An ontology for healthcare systems

Francois Goyer [1,2], Paul Fabry [1,2], Adrien Barton[3,1,2] and Jean-François Ethier [1,2]

[1] *Centre Interdisciplinaire de Recherche en Informatique de la Santé de l'Université de Sherbrooke (CIRIUS), Université de Sherbrooke, Québec, Canada*
[2] *Groupe de Recherche Interdisciplinaire en Informatique de la Santé (GRIIS), Université de Sherbrooke, Québec, Canada*
[3] *Institut de Recherche en Informatique de Toulouse (IRIT), CNRS, Université de Toulouse, France*

Abstract

Modern patient care is becoming increasingly complex and is now most commonly delivered through healthcare systems. Understanding the structure surrounding care is an important tool in optimizing it. This article proposes a unified ontological analysis of healthcare systems following the OBO Foundry Methodology, by exploring the relationships between the caring of individuals, the health workers and healthcare providing organisations. This ontological model strives to enable interoperability in the context of Learning Health Systems.

Keywords

healthcare, healthcare procedure, roles, healthcare ontology

1. Introduction

Learning health systems (LHS) aim at improving patient care by documenting clinical data, deriving knowledge from it, and modifying its practices considering this emerging knowledge. Advances in modern healthcare have significantly increased the variety and quantity of available clinical data. However, the fact that this data is scattered among different record sources with possibly different semantics is a major hurdle to the implementation of LHS. To address this, the use of applied ontologies is a promising solution as they provide source-independent representation of clinical data.

In prior work [1], we described the different processes directly involved in the health care of individuals, namely, health procedures and health activities. These classes laid the groundwork to represent health data, whether it emanates from home (e.g. a report of a blood pressure measurement with one's personal machine) or from organisations such as laboratory evaluations [2] or prescriptions [3].

While information concerning health procedures themselves is important, the context in which they are performed is also valuable for an LHS. For example, considerations on the location (ambulatory vs hospital) [4] or profession of the health professionals involved in a health procedure [5,6] may also influence the quality, completeness or cost-effectiveness of patient care. Such information can lead to the optimization of (often) limited healthcare resources. This is for example particularly important to evaluate the impacts of the increase in telemedicine activities seen in the recent months due to covid-related restrictions [7]. Such questions are at the core of large initiatives like the Health Data Research Network Canada [8] aiming at facilitating the use of medico-administrative data across multiple provinces and territories to explore both clinical and management questions. Another domain is the use of quantified-self measurement devices, which is expanding. It offers new clinical opportunities but also additional challenges in handling and analyzing data correctly [9]

This mandates the need for an ontological analysis of the structure of healthcare systems and

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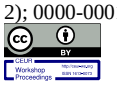
EMAIL: francois.goyer@usherbrooke.ca (A. 1); paul.fabry@usherbrooke.ca (A. 2); adrien.barton@irit.fr (A. 3); jf.ethier@usherbrooke.ca (A. 4)
ORCID: 0000-0002-7626-1026 (A. 1); 0000-0002-3336-2476 (A. 2); 0000-0001-5500-6539 (A. 3); 0000-0001-9408-0109 (A. 4)


how they relate to health procedures; the latter being focused on the "what" of clinical data, whereas the former in the "where", "when", "by/to whom" and "why".

This task is made challenging by the fact that healthcare systems are diverse and common language terms used to described them are often ambiguous. In accordance with the principles of the OBO Foundry [56], we propose an ontology for healthcare system centered on a representation of its organisations. In the following we begin with a review of existing definitions surrounding healthcare and their shortcomings. We then outline our proposed model with examples delineating their implications.

2. State of the art

The terms "healthcare" or "health care" are commonly used to describe different entities, often interchangeably. Online dictionaries provide very broad definitions:

- **Merriam-Webster** [12]: health care or healthcare - efforts made to maintain or restore physical, mental, or emotional well-being especially by trained and licensed professionals
- **Cambridge dictionary** [13]: healthcare or health care - the activity or business of providing medical services

In both cases, the exact scope of what constitutes "healthcare" is left vague. For Merriam-Webster, "healthcare" seems to involve trained and licensed professionals but not exclusively while Cambridge definition encompasses both processes (activity) and organisations (business).

This duality is also present in classes present in the OBO foundry:

- **GSSO** [14]*: health care* (BFO:process) - The prevention, treatment, and management of illness or the preservation of mental and physical well-being through the services offered by the medical, nursing, and allied health professions
- **OPMI** [15]: *health care* (BFO:process) - Health care or healthcare is the maintenance or improvement of health via the prevention, diagnosis, and treatment of disease, illness, injury, and other physical and mental impairments in human beings.

The definition by GSSO incorporates the notion that healthcare is delivered through structured services (organisation) while the OPMI one refers to the processes themselves irrespective of context.

While certainly not systematic nor approved by an authoritative body, some stakeholders [6] argue both spellings "healthcare" and "health care" may be used independently to delineate these different facets of caring for someone's health. In this scheme, the term "health care" would refer to the acts of providing care while the term "healthcare" refers to the industry itself.

Considering the lack of consensus, we have chosen for the class labels introduced in this work to use the term "healthcare" exclusively in the context of organisations. To avoid confusion, when referencing the processes directly involved in health, the "care" part of "health care" will be dropped in favor of "health".

Other classes pertaining to the healthcare system present in OBO also share considerable overlap. The term "hospital" provides a notable example:

- **NCIT**: *hospital* - An institution that provides medical, surgical, or psychiatric care and treatment for the sick or the injured.
- **ENVO** [16]: *hospital* - A hospital is a building in which health care services are provided by specialized staff and equipment.

These distinct entities are both conveyed by the indefinite term "hospital", the facility or the healthcare organisation. A detailed analysis of all healthcare related terms in the OBO foundry is outside the scope of this work, however we believe these excerpts are sufficient justification for a uniform and dedicated ontology of healthcare systems.

3. Methodology

During the development of an ontology, it is important to respect the univocity of terms, that is that the terms employed are always used with the same meaning [17]. Therefore, we avoid the single use of polysemous terms such as "healthcare" as a class label. Instead, using specific examples, the main entities related to healthcare will be outlined. Subsequently, several classes and object properties are proposed allowing us to formalize these entities based on a methodology consistent with OBO foundry principles.

These classes are constructed using a realist approach based on BFO [11]. Textual definitions following an Aristotelian structure and important axioms are provided. In addition, in accordance with the OBO Foundry principle of respect of

orthogonality between ontologies, we will reuse as much as possible classes and object properties from other ontologies. Additionally, object properties are introduced to describe the roles the various actors play in processes. They allow a more precise characterization of the participants of health procedures.

4. Results

4.1. Taxonomy and class structure

The taxonomy of the different classes discussed below are presented in figure 1 and their relations in figure 2.

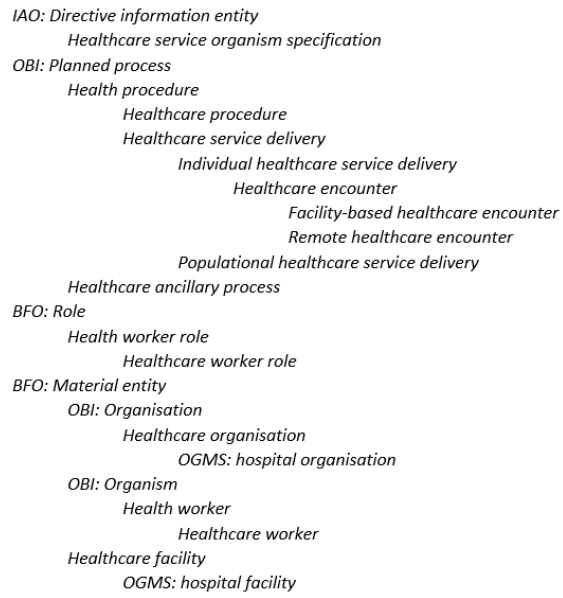


Figure 1 - Taxonomy of the different classes related to healthcare

4.2. The different aspects of healthcare

As outlined above, we consider the scope of "healthcare" too vast for a single entity (existing usages would point towards it being both a continuant and an occurrent for example). Instead, we propose a clear distinction between the different entities involved. Central to this framework, is the previously defined *health procedure* [1].

health procedure $=_{def}$ "A planned process guided by the objective of contributing to a desired effect on the health status of an organism or several organisms achieved through the treatment, diagnosis, or prevention of disease or injury. It has some components that are planned processes, including at least one that is a health activity."

Consider the following example: Mr. Jones feels unwell and decides to measure his pulse using his smartwatch. In this case, the evaluation of his pulse is a *health procedure* (**hp1**). Noticing that his pulse is abnormally high, he decides to go to the nearest hospital's emergency (**hf1**). The triage nurse (**Nurse Betty**) also performs a pulse evaluation using her machine (*health procedure* **hp2**); however, this pulse evaluation is a part of another process, a healthcare service delivery (**he1**).

Healthcare service delivery $=_{def}$ "A health procedure under the responsibility of an organisation that aims at providing a desired effect on the health status of individuals and their communities. It is usually composed of health procedures and possibly associated ancillary processes. It stems from an agreement between a requesting agent and a healthcare organisation"

This pulse measurement **hp2** is a part of an emergency department visit (which is a *healthcare service delivery*), a service agreed upon by a healthcare organization (**ho1**) and an organism (**Mr. Jones**) which was initiated when Mr. Jones requested the services of the healthcare organisation for his condition. It might include associated *healthcare ancillary processes* such as the provision of accommodation or meals. An ontology of services is beyond the scope of this article, but we can note some important aspects here. According to Nardi et al. [18], a service encompasses processes and distinct entities such as commitments or compensation. In the present article we focus on the service processes, which we refer to as "service deliveries". Mr. Jones was the requesting agent for this service, however in some instances the requesting agent might differ from the individual for which care is intended for (pediatrics, veterinary medicine etc.).

Furthermore, these healthcare service deliveries realize a *healthcare organisation role*:

healthcare service delivery subClassOf (realizes some *healthcare organisation role*)

With:

healthcare organisation role $=_{def}$ "A role that inheres in an organisation and is realized by providing some healthcare service delivery."

And:

healthcare organisation $=_{def}$ "An organisation that bears a healthcare organisation role"

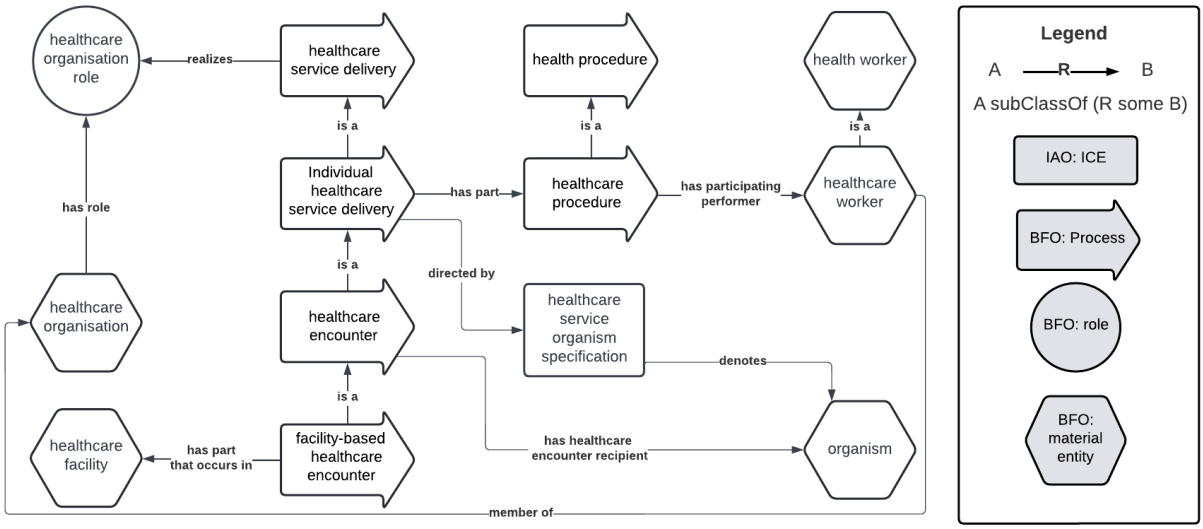


Figure 2 - Schematic representation of the main classes surrounding healthcare procedures

Healthcare services delivery are planned processes and are therefore directed by plan specifications. One such plan specification is:

healthcare service patient specification =$_{def}$ "A directive information entity identifying an organism for whom a plan of healthcare service delivery aims at providing a desired effect to its health status." (that is, a healthcare service patient specification can only direct a healthcare service delivery involving the specified patient)

4.3. Health worker and healthcare workers

Similarly to the way we have separated health procedures from healthcare service deliveries, we define the class *health worker* independently of any organisational context.

health worker =$_{def}$ "An organism that is the bearer of a health worker role."

health worker role =$_{def}$ "A role that inheres in an organism as a consequence of a training of this organism to perform some health procedures"

Health worker roles inheres in organisms[2] because they have been trained in a specific field. Examples include physician roles and physiotherapist roles. Health workers commonly provide health procedures as members of a healthcare organization, although they might also more rarely provide such procedures independently of any organisation. We therefore define:

healthcare worker =$_{def}$ "A health worker who is a member of a healthcare organisation"

healthcare worker subClassOf (*health worker* AND (member_of some *healthcare organisation*))

4.4. Participants in health procedures

With regards to clinical data, being able to describe the exact nature of the participation of agents in health procedures is paramount. In Mr. Jones' pulse measurement, both he and the triage nurse participate in this *health procedure*, albeit in significantly different ways. To better delineate these differences, we begin by considering that health procedures can themselves be composed of different processes. In turn, these processes can realize specific roles. Following this schema, we define two roles: *health procedure performer role* and *health procedure recipient role*. The performer role is realized by processes an agent plays in a health procedure, the recipient role by the processes that are done by an organism for which the desired outcome is aimed for; therefore, *health procedure recipient role* is a subclass of *health procedure performer role*.

[2] We chose a conservative stance with the use of organism to possibly include service animals.

This can be represented by two ternary relationships[3]:

participates_as_health_procedure_performer_in_process(X,Y,Z): The process Z has as proper part a process Y that realizes a health procedure performer role that inheres in organism X.

participates_as_health_procedure_recipient_process(X,Y,Z): The process Z has as proper part a process Y that realizes a health procedure recipient role that inheres in organism X.

To alleviate the model, we introduce two object properties derived from participate_in that derive a binary relation from each of these ternary relations:

X participates as health procedure performer in Z $=_{def}$ there is some Y such that *participates_as_health_procedure_performer_in_process*(X,Y,Z)

X participates as health procedure recipient in Z $=_{def}$ there is some Y such that *participates_as_health_procedure_recipient_in_process*(X,Y,Z)

Natural language definitions would be as follows:

X participates as health procedure performer in Z: The agent X participates in the health procedure Z as a performer.

X participates as health procedure recipient in Z: The agent X participates in the health procedure Z and Z aims at improving X's health status.

Following our example, Mr. Jones participates as health procedure recipient and the triage nurse participates as health procedure performer in the measurement of Mr. Jones' pulse **hp2**. When Mr. Jones measured his own pulse (**hp1**), he was a bearer of a health procedure recipient role and also a bearer of a health procedure performer role.

Not all *health procedures* have a recipient role: sometimes the target (organism for which a desired effect is intended) of these processes does not participate in them. For example, medical history taking (*health procedures*) are routinely done without the participation of the target, notably in pediatrics or geriatric care. Likewise, a radiologist's interpretation of an MRI does not involve the participation of the subject, whereas the process of image acquisition involved him as a recipient.

[3] In the two definitions below, Y can be seen as a processual roles in the sense defined by Frank Loebe [19], where X is the participant of Y. Such roles can be related to process profiles [20].

4.5. Healthcare service delivery and health procedures

Healthcare organisations provide different types of services which can be distinguished depending on whether they aim at the health of a single individual or a population.

The class *populational healthcare service delivery* aims at the health of a group of organisms but selects this group by specifying a common trait among them, thus characterizing a population. On such example would be a smoking cessation outreach campaign in a city. The group includes smokers living in a given city and might change in time (as people move in and out of the city or start or stop smoking, hence the individuals forming this population change in time).

On the other hand, individual healthcare service deliveries are intended for specific organisms and are directed by directive information entities:

individual healthcare service delivery $=_{def}$ "A healthcare service delivery that targets some specified individuals."

individual healthcare service delivery subClassOf (directed_by some *healthcare service organism specification*)

Similarly to health procedures, not all individual healthcare service deliveries have the targeted organism as participant. Those that do are divided into healthcare encounters:

healthcare encounter $=_{def}$ "A temporally-connected individual healthcare service delivery that aims to improve, maintain or restore the health of some participating organism"

Healthcare encounters are services which concern a particular organism as a target and for which that organism is a participant as a recipient. The recipient of these encounters can be defined in the following way.

X participates as health encounter recipient in Z: The organism X participates in the health encounter Z and Z aims at improving X's health status.

healthcare encounter subClassOf (has_participant_as_health_encounter_recipient some *OBI:organism*)

Mr. Jones' visit to the emergency department is a *healthcare encounter* in which Mr. Jones is the recipient. Healthcare encounters can also be structured by their location:

facility-based healthcare encounter =$_{def}$ "A healthcare encounter during which the recipient is expected to be located in a healthcare facility and is indeed located in one at least for part of its participation as a recipient"

facility-based healthcare encounter subClassOf (has_healthcare_encounter_recipient some *OBI:organism* AND (located_in_at_some_time some *healthcare facility*)

facility-based healthcare encounter subClassOf (has_part_that_occurs_in *healthcare facility*)

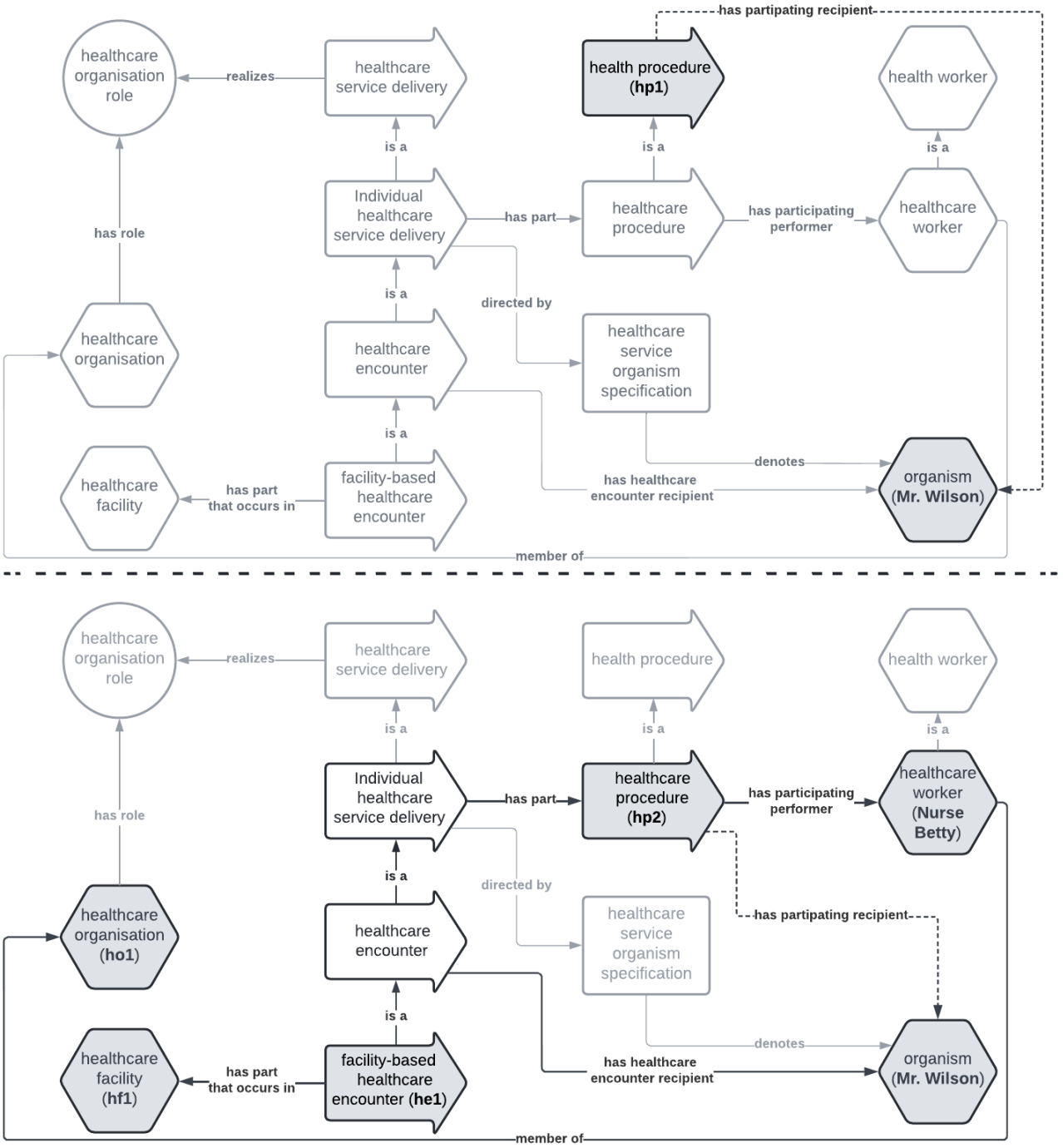


Figure 3 - Instances used in the two examples from section 4.2. The top part for Mr. Jones's pulse measurement at home, the bottom for his visit to the emergency department. Dashed lines represent relations between the mentioned instances that do not generalize in axioms at the class level.

remote healthcare encounter $=_{def}$ "A healthcare encounter where the organism that participates as performer does so only remotely, via telecommunication."

There is considerable overlap in common terms used to describe healthcare facilities. Terms like "hospital", "clinic" or "medical center" are often used interchangeably and can hold different meanings depending on jurisdictions. Furthermore, these words do not explicitly delineate their dual nature as in practice the terms can be used indiscriminately to identify either the organisation or the building. It is also common for a single healthcare organisation to operate in several facilities and the type of healthcare services provided may differ from one facility to another. Therefore, instead of using these terms as class labels and fixing their meaning arbitrarily, we propose avoiding them in favor of terms whose meanings are better circumscribed such as the classes from OMRSE [21]: *hospital facility* and *hospital organisation.*

Lastly, we define *healthcare procedure*:

healthcare procedure $=_{def}$ A health procedure that is part of a healthcare service delivery and that is performed by a healthcare worker while realizing its health care worker role.

healthcare procedure subClassOf (has_participant_as_health_procedure_recipient some *OBI:organism*)

individual healthcare service delivery subClassOf (has_part some *healthcare procedure*)

The different axioms presented here enable the explicit representation of all the different entities involved in Mr. Jones' pulse measurement in the emergency department: the healthcare organisation, the recipient, the performer and the healthcare facility (Figure 3).

5. Discussion

In this work we detailed the different entities at play in organisational healthcare and how they relate to health procedures, with a special emphasis on the axiomatization of the different participants in the relevant processes. Through dedicated object properties, recipients and performers can be related to health procedures. In addition, by adding sub-properties to participates_as_health_procedure_performer, it is possible to associate specific parts of a health procedure to an agent. For example, participates_as_health_procedure_surgeon and participates_as_health_procedure_anesthesiologist could be used to describe a surgical health procedure. Of note, terms like "surgeon" and "anesthesiologist" are often used to refer to social roles or former training of an individual. In the example above, these roles are concretized by specific parts of a *health procedure*. For example, in an emergency, an anesthesiologist might participate as a surgical assistant for a given procedure.

The use of (binary) object properties derived from the ternary relationships involved in these roles can be seen as a practical way to relate agents and how they participate in processes without the need to formally define the different parts of health procedures.

There is a large overlap between classes presented here and classes found in OMRSE and OGMS [22]. One such overlap is the class OMRSE:*health care encounter*:

OMRSE:*health care encounter* $=_{def}$ "A temporally-connected health care process that has as participants an organisation or person realizing the health care provider role and a person realizing the patient role. The health care provider role and patient role are realized during the health care encounter."

This class and our proposed *healthcare encounter* class differ mainly in their scope. In the latter, they include only processes of healthcare organisation, for example hospitalizations or out-patient visits. In turn, health procedures such as a nurse evaluation are part of these encounters. For the former, both processes are included. It also refers to the term "patient" which would deserve in itself further scrutiny as it is also used in different contexts to refer to various aspects, including administrative (registration), relational (patient of) and participant in a care process.

The proposed classes in this paper remain largely aligned with existing classes but bring more discerning power to allow the correct representation of processes, agents and associated data in the health domain. Further work and discussions with OMRSE and OGMS teams are needed in order to identify how to best integrate these classes in the current ontological landscape.

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7. References

[1] P. Fabry, F. Goyer, A. Barton, and J.-F. Ethier, An Ontological Analysis of Health Procedure Information, in International Conference on Biomedical Ontologies (ICBO 2021), Bozen-Bolzano, Italy, Sep. 2021.

[2] A. Barton, P. Fabry, L. Lavoie, J.-F. Ethier, LABO: An ontology for laboratory test prescription and reporting, in: 2019 Joint Ontology Workshops Episode V: The Styrian Autumn of Ontology, JOWO 2019, CEUR-WS.org, Graz; Austria, 2019.

[3] Ethier JF, Goyer F, Fabry P, Barton A. The Prescription of Drug Ontology 2.0 (PDRO): More Than the Sum of Its Parts. Int J Environ Res Public Health. 18(22) (2021) :12025. doi: 10.3390/ijerph182212025

[4] A. L. Wand, S. D. Russell, and N. A. Gilotra, Ambulatory Management of Worsening Heart Failure: Current Strategies and Future Directions, (2021) 15(1), 49-53. https://doi.org/10.17925/HI.2021.15.1.49

[5] S. U. T. Collaboration, Organised inpatient (stroke unit) care for stroke. Cochrane Database Syst Rev. (2013) (9):CD000197. doi: 10.1002/14651858.CD000197.pub3.

[6] P. Parag and T. C. Hardcastle, Interpretation of Emergency CT Scans of the Head in Trauma: Neurosurgeon vs Radiologist, *World J Surg*, vol. 46, no. 6, pp. 1389–1395, (2022), doi: 10.1007/s00268-022-06525-w.

[7] A. Kichloo *et al.*, Telemedicine, the current COVID-19 pandemic and the future: a narrative review and perspectives moving forward in the USA, *Fam Med Community Health*, vol. 8, no. 3, p. e000530 (2020), doi: 10.1136/fmch-2020-000530.

[8] L. T. Dahl *et al.*, The SPOR-Canadian Data Platform: a national initiative to facilitate data rich multi-jurisdictional research, *Int J Popul Data Sci*, vol. 5, no. 1, p. 1374, doi: 10.23889/ijpds.v5i1.1374.

[9] J. Rudner, C. McDougall, V. Sailam, M. Smith, and A. Sacchetti, Interrogation of Patient Smartphone Activity Tracker to Assist Arrhythmia Management, *Ann Emerg Med*, volume 68, no. 3, pp. 292–294 (2016) , doi: 10.1016/ j.annemergmed .2016.02.039.

[10] M. R. Kamdar, T. Tudorache, and M. A. Musen, A Systematic Analysis of Term Reuse and Term Overlap across Biomedical Ontologies, *Semant Web*, vol. 8, no. 6, pp. 853–871, (2017).

[11] B. Smith *et al.*, The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration, *Nat Biotechnol*, vol. 25, no. 11, pp. 1251–1255, (2007), doi: 10.1038/nbt1346.

[12] Definition of HEALTHCARE. https://www.merriam-webster.com/dictionary/healthcare (accessed May 27, 2022).

[13] healthcare. https://dictionary.cambridge.org/dictionary/english/healthcare (accessed May 27, 2022).

[14] C. A. Kronk and J. W. Dexheimer, Development of the Gender, Sex, and Sexual Orientation ontology: Evaluation and workflow, *Journal of the American Medical Informatics Association*, vol. 27, no. 7, pp. 1110–1115, (2020), doi: 10.1093/jamia/ocaa061.

[15] The Kidney Precision Medicine Project Consortium *et al.*, OPMI: 10th International Conference on Biomedical Ontology, ICBO 2019, *CEUR Workshop Proceedings*, vol. 2931, (2019)

[16] P. L. Buttigieg, N. Morrison, B. Smith, C. J. Mungall, S. E. Lewis, and ENVO Consortium, The environment ontology: contextualising biological and biomedical entities, *J Biomed Semantics*, vol. 4, no. 1, p. 43, Dec. 2013, doi: 10.1186/2041-1480-4-43.

[17] R. Arp, B. Smith, and A. D. Spear, *Building Ontologies with Basic Formal Ontology*. Cambridge, MA, USA: MIT Press, 2015.

[18] J. C. Nardi *et al.*, Towards a Commitment-Based Reference Ontology for Services in *2013 17th IEEE International Enterprise Distributed Object Computing Conference*, Vancouver, BC, Canada, Sep. 2013, pp. 175–184. doi: 10.1109/EDOC.2013.28.

[19] F. Loebe, Abstract vs. social roles - Towards a general theoretical account of roles, *Applied Ontology*, Jan. 2007,

[20] B. Smith, "Classifying Processes: An Essay in Applied Ontology," *Ratio*, vol. 25, no. 4, pp. 463–488, 2012, doi: 10.1111/j.1467-9329.2012.00557.x.

[21] A. Hicks, J. Hanna, D. Welch, M. Brochhausen, and W. R. Hogan, The ontology of medically related social entities: recent developments, *J Biomed Semantics*, vol. 7, p. 47, Jul. 2016, doi: 10.1186/s13326-016-0087-8.

[22] R. H. Scheuermann, W. Ceusters, and B. Smith, Toward an Ontological Treatment of Disease and Diagnosis, *Summit on Translat Bioinforma*, vol. 2009, pp. 116–120, Mar. 2009.