A Diagrammatic Representation for Entities and Mereotopological Relations in Ontologies

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Abstract. *In the graphical representation of ontologies, it is customary to use graph theory as the representational background. We claim here that the standard graph-based approach has a number of limitations. We focused here on a problem in the graph-based representation of ontologies in complex domains such as biomedical, engineering and manufacturing: lack of mereotopological representation. Based on such limitation, we proposed a diagrammatic way to represent entity's structure and other forms of mereotopological relationships between the entities. The experiments we carried out indicate we achieved the expected benefits.*

1. Introduction

In graphical representations of ontologies, it is customary to use graph theory to represent the taxonomical structures formed by *is_a* and *part_whole* relationships, as well as many others. Such relationships are used in both simple and complex domains, in which very complicated *part_whole* and mereotopological relationships stand out.

We shall focus here on a problem in the graph-based representation of ontologies in complex domains such as biomedical, engineering and manufacturing: lack of mereotopological representation. By lack of mereotopological representation, we mean that the standard graph representations neither provide a meaningful graphical account of well-known mereological features, such as proper parts and overlapping, nor provide a meaningful graphical account of mereotopological features, such as entity spatial distribution, boundaries, and containment.

Such drawback can cause serious problems for ontology understandability and use. Is there, then, a better way to mitigate the above-mentioned problem, one that will make the visual representation of entities clearer and more intuitive for ontologists? In what follows, we address this issue.

This document is organized as follows. In Section 2, we present the rationale for a diagrammatic representation for entities and mereotopogical relations in ontologies. In Section 3, we present such a diagrammatic representation. In Section 4, we present an application of the representation. Finally, in Section 5 we present the conclusion of the work.

2. Rationale for a Diagrammatic Representation of Entities and Mereotopological Relationships in Ontologies

In this section, we describe the main theoretical factors we will take into account as the rationale for elaborating a diagrammatic representation for ontology's entities and mereotopological relations: Gestalt Principles, Higraph, Mereology, Mereotopology, and Diagrammatic Representation.

Gestalt principles describe the various ways we tend to visually assemble individual objects into groups or 'unified wholes' (Wong, 2010). Because we follow such principles, it is not an exaggeration to say that we are able to see things that go beyond the sum of their parts, such as new forms, new arrangements, emergent properties, and so on (Kobourov et al., 2015; Wong, 2010).

David Harel (Harel, 1988) proposed a visual formalism of topological nature called higraph (hierarchical graph). Higraphs are a combination and extension of graphs and Euler/Venn diagrams, enabling compact representations of elements related set theoretically together with some special relation on them provided by the edges. Concisely, higraphs can be seen as an extension of ordinary graphs by and/or decomposition of vertices. The two essential ideas, which enable this extension, are the provision for depth, or hierarchy depicted by encapsulation, and the notion of orthogonality, or Cartesian product.

Varzi (1996) recognized the need for supplementing mereological notions (Varzi, 2016) with topological notions and defined some strategies for that. The simplest one, which is of our interest here, is that mereology can be seen as the ground theory on which theories of greater and greater complexity (including topology as well as, say, morphology or kinematics) can be built by supplying the necessary notions and principles.

Another view of mereotopology is that of Barry Smith (1996), in which he puts mereotopology and topology together to formulate ontological laws pertaining to the boundaries and interiors of wholes, to relations of contact and connectedness, to the concepts of surface, point, neighborhood, and so on.

Following up previous work on trying to explain connection in terms of boundary sharing, Cohn and Varzi (1999) carried out a more detailed analysis on how two regions may share a single boundary point, an extended boundary segment, or an entire, maximal boundary.

In our view, the mereotopological notions described in the literature have not been seriously taken into consideration to augment the graphical representation of ontologies. Therefore, in the present work, we are interested in how parts are spatially distributed in relation to each other and how entities are located and connected to others. We should also mention here that we are making the case for complex domains such as biomedical, engineering and manufacturing.

Gurr (1999) sketches a theory of diagrammatic communication, in which he tries to provide an answer to the question: 'what makes for an effective diagrammatic representation?' He argued that a significant determinant of effectiveness in representational systems is the degree of closeness of match of structure and properties in a representation to that which it represents.

3. Diagrammatic Representation of Ontology's Entities and Mereotopological Relations

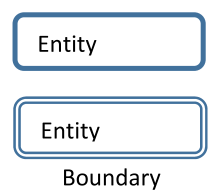
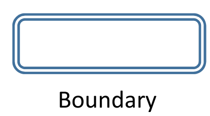
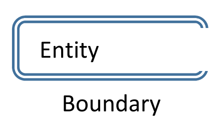
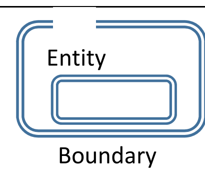
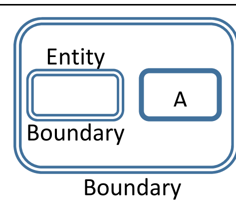
Our proposal of a diagrammatic representation for entities in ontologies is based on the ideas described in Section 2 aiming at a more intuitive and expressive representation of ontologies. Therefore, in what follows, we describe our proposal for representing entities and mereotopological relations.

3.1 Entity Representation

Entities have a name and a type. The types of entities are the following: without a defined boundary, with a closed external boundary, with an open external boundary, and with external and internal boundaries, which can be open or closed. In addition, entities can be atomic or composed.

Table 1 presents the representation of some of the types of atomic and composed entities. For almost of them, we provide a concrete example.

Table 1. Representation of types of atomic entities.

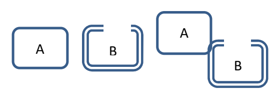
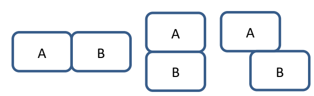
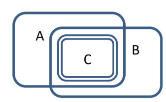
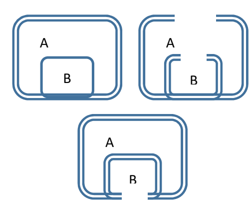
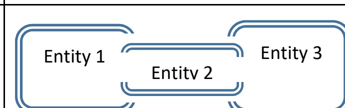
Entity Type	Representation	Example
Two kinds of representation here. The first one is that of an atomic entity without a defined boundary (e.g., a stone), and the second is of an atomic entity with a closed external boundary. This second entity is supposed to have some kind of interior matter. An example is a cake with a sugar shell.		 
An entity that is a closed boundary, whose name is the boundary name, such as an empty box. Boundary entities do not have any interior matter.		
An atomic entity with an open external boundary at the center right side. The entity is supposed to have some kind of interior matter; an example is a bitten apple.		
An entity with an external open boundary and an internal closed boundary. The Entity is a whole and the internal part is a hole. An example of this is a bitten donut.		
A composed entity with external and internal closed boundaries and with one part whose name is A, in which A is located between the boundaries. Entity is a whole and the interior of the internal boundary is a hole. Part cardinality is given by explicitly representing the parts. We can have several levels of *part-of* relations.		

Concerning boundary’s openings, it is important to mention that a boundary can have one or more openings. Openings can also be partial or total.

3.2 Mereotopological Relations

We take into account here the following mereotopological relations for entities: non-adjacency, external adjacency (weak and extended), overlap, adjacency of parts with an entity’s interior boundary, adjacency between boundaries, and boundary penetration. The defined adjacency relations are mainly inspired on the notions of modes of connection advanced in (Cohn and Varzi, 1999). Table 2 presents some adjacency relations between atomic or composed entities.

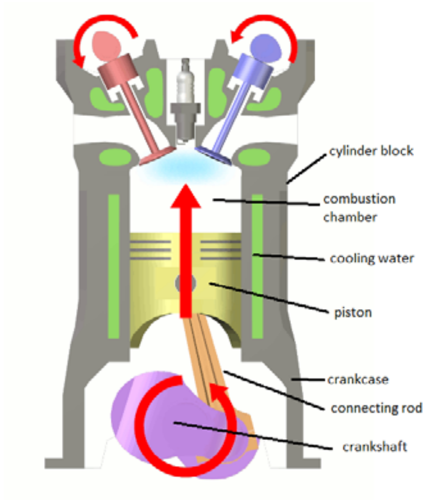
Table 2. Representation of mereotopological relations between atomic or composed entities.

Entities involved	Representation
An entity without a defined boundary and another with an open boundary at the center top. In the first pair, they are not adjacent. In the second, they are weakly adjacent.	
An entity without a defined boundary and another of the same type. Three examples of extended adjacency.	
Two composed entities without a defined boundary which have a shared part, i.e., they overlap. The shared part could be without a defined boundary or with an open boundary. We could also have different combination of overlapping entities.	
Extended adjacency between an atomic entity and the closed boundary of the whole of which it is a part. When both the whole and its part have an open boundary, the interior of the part can be accessed from the outside through the matter of the whole or directly when the open boundaries are adjacent.	
Two entities with only one opening and another with two openings. Entity 2 can be seen as a conduit connecting Entity 1 and Entity 3, i.e., Entity 2 penetrates the other entities.	

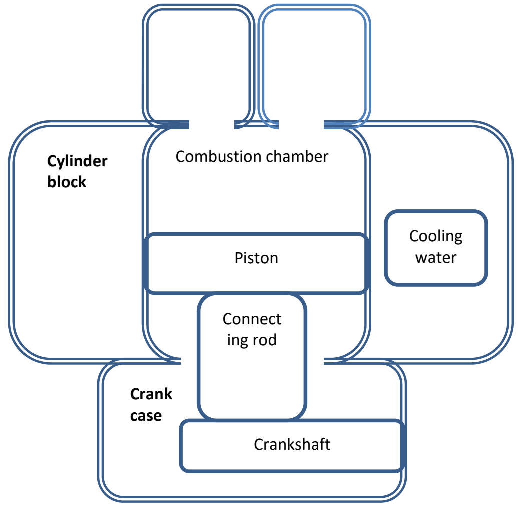
4. Application of the Representation

In the manufacturing realm, for instance, it is usual to find entities with boundaries, openings and some of these entities penetrate other entities. Figure 1a presents a significant part of a combustion engine. By using graphs, it would be easy to mention the parts involved. In contrast, to describe the relative position of parts and how they are mereotopologically related it would not be that easy.

We claim here that graph-based representation is not able to capture such semantic relations involved in this kind of complex case. In contrast, the proposed representation can capture important details that are overlooked sometimes.



a)



b)

Figure 1. a) Illustration of a combustion engine[1]; b) Representation of part of the combustion engine with the diagrammatic mereotopological relations.

As we can see in Figure 1a, the cylinder block has external and internal boundaries with cooling water present all the way around between these boundaries. We can also see that crankshaft is attached to the crankcase and that the connecting rod is also connected to both crankshaft and piston. Connecting rod penetrates both crankcase and combustion chamber through their openings. Combustion chamber has also two upper openings that are adjacent with the bottom openings of intake and exhaust valves.

Figure 1b presents part of such an illustration designed with the diagrammatic representation being proposed. As is the purpose of the diagrammatic representation being pursuit, mereotopogical and spatial relations are preserved. With the diagrammatic representation, readers do not have to read nodes and links in a graph to elaborate a mental image of the situation. The diagrammatic representation provides readers with this image, which is very close to the object in reality.

The proposed representation is in accordance with Gurr (1999) when he argues that the “effectiveness of a representation is to a significant extent determined by how closely the semantics of the representation resembles that which it represents. One benefit that certain diagrammatic representations offer to support this is the potential to directly capture pertinent aspects of the represented artifact.”

5 Conclusion

By applying some Gestalt principles and ideas from higraph, we eliminated the need of having links widely scattered, once they are now enclosed entities representing the parts of the whole. With the visual representation, we could eliminate *part_whole* links.

The diagrammatic representation of mereotopological relations opens up the possibility of representing many features that have not been taken into consideration in ontology graphical representations. The offered possibilities allow representing many arrangements in reality to attend the needs of complex domains, such as medicine, engineering and manufacturing.

With the proposed diagrammatic representation, our main intent was to obtain a balance between expressiveness, meaningfulness and intuitiveness for ontology users.

As future work, we intend to design ontologies from different domains with the use of the diagrammatic elements, and elaborate a more complete formal semantic for the diagrammatic representation. We intend also to investigate the representation of the dynamic features of parts, wholes and connections.

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[1]For the present work, annotations were added to the original picture by Eric Pierce, distributed under Creative Commons Attribution-Share Alike 3.0 Unported license. https://commons.wikimedia.org/wiki/File:Four_stroke_cycle_compression.png