THE ONTOLOGY FOR THE TELEHEALTH DOMAIN – TEON

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Abstract

Information about telehealth is distributed over many systems, generating content overlap and heterogeneity. As a way to standardise nomenclatures and organise content in telehealth systems and applications, the use of standardised vocabularies is recommended. However, most of them rely on informal text-free definitions that bring confusion. Together with this limitation, and due to recent Brazilian regulations concerning the delivery of telehealth services, a Telehealth Ontology (TEON) was developed. This study describes and presents TEON, elucidating its main use-case, its applicability and potential to improve information exchange, interoperability and decision support. TEON was developed based on the upper-domain ontology BioTopLite2 (BTL2) and Ontology for Biomedical Investigations (OBI). The scope of the work includes a set of competency questions to guide the domain modelling. TEON was formalised with Description Logics (DL) and the Web Ontology Language v.2 (OWL2). The telehealth services are composed of three main components: actors, the service itself and temporal-location barriers. The main roles are identified as the requestor, the teleconsultant and the manager. With TEON, we are able to specify if services are synchronous or not. Services are described by means of participants in the process, i.e. by specifying the agents and patients according to their roles. The envisioned use of TEON is to enable the integration of heterogeneous databases from different telehealth systems, considering the formal perspective embedded in ontologies. Currently, TEON is being included in HealthNet (teleconsultation), INDU (tele-education), dataNUTES (management), and SMART (monitoring) through an integration interface, in order to generate indicators and reports to support telehealth managers' decision-making and to facilitate providing indicators to the system for monitoring and results evaluation of the National Brazilian Telehealth Program of the Ministry of Health.

Keywords: telehealth Services; ontology; representation; medical informatics; Brazil.

Introduction

With the increasing requirement for computer and mobile applications under the telehealth domain, a frequent and limiting problem found is the lack of common vocabularies. Vocabularies, ontologies and hierarchical representations, such as Gene Ontology (GO)[1,2] or the Standardised Nomenclature of Medicine – Clinical Terms (SNOMED CT)[3] would bring potential benefits for the telehealth domain. For instance, heterogeneous database integration, systems development support, decision support, information retrieval or text mining for telehealth.

Despite the amount of data generated daily by telehealth systems, these are often spread over many sources. Data about subject of care, medical images, samples, reports, procedures, medicines are often stored by Electronic Health Records (EHR) systems. For the delivery of most telehealth services such as; second opinion, telediagnosis, continuing education or teleconsultation, not only medical understanding is required.

Notions regarding distance, synchronous or asynchronous, services, among others are interconnected and require a formal description for a clear understanding. Understanding about the subtleties of telehealth was introduced by Bashshur in a taxonomy for telemedicine.[4] However, terminologies are not expressive enough to represent the subtleties from telehealth domain, such as the active or passive participants of a service.

Besides the requirements for the domain, the Brazilian Ministry of Health through the National Telehealth Network[5] program (introduced in 2014 and updated in 2015), published a technical report on how telehealth services would be monitored and evaluated.[6]

In Brazil, telehealth is mainly delivered as an additional primary care service but is not restricted to only this.

Currently, several telehealth related systems need to interoperate and exchange data. In order to enable a seamless integration, and satisfy Brazilian requirements regarding retrieval of information about the delivery of telehealth services, the Telehealth Center of Clinics Hospital of the UFPE, a member of National Telehealth Network Program[5] started a study to develop the Telehealth Ontology (TEON).[7,8]

As a formal representation of world components, ontology can be described as poly-hierarchies composed of representational units, e.g. named classes interconnected by means of a set of relations. Examples of ontologies are the BioTopLite2 (BTL2),[9] GO and the Ontology for Biomedical Investigations (OBI).[10] Ontologies are used in computer science in order to enable: integration of heterogeneous sources,[11–13] text mining[14] case-based reasoning,[15] among others. From the broad application of ontologies to enable a richer semantics, this work describes and presents TEON, elucidating its main use-case, its applicability and potentialities to improve information exchange, interoperability and decision support.

Methods

Scope

The ontological scope strictly followed a set of four competency questions (CQs): which and what are a) the subareas of telehealth; b) the services embedded; c) the roles performed by the services' actors; and d) the processes related to the delivery of such services?[16]

These CQs were created as a guide in order to derive the content that must and must not be included. Content embedded in TEON is currently restricted to:

- services, e.g. teleconsultation, second opinion, and telediagnosis, among others
- actors, e.g. teleconsultant, the requestor, among others
- service delivery related processes and components, e.g. information transmission between the provider and the requestor and technological aspects.

It is not the intention for TEON to be a reference terminology, but a tool to provide a formal baseline about the domain under consideration. This notion is related to the use of (only) textual descriptions from terminologies.

Currently, TEON is being developed as a formal ontology to enable the integration of the telehealth HealthNet Platform (Java based) for teleconsultation and telediagnosis;[17] INDU Platform (Moodle based) for tele-education; the management information system, dataNUTES;[18] and the National Telehealth Monitoring System (SMART).[19] All these systems are used by the Núcleo de Telessaúde (NUTES)[20] through the telehealth network project RedeNUTES.[21] Such systems are under modification to retrieve telehealth related data concerning the delivery of services, according the current Brazilian requirements. As a formal ontology, TEON includes classes about the telehealth domain, not restricted by any application.

Ontological background and knowledge acquisition

TEON expands the upper domain ontology BTL2.[7] BTL2 includes basic classes and relations that enable the description of specificities from the biomedical domain. General classes such as *Process*, '*Material entity*' or '*Information entity*' are formalised under BTL2 together with relations derived from the Relation Ontology (RO).[22] Another ontology used is OBI[10] due to the formal and generic description about services and the process of delivering services.

Knowledge about telehealth was harvested from specialised literature. Classes were created after checking the Bio-ontologies Bioportalabout terms already described in other sources.[23] These sources are ontological, or based on controlled vocabularies like SNOMED CT. Knowledge was structured in TEON from frequent meetings with experts in the field, with the requirements embedded in the Brazilian Ministry of Health regulatory documentation taken into account.[6]

Ontology engineering approach

TEON is based on the ontology engineering approach, Methontology.[24] Normalisation was performed in order to achieve explicitness and modularity by means of untangling asserted graphs into disjoint orthogonal axes, as described by Rector.[25] To avoid naming confusion, classes names were created according to Schober et al., when not directly imported from BTL2 or OBI. [26]

TEON was created using the formal language DL and formalised with the Web Ontology Language v.2

(OWL2).[27] The ontology was built and edited via Protégé v.5, with the support Fact++ v. 1.6.8 in order to perform automated classification and consistency checking.[28] TEON is available in NUTES website.[8]

Results

Telehealth Ontology

The main components of TEON are *actors*, *services* and *time-space* classes and axioms.

Actors can bear roles related to health activities, viz. subject of care, physicians, nurses, among others, and roles strictly related to the delivery of the telehealth services. These are:

- **Requestor** (of the service)
- **Teleconsultant**, e.g. the person or institution who receives the service demands
- **Manager**, responsible to evaluate and take responsibility on how services are delivered.

The requestor represents the person who is requesting any telehealth service. Axiomatically, the requestor role is described as follows.

> ‘*Requestor role*’ equivalentTo ‘*Occupational role*’
> and (‘**inheres in’** some (’**agent in’** some‘ *Telehealth service*’))

This axiom describes that it is inhered to the bearer of a requestor role to be the active participant in a telehealth service.

Teleconsultant role is devoted to the individual (passive participant) responsible for receiving and processing the service.

> ‘*Teleconsultant role*’ equivalentTo ‘*Occupational role*’
> and (‘**inheres in’** some (**‘is patient in’** some ‘*Telehealth service*’))

The manager, in contrast with the other roles, acts merely as being able to evaluate the services delivered. Later, the manager is responsible for planning and other related activities.

> ‘*Management role’*equivalentTo ‘*Occupational role*’
> and (**‘is realisation of’** only *Evaluation)*

Services

To represent services, OBI states that services are planned processes in which two different entities are bearers of consumer and provider roles. (**Error! Reference source not found.**) During the delivery of a single service, not only people can bear roles related to services, but also entities like institutions and organisations. For instance, a ‘teleconsultation service’ can be described as a service with two main participants: the service provider (e.g. physician or institution) and the consumer (e.g. the requestor, which can be the referring physician or the patient).

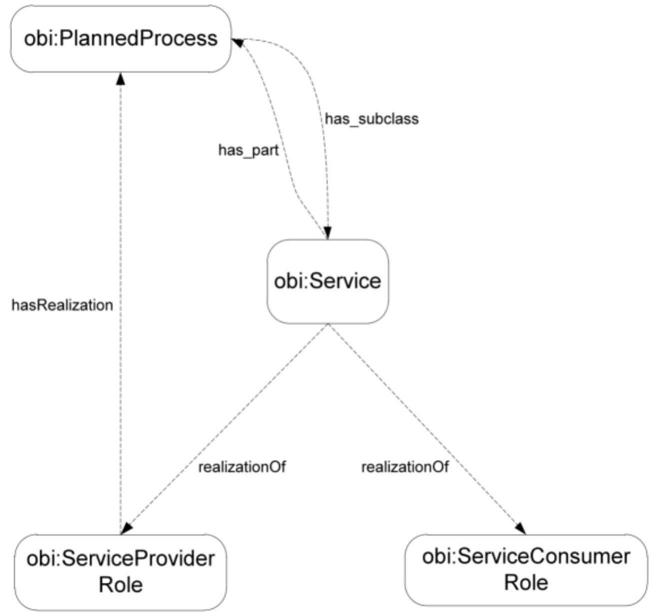

Figure 1. Service model reused from OBI.

The strategy to reuse knowledge from OBI includes the mapping of the ‘*Requestor role*’ and ‘*Teleconsultant role*’ to ‘*Service consumer role*’ and ‘*Service provider role*’, respectively. This was performed in order to determine that, in all services delivered, the requestor consumes services; and, the provider delivers services.

Another important feature of telehealth services is the delivery following health-care specialties, viz. telecardiology, teledermatology and telepsychiatry. Services of this nature can be constrained by how they are delivered, e.g. teleconsultation, second opinion, telemanagement, telediagnosis, health tele-education, among others, and are available in TEON.

Next, we introduce the notion of a generic telehealth service. A telehealth service has, at least three main participants:
the requestor, the teleconsultant or a related institution. According to this, we are able to define that during a teleconsultation, we have:

- Active participants (**'has agent'**), like physicians
- Passive participants (**'has patient'**) like the subject of care.

Both relations (**'has agent'** and **'has patient'**) are sub-relations of **'has participant'.**

''*Telehealth service'* equivalentTo*Service*
and ('**has participant'**some (**'isbearer of'** some
('*Requestor role' or 'Teleconsultant role'* or *Institution*)))

Synchronous and asynchronous services

After defining the roles and broader definitions of the domain, we consider that telehealth and services are delivered following a simple strategy: the differentiation between the moment when a service is requested and when it is performed. In other words, the delivery of services can be defined as synchronous or asynchronous.

Following this, we included the following axiom which means that in a synchronous transmission, there is a co-occurrence of reply and request actions.

'*Synchronous transmission'* equivalentTo '*Information transmission'*
and ('**cooccurring with'** some ('*Reply action'*or '*Request action'*))

The axiom for asynchronous transmission processes refers to the communication transmissions in which the reply and the request do not occur simultaneously.

'*Asynchronous process'* equivalentTo '*Information transmission'*
and not ('**coocurring with'** some ('*Reply action'* or '*Request action'*))

Spatial Distance between the Service Provider and the Service Requestor

One important component of the tele-health services delivery is the spatial distance between the service provider and the requestor. By definition, service provider and consumer are disjoint, i.e. the same object is not allowed to act as consumer and provider at the same time. As the OWL2 language does not allow asserting two individuals with the same identity without the loss of computational completeness, we can only guarantee that two individuals are not the same, at the same moment, in the same location. For instance, our representation allows description of a teleconsultant and a requestor working in the same facility, the first answering a question of the second; and, can be still qualified as a telehealth service delivered.

Applicability under the telehealth domain

The main uses envisioned for TEON in our current systems, HealthNet, INDU and dataNUTES; and, the national monitoring system SMART are shown in Figure 2, which describes TEON dealing with information regarding telehealth services. Most information

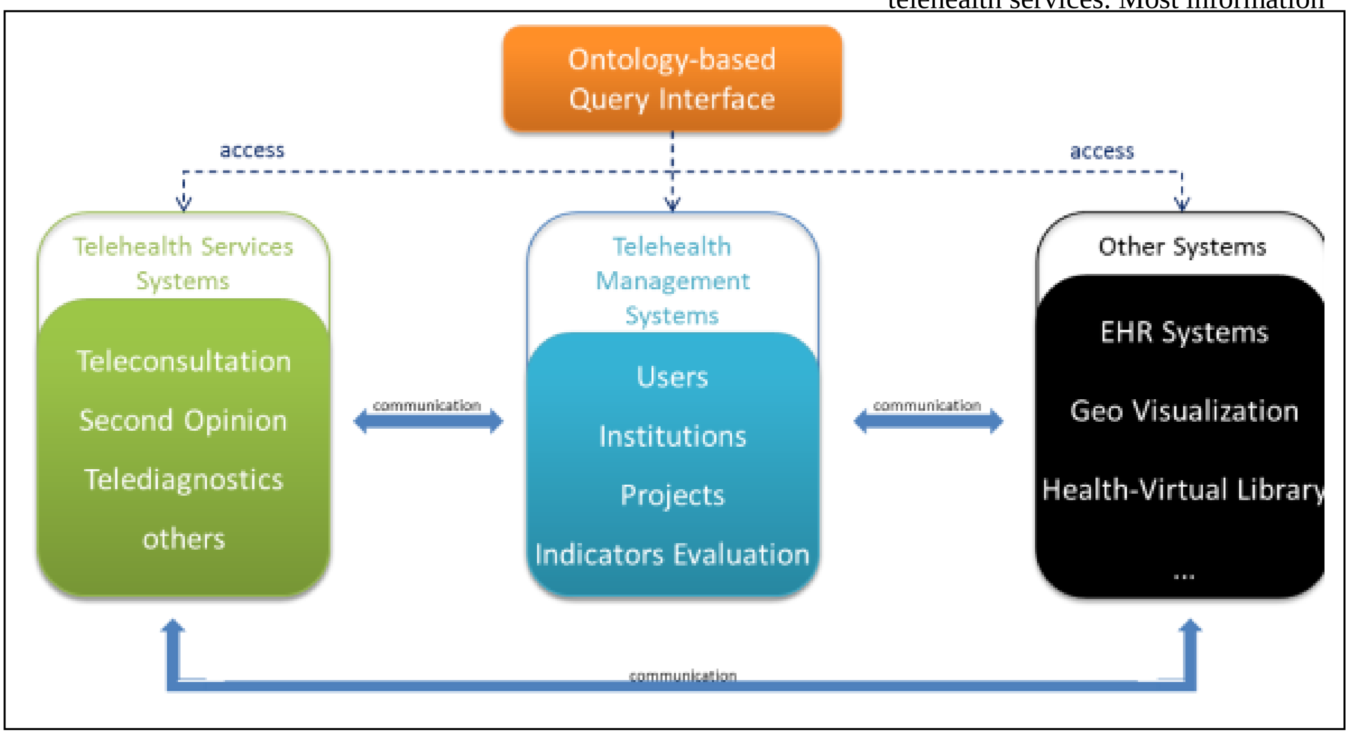

Figure 2. Example of a telehealth ontology use.

produced by telehealth and/or by tele-education platforms can be related to management systems.

In addition, telehealth systems often require communication with other health-related software systems like EHR systems, SMART, the National Health Care Facilities Records (*Cadastro Nacional de Estabelecimentos de Saúde*, CNES),[29] among others.

Currently, the envisioned usage for TEON is to enable a semi-automated integration of several telehealth systems to generate reports, as in **Error! Reference source not found.**. These reports must be generated and sent to SMART monthly, as a requirement for monitoring telehealth services delivery in Brazil.

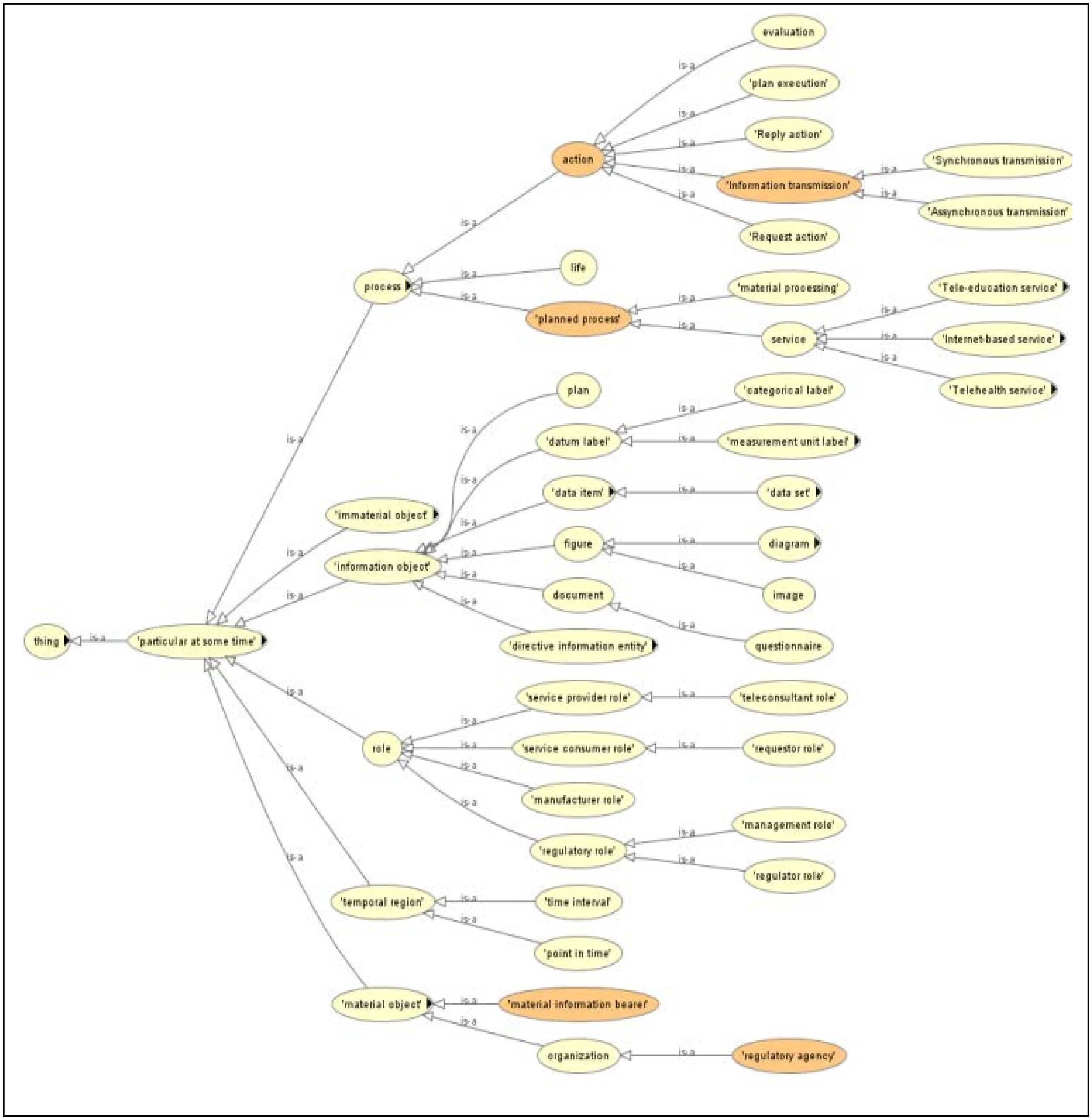

Figure 3. Teon hierarchy.

Metrics

TEON actually contains 141 classes strictly related to the description of the telehealth domain, 12 equivalent class axioms, 289 subclass axioms and 9 hidden Class Inclusion Axioms (GCI), all under the DL SRI expressivity. (Figure 3)

Discussion

We introduced the service and actor classes and respective axioms, which are the basis for telehealth definition. With the use of semantic web tools and reusing other ontologies, most of the health situations have been modelled using OWL and DL for an easier and formal understanding. Using DL, the basis of the telehealth domain was hierarchically structured as a set of formal classes and relations provided by BTL2, OBI, and the new ones related to the domain under consideration.

Ganguly et al. and Kara and Dragoi described the use of ontologies to support telehealth-related applications.[30,31] However, these studies used ontologies in context-aware applications, lacking information about domain, and focusing only in aspects of, for example, diseases or the pervasive environment.

Taking into account the content of TEON, other studies focused in the taxonomical description, mainly, of telemedicine. Tulu et al., in the first attempt to describe the telehealth areas taxonomically, aimed at helping program planners and telemedicine users to understand and develop computer-based systems.[32]

Bashshur proposed a taxonomy for telemedicine using communication modality, technological configuration, composition and the relationship among participants.[4] Telemedicine, telehealth, eHealth and mHealth were considered (in the same level) as the main components of the health-related Information and Communication Technology (ICT) domain, as in TEON.

Compared with these studies, ours show a higher degree of formality, mainly because of the adoption of DL. The difference in the underlying definitions, when compared with the informal descriptions available, is significant. TEON can be used to formally specify any telehealth service, including how it is delivered, participants, and when each component of the service was allocated.

For instance, during an asynchronous teleconsultation service, it is possible to represent with TEON the participants (requestor or teleconsultant) and technological media as material or immaterial objects as locations the services are delivered (i.e. included). When creating or developing a telehealth-based system or application, TEON can be incorporated into a layer capable to support reasoning, information retrieval, text mining and heterogeneous systems integration.

Under the requirements of the Brazilian government, TEON can be applied and expanded to enable integration of telehealth systems. Integration of Brazilian health-related systems can be achieved via the adoption of an ontology-based database integration approach, such as any compliant with *Ontology-based data access* (OBDA).[12] Within OBDA, TEON might enable information retrieval from several telehealth systems simultaneously, acting as a common and shared vocabulary.

Nevertheless, we are aware of the limitations of the current work, such as some performance limitations that come together with the ability of using reasoning procedures, DL and data.

Conclusion

In the current work, we have described the formal description of telehealth services delivery in TEON. The roles played by the actors, temporal dimensions, and the location distance were highlighted. We also highlighted the possible applicability of ontologies in several situations, and so extensions for TEON. The intended usage is to enable heterogeneous database integration, as a requirement for generating reports from simultaneous and heterogeneous telehealth systems. These reports must be sent through SMART for monitoring of telehealth services delivery by the Brazilian Ministry of Health.

An improved version of current model and a fully-fledged integration supported by TEON is currently under development to enable communications between different systems.

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