*Challenges of Trustable AI and Added-Value on Health*
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# Temporal Medical Knowledge Representation Using Ontologies

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**Abstract.** Representing temporal information is a recurrent problem for biomedical ontologies. We propose a foundational ontology that combines the so-called three-dimensional and four-dimensional approaches in order to be able to track changes in an individual and to trace his or her medical history. This requires, on the one hand, associating with any representation of an individual the representation of his or her life course and, on the other hand, distinguishing the properties that characterize this individual from those that characterize his or her life course.

**Keywords.** Knowledge representation, biomedical ontologies, temporal representation, historical aspects

## 1. Introduction

Every living thing goes through all kinds of changes in its life course, and goes through episodes of health and disease. Medical knowledge reflects this, and medical textbooks define disease entities as sets of possible alternative courses [1].
These considerations, which are commonplace, lead to significant difficulties when one wishes to represent temporal medical information using ontologies based on Description Logics that admit only unary or binary relations, which restricts the possibilities of temporal indexing [2].

In the field of early detection and intervention in psychosis, which is our particular area of interest[2], temporal aspects are omnipresent, whether we consider the period of brain maturation in adolescence, the early phases of psychosis, the dynamic process of early psychosis, the duration of untreated psychosis, or schizophrenia as the last of a series of stages [3].

It is these problems of representing temporal aspects, recurrent in biomedical ontologies, that we address here by hypothesizing that the ontological commitment made in the foundational ontology is part of the solution. To this end, we present a foundational ontology and some examples of modeling of the situations considered.

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[2] https://psy-care.fr/ - The clinical study to which the PsyCARE project will give rise will enable us to gather information allowing us to establish the knowledge graph of the patients in the study.

## 2. Methods

### *2.1. Petite Ontologie Fondationnelle (POF)*

POF is a foundational ontology with 35 classes whose construction is based on two principles:

- a principle of individuation with respect to space and time, largely inspired by Zemach [4], which allows us to distinguish five kinds of individuals: objects, projects, events, properties, pieces of information;
- a mereotopological principle of division, assembly, situation of entities leading to distinguish: the whole, the part, the interface, the composition, the position.

The version we present here[3] is completed with a core ontology part simplified for our purposes.

### *2.2. Three-dimensionality and four-dimensionality*

Representing in an ontology both objects that retain their identity through time (this chair, my nephew Louis, defined by the space they occupy - we speak of *three-dimensional* or 3D entities) and events (Louis' stay in Madrid[4], defined in space and time - we speak of *four-dimensional* or 4D entities) seems desirable: this is what natural language does, what "common sense" invites us to do, what important foundational ontologies in the biomedical domain do [5][6].

However, insisting on the properties that an object retains over time leads us to neglect, on the one hand, the fact that this object has not always existed and will not always exist, and, on the other hand, the changes that it will undergo during its existence. Furthermore, this representation raises a question of granularity: objects participate in events, but within these objects, smaller objects participate in smaller events. While this granularity of 3D entities is often considered and commonly represented as "Levels of Organization" or as a pyramid (e.g. Life's Complexity Pyramid), the equivalent does not exist for 4D entities, even though medical knowledge is always confronted with the articulation of different levels of event granularity.

From these two considerations, it follows that:

- a 3D entity must be considered from the point of view of the events in which it participates, but also of the events it hosts;
- a full-fledged representation of what we call an object should include, in addition to a class in the 3D branch of the ontology accounting for what persists in time, its counterparts in the 4D branch of the ontology to account for the fact that its existence is a limited process in time and space;
- the four-dimensional framework is more comprehensive than the three-dimensional framework and even if one wishes to retain 3D entities, it is more appropriate to focus on modeling 4D entities.

[3] https://framagit.org/jacqueshilbey/pof-mie-2022

[4] The example of Louis contracting an infection while in Madrid and subsequently receiving treatment is discussed below.

### 2.3. Implications on change representation

We can specify the notion of change from the six types of motion according to Aristotle [7]: generation, destruction, increase, decrease, alteration, change of place. Applied to a living organism, these types become: conception and death, quantitative changes, qualitative changes, and spatial displacement.

The representation of objects as continuants in time does not allow for the representation of their appearance and disappearance, whereas the representation of a life course includes the idea of an initial and a final space-time for it. On the other hand, a good reason for wanting to keep the three-dimensional representation is physical displacement: the notion of a change of place does not in itself carry the notion of a change in the entity that makes that spatial displacement. In the case of quantitative or qualitative changes, a more precise examination of the type of property involved in the change under consideration is necessary.

"Rigid" properties [8], which are only likely to be lost with the destruction of the entity, often appear in the ontology's taxonomy of classes (being a person). Descriptive properties such as height, weight, temperature, are no more likely to be lost by a material entity, but their value is likely to change over time.

The validity of the attribution of typical "anti-rigid" properties such as being in a *phase* (being an adolescent), holding a *role* (being a physician), or being in a *state* (being diseased), changes over time. They do not characterize identity over time, but rather a temporal part (or several temporal parts) of a life course. A phase can be naively defined as a temporal slice of a life course, although determining its boundaries can be a conundrum [9]. A role can be seen as a type of participation in certain events in the history of an entity. A state such as "being diseased" requires yet another model, insofar as the disease itself is an event, a process. This is why we propose to consider the course of the disease as an event whose spatiotemporal situation has as its spatial extension the continuant in time itself. This is justified by the fact that a continuant in time is precisely defined by the portion of space it occupies.

## 3. Results

We present a simple example: "Louis contracted an infection while in Madrid" and propose a representation (Figure 1) following the principles outlined above. An episode is defined by its spatiotemporal continuity and its narrative unity; a history is a composition of episodes. The representation of time *per se* is not deepened here: we just use two classes (*instant* and *temporal interval*) which are the temporal entities of the W3C Time Ontology in OWL[5].

SPARQL queries performed on the ontology are available in the same place as the ontology itself. They are accessible from the links in the footnotes.

**Health Status**[6] is a property whose value changes over time but whose assignment is always valid. The different instances that qualify the 3D entity are both instances of the "HealthStatus" class and instances of the subclasses of the corresponding value region. They are temporally indexed ("has beginning" and "has end" data properties) and can thus be queried according to their order or on a temporal interval.

[5] https://www.w3.org/TR/owl-time/

[6] https://framagit.org/jacqueshilbey/pof-mie-2022/-/blob/main/HealthStatus.rq

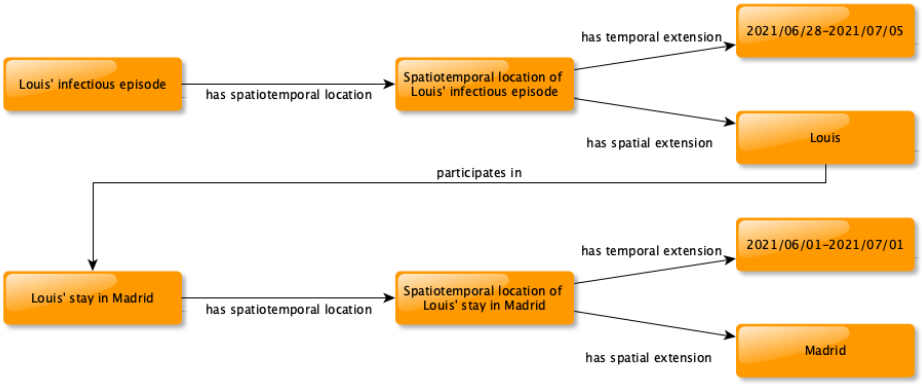


**Figure 1.** An object can participate in an event or be its spatial extension.

The **Medical History**[7]can be defined from the "internal" history[8] and the "external" history[9] of the individual as the whole made up of the events of medical interest of which it is the place and the events in which it takes part as a patient. This implies: on the internal history side, characterizing the events of medical interest either by creating a class or by assigning them a property for this purpose; on the external history side, creating as a sub-property of the property "participates in" a property "participates as a patient in", which carries the indication of the role.

As we have mentioned, it can be difficult to reach a consensus in the definition of a **Phase of Life**[10]. We can propose a minimal modeling, as the set of events of the internal or external history whose temporal extension has an intersection with a certain temporal interval. A more precise modeling would require that a life phase be defined at the level of the individual, from distinctive events.

## 4. Discussion and Conclusions

In this paper, we propose a new way to represent the temporal aspects of medical knowledge. We keep the representation of three-dimensional entities but limit it to what gives these entities an identity in time and their ability to participate as a whole in events. To the extent that they appear, change and disappear, these entities can also be considered as aggregates of processes.

The notion of history associated with a continuant in time already exists in a foundational ontology like BFO. Considering the granularity of 4D entities led us to subdivide it into external history, which is usually referred to as "life course", and internal history, which we will refer to, for lack of a better term, as "entire life process". In most medical specialties, the pathological processes are essentially episodes of this internal history. Taking it into consideration also makes sense in a pathophysiological approach to psychiatry.

[7] https://framagit.org/jacqueshilbey/pof-mie-2022/-/blob/main/InternalHistory.rq
[8] https://framagit.org/jacqueshilbey/pof-mie-2022/-/blob/main/InternalHistory.rq
[9] https://framagit.org/jacqueshilbey/pof-mie-2022/-/blob/main/ExternalHistory.rq
[10] https://framagit.org/jacqueshilbey/pof-mie-2022/-/blob/main/PhaseOfLife.rq

In the light of the above, we have been led to reconsider the attribution of properties to entities. Rigid properties can be represented as they are in BFO or DOLCE. But we substitute the consideration of anti-rigid properties of a 3D entity with that of temporal slices of internal or external history associated with that entity, whether we speak of phases or states; roles intervene as modalities of the entity's participation in events of its external history. Further research is needed to refine the modeling of stages, for example of a disease. Another research direction could be the establishment of SWRL rules in order to infer, for example, health status from an episode of disease.

We have mainly aimed here at the adequacy of the representation. As Burek et al. [2] remind us, there is no quality change representation choice that performs better than others in all dimensions. The aspects of scalability and extensibility will be investigated later, when integrating the data produced by the PsyCARE project.

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