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Vital Sign Ontology

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ABSTRACT

We introduce the Vital Sign Ontology (VSO), an extension of the Ontology for General Medical Science (OGMS) that covers the consensus human vital signs: blood pressure, body temperature, respiratory rate, and pulse rate. VSO provides a controlled structured vocabulary for describing vital sign measurement data, the processes of measuring vital signs, and the anatomical entities participating in such measurements. VSO is implemented in OWL-DL and follows OBO Foundry guidelines and best practices. If properly developed and extended, we believe the VSO will find applications for the EMR, clinical informatics, and medical device communities.

1 INTRODUCTION

The Vital Sign Ontology (VSO)[1] is a realist ontology covering the four bodily qualities that have by consensus been identified as human 'vital signs': blood pressure, body temperature, heart rate, and respiration rate. These qualities are measured at least once in almost every healthcare encounter and they are continuously monitored in intensive care situations. The vital signs are universally accepted as clinically significant not only because they are signs of life (they collectively help to differentiate a living from a dead human organism), but because they are reliable indicators of a patient's current and future health state. Our goal in developing VSO is to provide a scientifically rigorous, consistent, computable, and extensible controlled vocabulary to facilitate data exchange and annotation in applications where a reference to vital signs is required. The terms in VSO are defined using both concise natural language definitions and OWL-DL.

Although the vital signs are typically measured together and reported together, there is little ontological support for the class 'vital sign' being a universal. There are, in fact, very many signs that an organism is alive and very many indicators of its future health state, so without a principle of exclusion, we should expect the class of vital signs to be much larger than the consensus four. As such, the notion of 'vital sign' demands some attention from the ontology community.

We take universals to be the counterparts in reality of (some of) the general terms used in the formulation of scientific theories [1]. Unlike 'vital sign', the classes 'blood pressure', 'body temperature', 'pulse rate', and 'respiration rate' are universals. These would be classified as qualities and seem to have all of the following features in common:

(1) **Measurability**: Vital signs have been measured (with increasing accuracy) for a large part of medical history.
(2) **Necessity**: With rare exceptions (e.g., pulseless artificial hearts), the vital signs must be present in a living human organism.
(3) **Punctuality**: A rapid and significant change in vital signs typically signifies a rapid deterioration or improvement of health state. This is in contrast to lagging indicators such as fluid intake level, which would lead to thirst before dehydration has an impact on the core four vital signs.
(4) **Regulated**: The mechanisms of human homeostasis induce a response whenever any of these qualities departs from an acceptable range.
(5) **Causal relevance in many pathological processes**: At least one of the vital signs will be affected in any significant short-term departure from health. The subclass of disease courses in which vital signs change is very large.
(6) **Well understood**: Vital signs are interpreted within an entrenched theoretical framework of anatomy, physiology, and pathophysiology. Within these fields, there are well established ranges of normal values for vital sign measurements and well established ranges of abnormal values for particular conditions.
(7) **Signs of cardiovascular functioning**: The consensus four vital signs are qualities of anatomical components of the circulatory and respiratory systems.

Using these features as principles of exclusion, we may get nearer to the essence of the four traditional vital signs used

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[1] http://www.buffalo.edu/~ag33/vso.owl

to assess basic body functioning. In certain clinical contexts, these may be expanded to include other signs such as ‘oxygen saturation’ [2], end-tidal CO_2 [3], and pain [4].

VSO describes the properly functioning physiology associated with the vital signs. Departures from proper functioning fall outside of the purview of VSO but can be described by combining terms from VSO and a disease ontology. A brief description of how the VSO can be used in these circumstances is given in the discussion section.

2 VSO AND OBO

VSO contains terms for the consensus vital signs, as well as vital sign measurement processes, vital signs measurement data (the outputs of such processes), and the various anatomical entities that the vital signs are qualities of.

The Ontology for General Medical Science (OGMS) contains a set of high-level clinical terms, including: ‘disease’, ‘disorder’, ‘syndrome’, ‘sign’, ‘symptom’, ‘disease course’, and ‘diagnosis’. OGMS is built around a general theory of disease described in [5]

VSO interoperates with OGMS and fills a niche in the suite of Open Biomedical Ontologies (OBO). VSO depends on the following ontologies:

- Basic Formal Ontology (BFO): *continuants, occurrents*
- Ontology for General Medical Science (OGMS): *sign*
- Ontology for Biomedical Investigations (OBI): *measurement process, measurement datum*
- Phenotypic Qualities Ontology (PATO): *rate, temperature, pressure*
- Foundational Model of Anatomy (FMA): *anatomical entities*
- Gene Ontology (GO): *biological processes, regulation of a biological quality*

There is currently no OBO coverage for cardiopulmonary physiology or medical device types. As such, VSO includes a thin representation of the cardiac cycle phases and vital sign measurement devices. The scope of VSO is currently limited to *human* vital signs, although it can potentially cover many similar organisms.

VSO imports the theoretical commitments of OGMS, including a particular theory of signs and symptoms as they relate to disease. Although the issue of signs and symptoms is by no means settled in the OGMS community, OGMS is committed at least to an objective/subjective distinction between signs and symptoms. Signs are objectively observed, measured, and quantified. Symptoms are experienced, in a first person, subjective, private sort of way. As such, entities such as pain, which many consider to be a fifth vital sign, would actually be considered the first vital symptom according to current distinctions in OGMS.

In OGMS, the term ‘sign’ refers to a disjunctive or defined class encompassing several OGMS universals. The presence of disorders, diseases, disease courses, and pathological processes can all signify something (and thus could be signs). As such, ontology developers seeking to use OGMS are advised to subclass entities on the basis of these universals. There is something epistemic about signs; a sign is not a sign unless it signifies something to someone, and it cannot signify something to someone unless some framework for its interpretation is established. Since the universals represented in an ontology should be understood to exist independently of any epistemic phenomena, ‘sign’ cannot be a universal. However, these issues are left to OGMS, as they do not have a significant impact on the vital signs in VSO.

3 ORGANIZATION

The relational organization of VSO is described using the OBO Relation Ontology (RO) relations and proposed extensions. The basic relational structure of the term ‘systolic left ventricular pressure’ is illustrated in Figure 1.

3.1 Blood Pressure

Blood pressure is defined as the pressure exerted by circulating blood on the walls of blood vessels. In VSO, ‘Blood pressure’ is asserted as a pato:pressure (which is a bfo:quality) as well as a member of the defined class ‘vital sign’. Blood pressure subtypes are first differentiated by the cardiac cycle phase during which the quality exists: systole (the period of contraction) or diastole (the period of relaxation). These, along with other temporal intervals in the cardiac cycle, are represented in VSO because they are of central importance to describing vital signs and, as previously stated, there is currently no OBO coverage of cardiac cycle terms. Systolic and diastolic blood pressure are further differentiated by the blood vessel wall (FMA anatomical entity) that the pressure is exerted towards. We use the RO relation ‘towards’ as a relation binding a quality to a material entity. The anatomical location helps to differentiate between central and peripheral blood pressure. For this purpose, anatomical terms are imported from the FMA using the MIREOT mechanism [6].

The two levels of differentiation yield necessary and sufficient conditions for blood pressure subtypes:

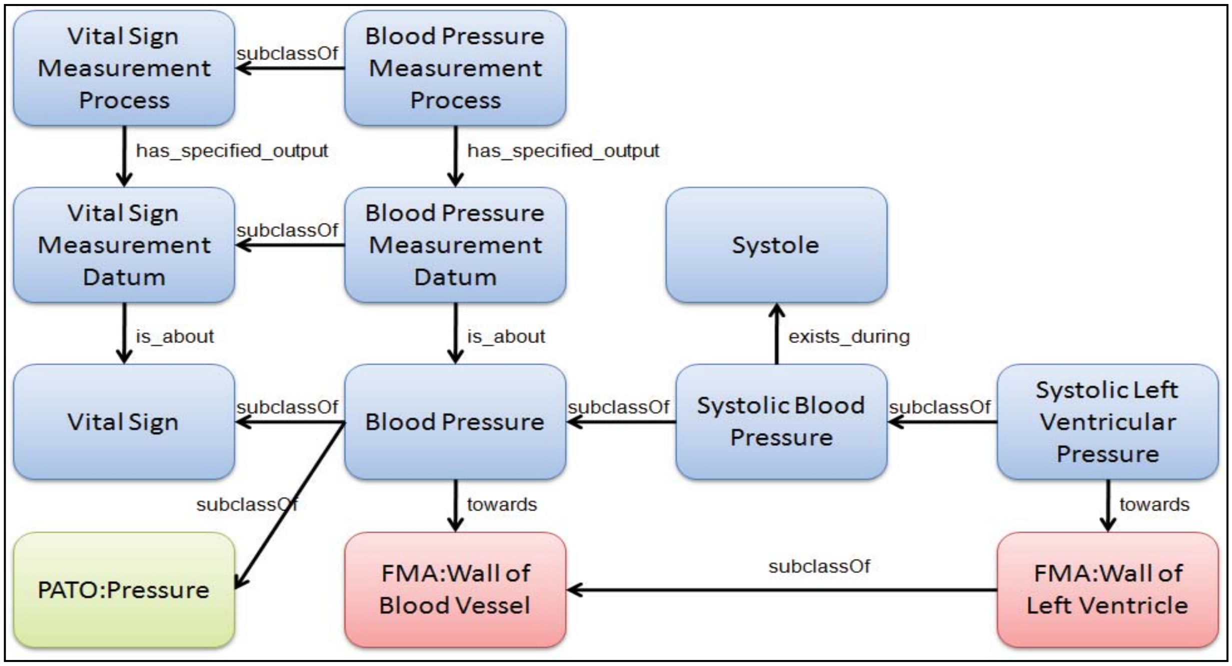

Figure 1VSO relational structure around the term 'systolic left ventricular pressure'

'systolic blood pressure' =
 'blood pressure' AND
 exists_during SOME systole

'systolic left ventricular pressure' =
 'systolic blood pressure' AND
 towards ONLY 'wall of left ventricle'

The ordering of differentia in the hierarchy impacts the way in which blood pressure can be referred to by VSO users. It is possible to refer to 'blood pressure' without specifying the anatomical location or cardiac cycle phase, and it is possible to refer to 'systolic blood pressure' without specifying anatomical location (as is typical in clinical settings), but to refer to 'left ventricular pressure' without specifying cardiac cycle phase a new class must be built via cross products:

'left ventricular pressure' =
 'blood pressure' AND
 towards ONLY 'wall of left ventricle'

The fact that 'left ventricular pressure' is not in the asserted (single-inheritance) hierarchy of VSO, therefore, does not deter a user from referring to it. This is important because there are very many ways to differentiate vital signs (see section 4 below) and these are bound to vary from application to application.

3.2 Body Temperature

Body temperature is defined as the temperature of a part of the human body. Body temperature subtypes are differentiated by the anatomical part where the measurement occurs. The body temperature is fairly uniform regardless of measurement site, but it is important to represent the site because normal values for temperature vary by site in small but clinically significant ways, and because different patients will require temperature monitoring in different ways. For example, rectal thermometry is typically used for very young patients.

Many of the anatomical sites where temperature is measured are holes, lumens, and cavities. There are general ontological issues with measuring qualities of immaterial parts (Is the depth of a (dental) cavity a quality of the cavity or a quality of the tooth in which it is a cavity?). These can be resolved in VSO by noting that the air temperature in any one of these ontological holes may actually be what gets measured. This measurement is used as an inference to the temperature of the enclosing part, which is in turn used to infer the body temperature. All vital sign measurements lie on a spectrum of how direct or inferred the measurement is.

Blood pressure, pulse rate, and respiration rate are all qualities whose measured values oscillate and that are interpreted by the ways in which their values oscillate. Body temperature also oscillates, albeit over a longer window. In fact, this can be used as a fertility sign in women. This illustrates that a reasoner should be able to infer that any of the vital signs may signify different things in different contexts.

3.3 Pulse Rate and Respiratory Rate

Pulse rate is defined as the rate at which an artery pulses (i.e., participates in expansion-contraction cycles) as blood passes through it. Pulse rates subtypes are differentiated by the particular artery (from the FMA) that is undergoing a pulsation process. Pulse rate is often conflated with heart rate, although they are not identical (ontologically or clinically) and is one of a network of closely related signs observed or inferred by monitoring the pumping of the heart: cardiac output, stroke volume, ejection fraction, among others. Respiratory rate is defined as the rate at which an organism breathes and is not differentiated any further in the current version of VSO.

Rates are qualities in both PATO and BFO. Specifically, rates are temporal derivative qualities[2], depending simultaneously on their bearers and time. The measurement processes for pulse rate and respiration rate will, in turn, involve measurements of an anatomical site (e.g., by palpation) and of time (e.g., by stopwatch).

4 VSO INFERRED HIERARCHY

In clinical settings, vital signs are contextualized relative to not only anatomical location (*left-ventricular* blood pressure), but also: kinetic state (*resting* pulse rate, *ambulatory* blood pressure), postural state (*sitting* blood pressure), time of day (*night-time* respiration rate), stage within a process (blood pressure during *REM sleep*), stage within a life course (*premenopausal* body temperature), measurement method (*invasive* blood pressure measurement), relative to a therapy or treatment (*postoperative* blood pressure) and relative to a disease state (*sepsis-induced* hypotension).

Creating a code and a class (in an ontology) to accommodate each of these would quickly result in a resource that is difficult to maintain and extend. Instead, we can create any of these compositional classes by importing terms from relevant OBO ontologies and description logic restrictions. For example, blood pressure is known to rise during the REM sleep stage, and thus, we may want to refer to entities such as 'REM systolic blood pressure':

'systolic blood pressure during REM sleep' =
'blood pressure' AND
exists_during ONLY systole AND
occurs_during SOME REM sleep

Notice that the DL easily allows us to demarcate the temporal interval relative to both the REM stage of sleep and the oscillating periods of systole within REM.

[2]See http://code.google.com/p/bfo/wiki/Bfo2DeterminableDeterminate

5 DISCUSSION

When VSO is paired with disease ontologies (such as the Infectious Disease Ontology), it becomes possible to specify that a certain vital sign profile is a consequence of a particular pathological process in a disease course (e.g., 'sepsis induced hypotension' or 'recurrent fever in *P. falciparum* malaria'). This technique is being applied in the semantic alarm framework for multiparameter monitoring devices [7].

We are confident that VSO can also find application in settings where multiple devices from multiple manufacturers need exchange vital sign data. Such devices typically report data in manufacturer-specific formats. Since VSO is designed to be application and manufacturer agnostic, it could be used as a contract for the meaning of shared vital signs data. Also, in such settings, if different devices are measuring the same vital sign (in a different way), data provenance and the measurement process associated with the redundant devices may become important. VSO can help in this regard because it contains terms for the various measurement processes involved.

6 CONCLUSION

VSO fills a gap in OBO ontology coverage of clinical signs. Preliminary development of the VSO has uncovered a host of interesting ontological issues that we believe are worthy of attention from the bio-ontology community. Further development of VSO will require coordination of existing resources and the principled creation of new ones. We believe this will establish VSO as a valuable resource for systems that produce and consume vital sign data.

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