the semantic data interoperability features, the metadata interoperability has been considered as the vital feature to enhance alignment in the ontology mapping.

I.2 Semantic base ontology model using WoO

The semantic base ontology consists of the generic concepts to support the semantic data interoperability for healthcare applications. It includes the base object entity which represents a RWO. The RWO has the operation mode as it may represent any sensor or actuator, however if the RWO represents any other information this mode will be set to none. A BOE is an entity to hold a base object. The BOE can have input features as well as output features. Each feature has associated metadata with it which presents the details on the BOEs and the operations that can be supported on this abstraction. The CEs are the entities in the base ontology that will contain the collection of BOE entities. They also have features and associated metadata.

I.3 CMO model using WoO

From the structural point of view of the CMO indicated in clause 9.3.2 mediation concepts such as, structure concept, list of aligned sequences, list of expected match sequences, core domain list, core range list, source sequence concepts, and target sequence concepts are provided.

I.4 Alignment model to support semantic data interoperability

To express an example of semantic data interoperability, Figure 6 of clause 10.3 is applied to show two information models, J and K which provide information about two different systems, and both follow the base ontology model. As both models express the arm concept and their features in slightly different ways. It is requested to enable semantic data interoperability among both systems.

I.5 Semantic alignment ontology model using deep learning

The model provides semantic data interoperability based on deep representation learning of ontologies which constitute two steps. As shown in Figure I.2, first representations are generated from the ontology graphs using the deep learning method and the semantic alignment is provided. Second alignment is performed using the semantic association algorithm which considers the alignment based on the ontology graph structure. The results of both alignments are combined, and semantic data interoperability checking is carried out and then the final semantic data interoperability provisioning is given.

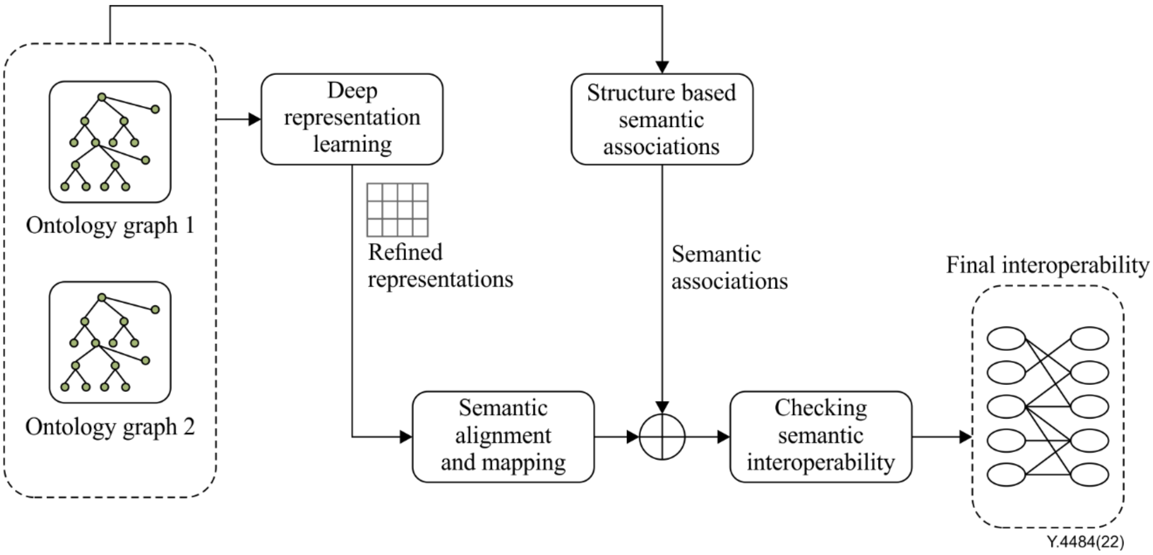

Figure I.2 – Deep semantic data interoperability provisioning process

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