

A formal ontology of artefacts

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Abstract. This article presents a formal ontology which accounts for the general nature of artefacts. The objective is to help structure application ontologies in areas where specific artefacts are present - in other words, virtually any area of activity. The conceptualization relies on recent philosophical and psychological research on artefacts, having resulted in a largely consensual theoretical basis. Furthermore, this ontology of artefacts extends the foundational DOLCE ontology and supplements its axiomatization. The conceptual primitives are as follows: *artificial entity*, *intentional production of entities*, *(state of) capacity*, *capacity to play a role in actions of a given type*, *function* and *functional object*. These primitives enable artefacts in general to be characterized as intentionally and successfully produced entities, and isolate an important subclass of “technical” artefacts to which a function is ascribed. Lastly, we emphasize the novelty of this ontology by comparing it with other works with similar objectives.

Keywords: ontology of artefacts, formal ontology, technical artefacts, function, knowledge representation, reification

1. Introduction

The NeuroLOG¹ project has developed an ontology as a component of a software platform designed to help neuroimaging researchers share resources (i.e., images and image processing software) (Temal *et al.*, 2006). This ontology is organized into sub-ontologies with different levels of abstraction. Schematically, three levels can be identified: at the most abstract level, the formal² DOLCE ontology³ (Masolo *et al.*, 2003) provides a set of abstract concepts (e.g. *physical object*, *event*, *quality*) and relations (e.g. *part-whole*, *constitution*) for structuring (by specialization) any type of domain. At an intermediate level, “core” domain ontologies (Gangemi & Borgo, 2004) define generic and central concepts in various domains including medical images (Temal, Dojat, Kassel & Gibaud, 2008), programs and software (Lando, Lapujade, Kassel & Fürst, 2008) in particular. Lastly, at the most specific level, the previously mentioned ontologies are then specialized to define more specific concepts in the fields of neuroimaging and image processing tools, respectively.

Our construction of this ontology revealed that the very abstract concepts delivered by an ontology such as DOLCE cannot be directly used to define a domain’s generic concepts such

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¹ <http://neurolog.polytech.unice.fr>

² The term “formal” is to be understood here as the opposite of “regional”. It indicates that the conceptualization is abstract and that it can account for the nature of specific objects existing in various fields of activity. Additionally, the term “formal” indicates that the ontology is specified in a logical language equipped with model-theoretic semantics, which is the case for DOLCE and our ontology of artefacts. The term “foundational” (often associated with DOLCE) means that the conceptualization is structured according to explicit, philosophical principles.

³ <http://www.loa-cnr.it/DOLCE.html>

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as *medical image* or *computer program*. In fact, the latter are artefacts - in other words, intentionally produced objects with an author and a function; unfortunately, DOLCE lacks the notions of *intentional production*, *author* and *function*. The development of this type of application ontology therefore requires the introduction of these intermediate-level concepts.

Analysis of how current ontologies account for artefacts shows that some useful generic concepts for accounting for the nature of these objects are already present in upper ontologies (such as OpenCyc⁴ or SUMO⁵). However, the principles underlying their structuring are not explicitly stated and the concepts are defined without reference to any theory, as recently reaffirmed by (Borgo & Vieu, 2009)⁶. In the same time, we noted that these objects (which shape human activities in all areas) have recently been investigated in the fields of philosophy and metaphysics (in order to understand their nature and their mode of existence), psychology (to understand the nature of the concepts of artefacts and how we categorize them) and semantics of language (to understand how we refer to these objects). A book edited by Margolis and Laurence (2007) reflects the ongoing, multidisciplinary interest in these objects and this expanding body of work. These two observations - the superficial treatment of artefacts in the current ontologies on one hand and the existence of new theories of artefacts on the other - prompted us to define a formal ontology of artefacts.

In the present article, we intend to show that (i) a conceptual analysis of these dedicated theories enables the identification and characterization of a set of basic concepts which reflect the nature of artefacts in general and (ii) it is possible to integrate these concepts into a coherent framework. Our proposed framework is a formal ontology of artefacts specializing the DOLCE ontology, while being largely independent of the latter. *In fine*, this framework consists of an axiomatized theory.

The outline of the article is as follows. In section 2, we start from a conventional philosophical notion of *artefact* and compare and contrast it with recent philosophical and psychological work in this field. This analysis prompted us to define an informal, conceptual framework outlining the notion of artefact by reference to a set of other notions (which are also examined in detail), namely *artificial entity*, *prior intention to action*, *(state of) capacity*, *instrument role*, *function*, *function ascription* and *functional object*. Thus, an artefact in general is defined as an artificial entity intentionally (in the sense of a prior intention) and successfully produced. Technical artefacts are then defined as artefacts which possess a function, either proper or accidental. In section 3, we present an overview of our ontological reference framework (DOLCE) and then show (in section 4) how we expanded it to define a formal ontology of artefacts. Lastly, section 5 compares our ontology with that of Borgo and Vieu (2006, 2009) and sheds light on some metaphysical theories of artefacts.

2. Towards a notion of artefact

Contemporary dictionaries give two definitions for the term “artefact”:

- An object made by human (e.g. a weapon or an ornament)

⁴ <http://www.opencyc.org>

⁵ <http://www.ontologyportal.org/>

⁶ These authors recently proposed a formal ontology of artefacts (Borgo & Vieu, 2009), the foundations of which are fairly different to those presented here. At the end of this article, we compare the two proposals.

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- An experimental result which is irrelevant to the natural phenomenon studied and due to the experimental framework (e.g. a shadow on an image of the lungs which turns out to be due to the particular medical imaging technique being used).

Both notions refer to a product or effect of technology, which corresponds to the etymology of the word “arte-fact”: something made or fashioned (*factum*) by skill or art (*arte*). However, the notions differ in terms of whether the artefact corresponds or not to a desired result.

In philosophy, an artefact is commonly defined as an “*entity intentionally made or produced for some reason*” (Hilpinen, 2004). The philosophical notion seeks to be more precise than the standard dictionary definition⁷ by highlighting two properties that are necessarily satisfied by all artefacts: they are “*intentionally produced*” and produced “*for some reason*”. In most cases, the *reason* equates to the expected *use* of the artefact – its intended *function*, in other words. Current philosophical analyses and work on the phenomenology of using artefacts show that these two properties are largely independent: on one hand, artefacts can be used for purposes other than those intended by their creator and, on the other hand, natural, non-intentionally produced objects can be used as tools. We therefore chose to analyze these properties separately and then sought to show how they can be combined to define special classes of artefacts. We shall start by analyzing the intentional production of objects and show that this phenomenon prompts one to draw a distinction between several kinds of produced entities – one of which is the artefact.

2.1. Artificial entities and productive intentions

The related notions of *action* and *intention* have been intensively studied in philosophy since the early 1970s. Following on from John Searle (1983), contemporary philosophers distinguish between two overall kinds of intention - a “prior intention” and “intention-in-action”, to borrow Searle’s terms - which differ according to their temporality, role and content (Pacherie, 2000). A *prior intention* consists in deciding which goal to pursue, designing a plan (in some cases) prior to the realization of the action and then guiding and rationally controlling the action⁸. It relies on a conceptual representation of the type of action to be performed, comprising an objective (i.e. a goal) and, optionally, a means of achieving it (i.e. a plan). Once the action has been initiated, the *intention-in-action* consists in the continuous guidance and control of the action by relying on a descriptive, context-sensitive representation of the said action. In our context, the term “intentional” is to be understood in the sense of a prior intention, because it assumes that a conceptual representation of the type of entity to be produced exists as a

⁷ Dropping the reference to humans opens the door to the consideration of animal-generated artefacts. Informally, these are constructions made by animals for hunting, protection and processing food and thus are very similar to human artefacts. The available data indicate that the vast majority of these constructs are only the result of instinct, relying on innate sequences of instructions (Gould, 2007). However, certain animal constructs (such as the twigs that New Caledonia crows convert into hooks to extract insect larvae from trunks) are undoubtedly part of a goal-oriented problem-solving activity (Weir, Chappel & Kacelnik, 2002) and should be considered as entities intentionally produced for a particular reason. The framework presented here accounts for these various categories of animal artefacts.

⁸ It is important to note that despite the presence of the word “prior” this intention does not end when the action is initiated; it continues throughout the action that it helps to control (Pacherie, 2000).

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component of the representation of the action to be realized⁹. This means that an artefact corresponds to an outcome targeted by its creator. Accordingly, each artefact necessarily has what we refer to as an *intentional author* (enabling us to retain the usual, more general meaning of the term "author", which does not necessarily involve prior intention). Hence, the philosophical notion fits with the conventional notion of an *intended artefact*.

In contrast, the second dictionary definition (that of an experimental "artefact") refers to a non-intentionally created entity (even in the sense of an intention-in-action). When one considers this matter more closely, it becomes clear that many categories of non-intentionally created entities are not artefacts. These include entities corresponding to unwanted "side effects" of intentional actions (e.g. experimental artefacts, sawdust, hair cuttings, grass cuttings, pollution, etc). By strictly adhering to the notion of intention, one can identify two other categories of non-artefacts: (i) the effects of actions without prior intention (e.g. when writing an article at my desk, I may unconsciously crumple a sheet of paper and turn it into a ball without having chosen this objective) and (ii) the effects of a series of non-coordinated, intentional acts that cannot count as a collective intention (for example, a path across a field that progressively results from a series of intentional acts consisting in taking the shortest route from one point to another cannot (according to Hilpinen (1992) and then Thomasson (2003)) be considered to be an artefact).

Even though reference to a (prior) intention allows one to establish the artefactual nature of the aforementioned entities, this condition appears to be lacking (or at least be only partly satisfied) for entities that are intentionally produced but do not correspond to the desired objective (subsequently to a failure) or for artefacts which are damaged to such an extent that they lose their status. In these two instances (in which prior intention to create is attested) which criteria should we use to decide whether a newly produced entity acquires the status of artefact or when an existing artefact loses that status?

The psychological theory of the nature of the concepts of artefacts proposed by Bloom (1996)¹⁰ (reworked and supplemented by Thomasson (2003, 2007)) enables us to answer this question. The theory extends the notion of intentionally produced entities by specifying that (i) the action must have been carried out *successfully* and (ii) the contents of the intention must refer to *existing artefacts of the same kind* (Bloom, 1996, p. 10):

We construe the extension of artifact kind X to be those entities that have been successfully created with the intention that they belong to the same kind as current and previous Xs. In other words, our understanding of the concept chair is that it includes all and only those entities that have been successfully created with the intention that they belong to the same kind as current and previous chairs (or, equivalently, with the intention that they be chairs).

Deciding on the success or failure of an action consists in assessing the extent to which (because success can be partial) the action's outcome corresponds to the intended goal. In the case of the intentional production of an artefact, success is based on the embodiment within the artefact of a set of properties corresponding to the concept underlying the kind of artefact. This concept - whether restricted to the artefact's author or shared socially by a community of agents (such as the *chair* concept) - thus forms part of the intention behind artefact production. Thus,

⁹ We further underpin this position later in the article.

¹⁰ This theory extends to the concepts of artefacts the theory proposed by Levinson (1993) for works of art.

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as stated by Thomasson (2007), the author of an artefact cannot simply refer to a sample of existing objects but must possess a concept of the kind of artefact that he/she intends to produce:

*The relevant sort of intention to make a thing of artefactual kind K must thus involve a substantive (and substantively correct) concept of what a K is, including an understanding of what sorts of properties are K-relevant and an intention to realize many of them in the object created.*¹¹

An entity becomes (or remains) an artefact of a certain kind from the moment when (or as long as) the properties of its kind are fulfilled; this state of affairs is judged by the author of the artefact or by an external observer. From this standpoint, concepts of artefacts play the same role and are of the same nature as concepts of natural objects.

It may be noted here that Bloom and Thomasson only regard as types of entities *essentially* artefactual types, namely (as defined by Thomasson) types including only artefacts in their extension (e.g., *chair, car, television*). But, in addition, other types exist whose instances have (for most of them) a natural origin (e.g., *water molecule, quantity of water*) or are simply artificial (e.g., *footprint*) and for which some instances are however artefactual (e.g., a molecule of water synthesized in laboratory, a quantity of water bottled for drinking¹², a footprint intentionally produced to trick a pursuer). For these instances, it seems reasonable to assume that the same rules apply for ascribing them the status of artefact: it is necessary and sufficient that they have been created successfully with the intent that they belong to a certain type of object and that the author possesses the concept of the type in question. In these cases, however, as the property to be intentionally produced is not part of the concept of the type (unlike for essentially artefactual types), one recognizes them as instances of a more specific type (e.g., a *synthesized water molecule, an intentional footprint*).

In summary, an artefact is an entity (i) that is produced with prior intention and (ii) successfully becomes a member of the kind of artefact produced. These characteristics define the space occupied by artefacts within the class of entities that may be created either without prior intention, or without any intention whatsoever (i.e. without intention-in-action), as is the case for the experimental “artefacts”.

In the next section, we examine the second property that must necessarily be satisfied by all artefacts (according to the conventional philosophical definition), namely production for a *reason*.

2.2. Functions and competencies

The *reason* in question is related to the expected effects of the produced artefact¹³. Depending on the kind of artefact, various categories of effect can be identified. For instance, most works of art are commonly considered to be artefacts designed to be of aesthetic interest and to convey an emotion (Levinson, 2007). Furthermore, a large number of more “functional” artefacts are

¹¹ According to Thomasson (2007), the fact that intention is not merely transparent (i.e. it does not solely refer to a sample of objects) explains the creation of prototypes when a new kind of artefact is created and when objects of this kind do not yet exist.

¹² Bloom discusses the artefactual status of these entities referred to by the term ‘water’ in (Bloom, 2007).

¹³ Here, we leave aside reasons related to the act of production itself, such as acquiring, demonstrating or teaching a skill. Consideration of these reasons would involve use of the notion of *plan* to express the fact that artefact production is a means to achieve a given objective, independently of the use of the artefact.

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designed to allow their author (or another agent) to *do something*; this practical objective is assimilated to their *function*. In this section we focus on the latter artefacts (commonly referred to as “technical artefacts”) and look at the notion of *function* in more depth.

Although several theories of function have been suggested in the literature (especially in philosophy and engineering) none has become widely accepted and most (in the field of philosophy) concern the function of natural biological entities and their parts. However, researchers at the University of Delft have recently proposed an artefact-dedicated theory of function that accounts for the phenomenology of artefact production and use (Houkes & Vermaas, 2004) (Vermaas & Houkes, 2006). This theory is rooted in a theory of actions and roughly assimilates an artefact’s function to *its ascribed capacity (according to an observer) to enable the performance of an action*. In our quest for a conceptual framework capable of accounting for all the properties of artefacts, we decided to adopt this notion of function. However, its integration requires clarification.

First of all, it is essential to clarify the notions of *capacity* and *function* because this enables us to ontologically distinguish between the entities to which these notions refer. To this end, we wish to emphasize the importance of distinguishing (according to Searle's terminology (1995)) between the *intrinsic* properties of an object (which include its *capacity*, in our view) and its *observer-relative* properties (notably the *function*). According to Searle, considering that an object is a screwdriver by referring to its function corresponds to a *relative* feature for the observer (Searle, 1995, pp. 9-10):

It is, for example, an intrinsic feature of the object in front of me that it has a certain mass and a certain chemical composition... But it is also true to say of the very same object that this is a screwdriver. When I describe it as a screwdriver, I am specifying a feature of the object that is observer or user relative. It is a screwdriver only because people use it as (or made it for the purpose of, or regard it as) a screwdriver.

To help understand this distinction, we have adopted two similar notions: *competence* and *agentive entity*¹⁴:

- A *competence* is an *ascribed capacity* to perform an action.
- An *agentive entity* is an entity which *is assigned* with the capacity to perform an action.

Firstly, the term “capacity”¹⁵ indicates a potential which an entity possesses (at least partly intrinsically) and which is exploited by that entity for the realization (as an agent) of an action, i.e. rendering the latter possible¹⁶. It is important to distinguish between a capacity (i.e. a potential or *disposition* (Mumford, 1998)) and the action to which it relates. The action referred to here is a type of action rather than an individual action, since the capacity to perform an action assumes the ability to repeat it. The term “competence” assumes the presence of an

¹⁴ The definitions that we use here come from the fields of artificial intelligence and philosophy (and the philosophy of action, in particular). In contrast to ordinary language, these disciplines draw a clear distinction between *capacity* and *competence*. This distinction is also found in the field of competence evaluation, in which competences are established on the basis of standards.

¹⁵ The terms “knowledge” and “know-how” are used more specifically to designate the capacity of an entity to reason as a “cognitive agent” or “knowledge agent”.

¹⁶ The restriction that we make to the intrinsic character of capacity relates to the fact that (i) a capacity can be gained or lost and (ii) items outside the entity (e.g. the use of artefacts) may turn to be decisive in the realization of the action.

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observer who ascribes an entity with the capacity to perform an action, therefore giving it the status of an ‘agentive entity’¹⁷. This recognition or assignment is a mental act that relies on the observer’s belief states. The result of this act is equivalent to ascribing the agentive entity with the (observer-dependent) idea of being able to perform an action. The conceptual status of competence is important: an ascription of competence does not imply that the agentive entity possesses (either momentarily or permanently) the capacity referred to by the competence¹⁸.

By analogy, we propose the following definitions for the notions *function* and *functional entity* (which concord with Houkes and Vermaas' notion of function, as mentioned above):

- A *function* is an ascribed capacity which *enables* the realization of an action.
- A *functional entity* is an entity which is assigned with the capacity to *enable* the realization of an action.

In terms of formulation, the only difference between the notions of *competence* and *function* relates to the presence of the verb “enables”. This verb indicates the existence of an additional entity (with respect to the agent), whose *use* contributes to the realization of the overall action. The capacity in question becomes the entity's capacity to play the role of an instrument during an action or, in other words, the capacity to contribute to the realization of an action by being used in a certain way¹⁹. As for *competence*, the conceptual status ascribed to the function is significant, for two reasons.

Firstly, it enables us to account for the fact that function ascription does not imply that the functional entity possesses (momentarily or permanently) the capacity to which the function refers. This corroborates the available psychological data (Bloom, 1996) and explains the difficulty in interpreting ascriptions of function as dispositional properties (Kroes, 2001). Function is certainly a supposed capacity (based on the observer's beliefs) but may turn out to be inexistent (such as the popular belief which ascribes a horseshoe hung on the wall with the capacity to ward off evil spirits). In this respect, Griffith (1993) provides an edifying example of the capacity once ascribed by engineers to the streamlined tail-end of old racing cars, which supposedly reduced the drag coefficient but turned out to do nothing of the sort (Griffith, 1993, p. 421):

When the designer has false beliefs about the real world, this results in artifacts functioning well in his hypothetical environment when they do not function in the real environment. The tail of the racing car did perform its function, but only in the mind of its designer.

Secondly, as commonly noted in the literature (e.g. (Searle, 1995), (Franssen, 2006)), ascription of a function assumes reference to a norm, since it becomes possible to refer to (i) functional entities as malfunctioning entities and (ii) entities that operate less well or better than others. In addition, this assignment also assumes a *usefulness* of the produced effect, which

¹⁷ The term “agent” is commonly used in two main ways: that of a temporal role played by an entity during an individual action (referred to as a “participation role” or “thematic role” in the literature (Sowa, 2000)) and that introduced here of an entity to which someone ascribes a competence. In order to distinguish between these two notions, we use the terms “agent” (for the role) and “agentive entity” (for the status). These two notions are related: an *agentive entity* is an entity to which an observer assigns a status, i.e. the ability to play the role of an *agent* in actions.

¹⁸ A person may consider him/herself capable of carrying out actions (i.e. he/she assigns him/herself with competences) but may not in fact have the corresponding capacities.

¹⁹ According to the theory of Houkes and Vermaas (2004), this use is accomplished through a *use plan* possessed by the agent of the action.

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prompts one to not consider certain capabilities as functions. Therefore, both the tides caused by the Moon and, to take the example of an artefact, the noise caused by a car when running, are not regarded as the “function” of these entities.

Assignment of the function with the observer-dependent, ideal status of an *intended* capacity echoes the notion of *function as (desired) effect* proposed in the field of engineering by (Chandrasekaran & Josephson, 2000):

All the meanings for the term “function” arise from the idea of a machine, system or a person doing something or having a property that is intended or desired by someone, or deemed as appropriate from someone’s point of view. Thus the ontology of function starts with the ontology of behavior, but it is distinguished by the fact that some agent regards it as desirable or intends the behavior. All the other terms – structure, behaviour, causal models – are neutral with respect to intent [...] Thus a central meaning of function is function as (desired) effect.

Let us return to our notion of an artefact's function by providing further details of its basis in a theory of action. As defined, a function (or ascribed capacity) is the capacity to enable an *agent* to perform an *action* by using the artefact. Hence, the reference to an action influences the boundaries of our notion by delimiting the capacities considered as functions. In this respect, one should note that biological and physiological functions are not taken into account. In fact, for the behaviour of an organ performing a physiological function, the absence of an intention encompassing a conceptual representation of a goal prevents us from considering this process as an action. In contrast, reference to an *action* does not necessarily involve the existence of a visible process or behaviour. Our notion of *action* assimilates an action to an event (of whatever kind) triggered by an intention. However, as notably emphasized by Hornsby (2004), the event in question may very well be a state. For example, in a certain context, not raising the hand may count as a voting action. Our notion of function therefore covers functions like being a warehouse for storing goods or the camouflaging function of the colour of a tank, as long as we assimilate the *intentional* states of goods storage and tank camouflage to actions²⁰.

To close this section on the details of our notion of an artefact's function, we contrast it with two paradigmatic notions of function: "system function" (introduced by (Cummins, 1975)) and "proper function" (introduced by (Millikan, 1984)).

We first note that our notion of function concurs with the notion of *causal contribution to a capacity of a containing system* which serves as the basis of the functional analysis by Cummins (1975, p. 765):

To ascribe a function to something is to ascribe a capacity to it which is singled out by its role in an analysis of some capacity of a containing system.

In fact, this corresponds almost word-for-word to our definitions, as long as one assimilates the “containing system” to a system composed of (i) an agent (or a community of agents) performing an action of a given kind and (ii) the artefact used. Setting aside the exact choice of words, an important difference lies in the considered notion of function, taken by Cummins to be an entity’s current capacity (1975, p. 757):

*If something functions as a pump in a system *s* or if the function of something in a system *s* is to pump, then it must be capable of pumping in *s*. Thus, function-ascribing statements imply disposition.*

²⁰ Here, to emphasize our opposite point of view, we have adopted examples of functions considered by (Burek, 2007) as not being related to actions.

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According to Cummins, a function corresponds to the *role* played by a capacity with respect to a containing capacity (and ascribing a function equates to specify this role), since the *function* and *capacity* are entities of the same ontological nature. As we mentioned above, our conception is different. By distinguishing between the two entities, we consider a "system capacity" (as an intrinsic feature of the artefact) and a "system function" (as an observer-relative feature). The term "system capacity" (in which "system" means the agent plus the artefact) specifies the type of capacity that it is possible to ascribe with our notion of "*artefact function*". As emphasized by Kroes (in his presentation of Searle's analysis of technical functions), the assignment of a "system function" adds elements to the "system capacity" (2003, p. 25):

The assignment of functions always involves more than just intrinsic features (causal features) of the world; it brings into play values (purposes, goals) and normative elements.

The notion of "proper function" (defined by Millikan (1984)) aims at accounting for the dependence of a function vis-à-vis intrinsic qualities of the functional entity or, more exactly, a type of entity. The dependence in question is two-fold, in fact: on one hand, a set of intrinsic qualities enables a capacity to express itself and generate useful effects; on the other hand, via feedback from the effect on the cause, this same set of intrinsic qualities exists today because it enabled production of these useful effects in the past. Indeed, a significant number of objects inherit (from ancestors from a "family of resembling objects" (Millikan, 1984) or a "type of copied objects" (Elder, 1995)) intrinsic qualities suited to the performance of one or more usages and are thus ascribed with one or more *proper functions*. These objects come from various categories. By way of an example, one can cite traits in living beings (e.g. the giraffe's long neck enables it to reach leaves high in a tree), behaviours (e.g. the male stickleback's mating dance favours fertilisation of the female stickleback's eggs) and, of course, certain artefacts (e.g. hammers, whose shape and material composition enable their users to assemble wooden planks by knocking in nails). These objects possess qualities which have been "copied"²¹ because the latter are causally responsible for useful effects. A "proper function" (according to the term and the definition proposed by Millikan (1984)) corresponds to useful effects which depend causally on these appropriate qualities. In the case of artefacts, the useful effects correspond to actions performed by users. The notion of "proper function" then enables one to define a sub-class of *artefact functions* for which the ascribed capacities depend causally on qualities that are copied over time by a family of agents.

Armed with this notion of *artefact function* and the more specific notion of an artefact's "proper function", we can return to our initial objective of fully characterizing these objects according to both the intentionality of their production and their function.

2.3. Artefacts (in general) and specific categories of artefacts

In section 2.1, we assimilated artefacts to intentionally and successfully produced entities (while constraining the intention of production to inclusion of the concept of the type of artefact to be produced). In section 2.2, we chose to avoid hastily assimilating the reason for producing an artefact to its function by admitting that some artefacts may not have any assigned function.

²¹ The term is used here in a metaphorical sense. The copying mechanism corresponds (depending on the case in question) to either natural selection or deliberate actions of agents which fashion new tools from old ones, in order to improve their functionality.

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This choice leads us to distinguish a subclass of “technical” artefacts within the class of artefacts in general. These technical artefacts possess one or more functions.

According to Kroes & Meijers (2006), technical artefacts have a dual nature, since they are both physical objects (for physical artefacts, at least) and functional entities. However, by omitting to consider the property of intentional production, this type of characterization includes objects that we do not wish to consider as artefacts (e.g. a pebble used as a paperweight or a tree trunk used as a bench for a picnic). Hence, the question of what type of action counts as “production” (and notably minimum production) arises. In as far as physical artefacts are concerned and in order not to stray from the conventional notion of artefact, we consider that this production must include at least one physical transformation. In other words, we rule out the mere selection (or even simple displacement) of an object, which can play a contextual role for ascribing a function to an object²². Consequently, and in order to emphasize the need for the property to have been intentionally created or transformed, we believe that it is more appropriate to talk about the *triple* nature of technical artefacts.

In order to refine our understanding of technical artefacts (and notably their functional dimension), we shall discuss the essential (*vs.* accidental) and social (*vs.* private) characteristics of their function(s).

When technical artefacts are copied objects, they possess by essence (according to (Elder, 1995)) a cluster of properties which includes one or more proper functions and intrinsic qualities²³. The notion of cluster expresses the dual or triple nature of technical artefacts. As the function characterizing the copied artefact is a proper function, this adds, as we saw, that it possesses qualities adapted to perform this function (“functional” intrinsic qualities). By the way, the existence of functional qualities for a copied artefact type explains that one unambiguously distinguishes between a token of this type (e.g., a screwdriver) and an object that possesses the same function in a certain context without possessing these same functional qualities (e.g., a coin used as a screwdriver) (Kroes, 2003). The use of copied artefacts in accordance with their proper function is *de facto* standard usage. However, a use planned and/or performed by the creator and/or users of artefacts may not correspond to their proper function(s); for example, a chair can be designed for exhibition in a museum; a screwdriver can be used as a lever to open the lid of a paint pot. These are accidental usages, which contrast with the conventional uses corresponding to the proper functions, and which lead to the ascription of functions that we call “accidental functions”. It should be noted that in such cases, knowledge of the artefact’s function has a different origin. The function is no longer inferred from knowledge of the type of object (as is the case for a proper function) but is ascribed when a particular use of the artefact is planned. Given the dynamic nature of the ascription of these functions, we consider (in accordance with Houkes and Vermaas (2004)) that technical artefacts contingently bear their accidental functions.

Lastly, a complementary and independent aspect of the characterization of technical artefacts relates to the individual or collective nature of the agent (an author, user or simple observer) ascribing the function, regardless of whether the latter is proper or accidental. For a large number of technical artefacts, the concept defining the type of artefact (e.g. *screwdriver*, *fridge*, *space probe*, etc.) is known to and shared by the members of a society. In line with Borgo and

²² To use an often cited example, we consider *de facto* that a natural object exhibited as a work of art is a functional object but is not an artefact because it has not been intentionally produced.

²³ It is important to note that Elder’s conception about *essentialness* does not apply to an isolated property (constraining it, according to a common view, to depend only on the laws of nature), but to a combination of properties (Elder, 2007, p. 38): “we should require only that the essential properties must cluster together non-accidentally, and in a cluster found in no other kind”. According to this more liberal approach, proper functions are considered to be essential not as isolated properties but as they belong to essential clusters of properties.

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Vieu (2009), we call these artefacts "social artefacts", in order to emphasize their dependence on a certain society. In fact, these social artefacts are copied objects which in essence bear their social proper function(s). In contrast, certain technical artefacts are ascribed with a function by an individual. This is the case for the previously cited example of a *footprint that is intentionally produced to deceive pursuers*; this possesses a function for the author and for him/her alone²⁴. This example is representative of the class of private technical artefacts, whose function is ascribed by (and is known only to) one individual. This is also the case of mnemonic processes (e.g. memory joggers and reminders) that we build for ourselves.

This analysis results in an informal conceptual framework that positions (i) the notion of artefact in general and (ii) notions of specific artefacts with respect to similar notions (such as "functional object" and "copied object"). We shall subsequently propose a logical formalization for this conceptualization. However, we first present our conceptual reference framework by introducing the primitives of the DOLCE ontology.

3. The ontological reference framework

The DOLCE ontology is a *foundational* ontology (in the sense given in footnote #2) which seeks to account for the ontological categories underlying human natural language and common sense (Masolo *et al.*, 2003). Its domain is that of *Particulars* (PT)²⁵ (that is to say entities that cannot be instantiated (e.g. "my car")), rather than *universals* (e.g. "car")). Four sub-domains of *Particulars* can be distinguished (see Fig. 1):

- *Endurants* (ED) are entities "enduring in time"²⁶. Within *Endurants*, *Physical Objects* (POBs) (e.g. a printed copy of an article) are distinguished from *Non-Physical Objects* (NPOBs) (e.g. the contents of this article), since the former are the only ones that possess direct spatial qualities. *Non-Physical Objects* include *Concepts* (CPTs) (e.g. your notion of ontology) reifying types of instances²⁷.
- *Perdurants* (PD) are entities "occurring in time" (e.g. your reading of this article). Within *Perdurants* and according to the principle of cumulativity²⁸, *Statives* are distinguished from *Events*. Within the latter, *Achievements* are distinguished from *Accomplishments* (according to whether they are atomic or not).

²⁴ In this example, the fact that the function ascribed by the author must not be recognized by the pursuers is very important!

²⁵ With respect to our notation, the informal labels on DOLCE's categories appear in the text in *italics* with *First Capital Letters* for the concepts and a *javaLikeNotation* for relations. The associated acronym (in parentheses) is the name of the predicate used for logical formalization of the ontology. In this section, we only specify this short name for categories which will appear in the formalization of our ontology of artefacts.

²⁶ Due to space limitations, we are only able to provide a very brief characterization of DOLCE's categories and we limit ourselves to categories of use in our ontology of artefacts. In particular, we do not mention the different temporal behaviours of the parts of *Endurants* and *Perdurants* (below). For a complete presentation, the reader is invited to refer to (Masolo *et al.*, 2003).

²⁷ The category of social *Concepts* was introduced in DOLCE by (Masolo *et al.*, 2004) when they were studying social roles. The fact that these *Concepts* have a defined lifetime (i.e. they are created by agents and can cease to exist) justifies their status as *Endurants*. As defined in (Fortier and Kassel, 2004), we consider here a more general class of *Concepts*, which includes private *Concepts* (dependent on individual agents) and social *Concepts* (dependent on a community of agents). In our definition of artefacts, we merely use a property of these *Concepts* to temporarily "classify" the instances.

²⁸ The mereological sum of two *Statives* (e.g. seating) is a *Stative* of the same kind, whereas this property is not valid for *Events* (e.g. a football match).

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- *Endurants* and *Perdurants* have *Qualities* that we perceive and/or measure (e.g. the weight of the printed copy of an article, the time it takes for you to read this article²⁹). Note that these *Qualities* are inherent to the entity that bears them, since they are characteristic for it and they are present throughout the course of the entity's existence.
- These *Qualities* take on values (*Qualia*) which correspond to relative positions in conceptual spaces (*Regions*). These positions are likely to vary over time – in any case for the *Qualities* of physical *Endurants* (i.e. *Physical Qualities*). A *Time Interval* (T) is an example of a *Region* for the *Qualities* of *Perdurants* (*Temporal Qualities*). Values of measurements can be associated with these positions (e.g. 25 grams, 20 minutes).

One can also note the main relationship between *Endurants* and *Perdurants*: the ternary relationship of temporal participation (PC). This means that: *an Endurant participates in a Perdurant for a given Time Interval*.

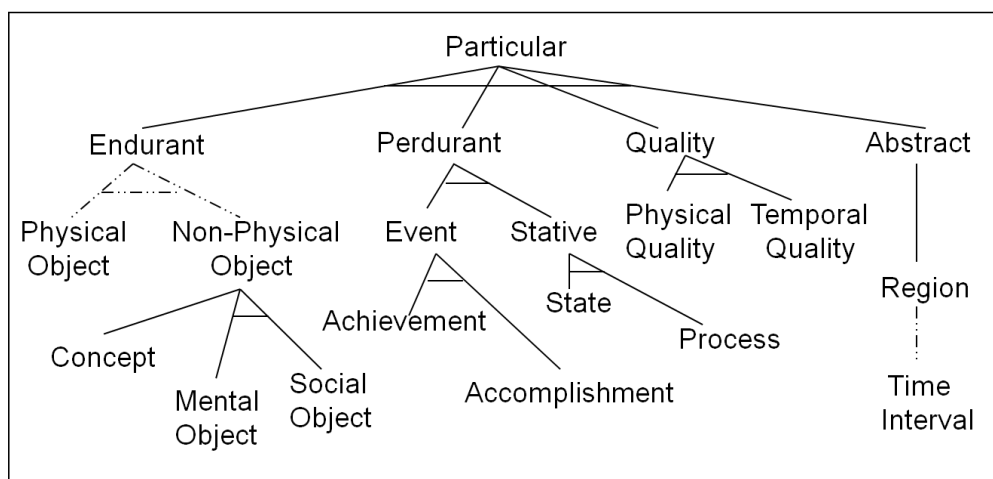


FIG. 1 – An excerpt of DOLCE's hierarchy of concepts³⁰

Before extending DOLCE to artefacts, we shall make a general remark concerning the latter's status within *Endurants*. We shall also situate actions among *Perdurants* and informally define three classes of actions to be used later on.

Within the domain of *Endurants*, the distinction between *Physical Objects* and *Non-Physical Objects* relates to the difference between two realities or modes of existence for the entities. The domain of *Non-Physical Objects* covers entities whose existence depends on either an individual (for *Mental Objects*) or a community of agents (for *Social Objects*). The latter are defined by Masolo *et al.* (2004, p. 267) as follows: “an entity is social if it is an immaterial (more precisely, non-directly extended in space) product of a community, i.e., if it depends on agents who, by means of some sort of convention, constitute, make use of, communicate about and accept it“. It should be noted that this distinction transcends the domain of artefacts. Indeed, the latter are defined by the origin of their existence (i.e. their intentional production) rather than a *mode* of existence, heard as a dependence vis-à-vis agents. This difference explains

²⁹ One can consider that each part of the "reading" *Perdurant* and the overall *Perdurant* has a duration.

³⁰ A solid line between two concepts represents a direct subsumption link between these concepts in DOLCE. In contrast, a dashed line indicates the existence of intermediate concepts. A line between lines signifies that the sibling concepts are incompatible (i.e. their extensions are disjoint).

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why we are able to distinguish between physical artefacts (e.g. a chair, a computer) and non-physical artefacts (e.g. a computer program, a literary work, an ontology).

Within the domain of *Perdurants*, we introduce a minimum ontology of actions (cf. Fig. 2). Taking into account current knowledge on the phenomenology of actions (Pacherie, 2008), we assimilate these *Actions* (ACT) to events controlled by an intention (intention-in-action or prior intention); this contrast with *Happenings* (HAPP) which lack an intentional cause. With the aim of conceptualizing our artefacts, we introduce three specializations of these *Actions*. Firstly, *Deliberate Actions* (DLBACT) are initiated by a prior intention comprising a conceptual representation of the intended goal. These contrast with *Non-Deliberate Actions* (NDLBACT) which are only controlled by an intention-in-action. Then, within the domain of *Deliberate Actions*, *Successful Actions* (SCFACTs) are carried out to completion and lead to their intended result.

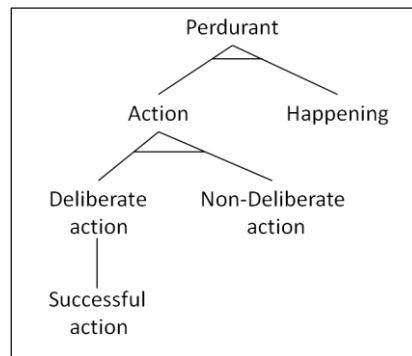


FIG. 2 – A minimal ontology of actions

4. Formalization of our notion of artefact

In this section, we formalize our notion of artefact. In line with DOLCE’s original specification mode, we elaborate a first order logical theory with different kinds of formulae: Axioms (A), Definitions (D), Theorems (T) and Facts (F). Free variables appearing in formulae should be regarded as universally quantified.

4.1. Participation roles

As we have seen in the informal analysis performed in section 2, our notion of artefact is ultimately based on participation roles such as *agent* and *instrument*, i.e. ways in which *Endurants* temporally participate in *Perdurants*. To model these roles, we introduce primitive relations which specialize the temporal participation (*PC*) relationship. We thus characterize the ternary relations *isAgentOfAt* (A1), *isInstrumentOfAt* (A2), *bearsAt* (A3) and *isConsequentOfAt* (A4), meaning respectively that (i) *x is an Endurant controlling (in the minimal sense of an intention-in-action) the Action y in which it participates during the Time Interval t*, (ii) *an Endurant x is used (by the entity controlling the Action y) to help perform this action during the Time Interval t*, (iii) *x is an Endurant bearing the State y during the Time Interval t*, and iv) *an Endurant x comes into existence or is in some new state, as an effect of a Perdurant y during the Time Interval t*. One should note that the participating entities (including

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the *isConsequentOfAt* relationship) are necessarily *Endurants*³¹ (T1-4). The latter relationship covers both situations in which an *Endurant* is created (e.g. a cake is baked) and those in which an *Endurant* is transformed (e.g. a window-pane is broken by a thrown brick), which enables us to use it to account for the various modes of production (via creation or transformation) of artefacts.

- (A1) $\text{isAgentOfAt}(x,y,t) \rightarrow \text{PC}(x,y,t) \wedge \text{ACT}(y)$
- (T1) $\text{isAgentOfAt}(x,y,t) \rightarrow \text{ED}(x)$
- (A2) $\text{isInstrumentOfAt}(x,y,t) \rightarrow \text{PC}(x,y,t) \wedge \text{ACT}(y)$
- (T2) $\text{isInstrumentOfAt}(x,y,t) \rightarrow \text{ED}(x)$
- (A3) $\text{bearsAt}(x,y,t) \rightarrow \text{PC}(x,y,t) \wedge \text{ST}(y)$
- (T3) $\text{bearsAt}(x,y,t) \rightarrow \text{ED}(x)$
- (A4) $\text{isConsequentOfAt}(x,y,t) \rightarrow \text{PC}(x,y,t)$
- (T4) $\text{isConsequentOfAt}(x,y,t) \rightarrow \text{ED}(x)$

An important constraint in the production of artefacts is that the latter is intentional (in the sense of prior intention); the artefact thus corresponds to the expected consequence. To account for this correspondence between the action's consequence and its result, we first introduce the primitive relationship *actualizesIntentionOfAt* (A5), meaning that: *the Endurant x corresponds to the entity targeted by the Action y (necessarily performed with success) during the Time Interval t*³². Next, in order to match the entity actualizing the intention of an action with the latter's consequence, we define the relationship *isResultOfAt* (D1) as the fact that an *Endurant* is the consequence of an *Action* and that it actualizes its objective at the same time. In contrast, one should note that an experimental artefact (the unwanted consequence of a successfully performed action) is not considered as a result of this action.

- (A5) $\text{actualizesIntentionOfAt}(x,y,t) \rightarrow \text{ED}(x) \wedge \text{SCFACT}(y) \wedge \text{T}(t)$
- (D1) $\text{isResultOfAt}(x,y,t) \stackrel{\text{def}}{=} \text{isConsequentOfAt}(x,y,t) \wedge \text{actualizesIntentionOfAt}(x,y,t)$
- (T5) $\text{isResultOfAt}(x,y,t) \rightarrow \text{ED}(x)$

These relations enable (i) the definition of classes of *Endurants* according to the way they participate in *Actions* (D2-5, T6) and (ii) the specialization of these classes according to the kind of *Action* in which the *Endurant* participates (D6-8, T7-9).

- (D2) $\text{Agent}(x) \stackrel{\text{def}}{=} \exists y,t(\text{isAgentOfAt}(x,y,t))$
- (D3) $\text{Instrument}(x) \stackrel{\text{def}}{=} \exists y,t(\text{isInstrumentOfAt}(x,y,t))$
- (D4) $\text{Consequent}(x) \stackrel{\text{def}}{=} \exists y,t(\text{isConsequentOfAt}(x,y,t))$
- (D5) $\text{Result}(x) \stackrel{\text{def}}{=} \exists y,t(\text{isResultOfAt}(x,y,t))$
- (T6) $\text{Result}(x) \rightarrow \text{Consequent}(x)$
- (D6) $\text{AgentOfWriting}(x) \stackrel{\text{def}}{=} \exists y,t(\text{Writing}(y) \wedge \text{isAgentOfAt}(x,y,t))$
- (T7) $\text{AgentOfWriting}(x) \rightarrow \text{Agent}(x)$

³¹ The axiomatization of DOLCE (Masolo *et al.*, 2003) leads to assimilation of the notions of "endurant" and "participant". In fact, according to DOLCE's axioms: Ad33 ($\text{PC}(x,y,t) \rightarrow \text{ED}(x) \wedge \text{PD}(y) \wedge \text{T}(t)$) and Ad35 ($\text{ED}(x) \rightarrow \exists y,t(\text{PC}(x,y,t))$), only *Endurants* participate in *Perdurants* and each *Endurant* participates necessarily in a *Perdurant*.

³² Given the lack of a theory of intentions and their contents, we are obliged to consider this relationship to be primitive.

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- (D7) $\text{InstrumentOfPaperKeeping}(x) =_{\text{def}} \exists y,t(\text{PaperKeeping}(y) \wedge \text{isInstrumentOfAt}(x,y,t))$
 (T8) $\text{InstrumentOfPaperKeeping}(x) \rightarrow \text{Instrument}(x)$
 (D8) $\text{ResultOfDiagnosing}(x) =_{\text{def}} \exists y,t(\text{Diagnosing}(y) \wedge \text{isResultOfAt}(x,y,t))$
 (T9) $\text{ResultOfDiagnosing}(x) \rightarrow \text{Result}(x)$

According to this formalization, our “participation roles” (e.g., *Agent*, *Instrument*) are potentially dependent on several *Actions* and several *Time Intervals*. According to (D2), an entity is an *Agent* as soon as it controls at least one *Action* during at least one *Time Interval*. These concepts are rigid (i.e. essential for all their instances) and thus do not have the property of dynamicity usually attributed to roles in general and participation roles in particular (Masolo *et al.*, 2004). In order to account for this property, DOLCE-Lite-plus defines “functional roles” at a conceptual level as descriptions of modes of participation, with these descriptions being “played by” *Endurants* (Masolo *et al.*, 2003). In fact, these two levels of modelling are complementary. As we shall see in the next section, we also introduce this type of functional role at a conceptual level, with latter having concepts of participation roles for instances.

This model prompts us to consider a taxonomy of participation roles under the *Endurant* concept (see Fig. 3). The figure primarily highlights our choice of model for the instances of these roles. Thus, taking the example of a physical object (such as a pebble) being used to enable to keep papers in place, our model only considers a single entity involved in two facts (F1-2). Note that this conceptualization complies with the current paradigm for modelling roles (Steimann, 2000)³³.

- (F1) $\text{Pebble}(\text{Pebble}\#i)$
 (F2) $\text{InstrumentOfPaperKeeping}(\text{Pebble}\#i)$

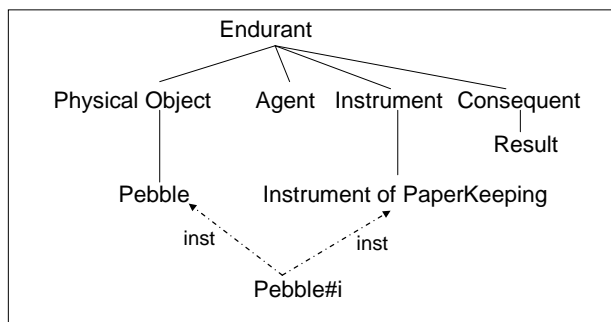


FIG. 3 – *Pebble#i* has for kind *Pebble* and plays the role of *InstrumentOfPaperKeeping*

4.2. Competences and functions

The modelling of *Agent* and *Instrument* participation roles now enables us to model the notions of *competence* and *function* in two steps. Firstly, we introduce *capacities*, which we assimilate to states representing the fact that entities temporally have causal potential to play a

³³ An alternative solution (studied by Masolo, Guizzardi, Vieu, Bottazi & Ferrario (2005)) is to consider two entities (the pebble *per se* on the one hand and the pebble as an instrument for keeping papers in place on the other) as instances of disjoint taxonomies. Indeed, Masolo *et al.* are studying several approaches in which a new entity called a “qua-individual” is introduced. However, they conclude that efforts to deepen the ontological nature of these entities are still needed.

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particular role in certain *Actions*. The strong ontological assumption we make here is that these capacities exist independently of external observers. In a second step, we introduce these observers and their ability to assign *competences* and *functions* to entities. We assimilate the latter to conceptual descriptions of capacities that observers attribute mentally to entities.

As building bricks in our definition of *capacities*, we first consider conceptual descriptions of participation roles; these correspond intuitively to *ideas* referring to modes of participation in *Perdurants*. To this end, we have resorted to *Concepts*. The minimum characterization of *Concepts* that we use for this paper is the property of these entities to classify temporally other entities. Hence, we introduce the relationship *classifiesAt* (A6) meaning that a *Concept* x classifies a *Particular* y during a *Time Interval* t or, in other words, that a *Particular* y satisfies during a *Time Interval* t the set of properties that make up the *Concept* x . Here, we take the opportunity of defining the *subsumes* relationship as a subsumption between concepts (D9)³⁴. Note the notation chosen to represent an instance of a *Concept*: the name of the predicate is placed between square brackets (e.g. (F3): [Pebble]). Within *Concepts*, the *ActionRoles* classify *Endurants* participating in *Actions* (D10). Within the domain of *ActionRoles*, *AgentRoles* and *InstrumentRoles* classify *Endurants* which play the role of *Agent* (D11) and *Instrument* (D13), respectively. By specializing according to the kind of *Action*, more specific *ActionRoles* can be defined (e.g. *DiagnosingAgentRole* (D12), *PaperKeepingInstrumentRole* (D14)). This specialization prompts the development of a taxonomy of classes of *Roles* (T10-13) whose instances, one should remember, are concepts (e.g. [AgentOfDiagnosing] (F4), [InstrumentOfPaperKeeping] (F5)).

(A6) $\text{classifiesAt}(x,y,t) \rightarrow \text{CPT}(x) \wedge \text{PT}(y) \wedge \text{T}(t)$

(D9) $\text{subsumes}(x,y) =_{\text{def}} \text{CPT}(x) \wedge \text{CPT}(y) \wedge \forall z,t(\text{classifiesAt}(y,z,t) \rightarrow \text{classifiesAt}(x,z,t))$

(F3) $\text{classifiesAt}([\text{Pebble}], \text{Pebble}\#i, t\#j)$

(D10) $\text{ActionRole}(x) =_{\text{def}} \text{CPT}(x) \wedge \forall y,t(\text{classifiesAt}(x,y,t) \rightarrow \exists z,t'(\text{ACT}(z) \wedge \text{PC}(y,z,t')))$

(D11) $\text{AgentRole}(x) =_{\text{def}} \text{CPT}(x) \wedge \forall y,t(\text{classifiesAt}(x,y,t) \rightarrow \text{Agent}(y))$

(T10) $\text{AgentRole}(x) \rightarrow \text{ActionRole}(x)$

(D12) $\text{DiagnosingAgentRole}(x) =_{\text{def}} \text{CPT}(x) \wedge \forall y,t(\text{classifiesAt}(x,y,t) \rightarrow \exists z,t'(\text{Diagnosing}(z) \wedge \text{isAgentOfAt}(y,z,t')))$

(T11) $\text{DiagnosingAgentRole}(x) \rightarrow \text{AgentRole}(x)$

(D13) $\text{InstrumentRole}(x) =_{\text{def}} \text{CPT}(x) \wedge \forall y,t(\text{classifiesAt}(x,y,t) \rightarrow \text{Instrument}(y))$

(T12) $\text{InstrumentRole}(x) \rightarrow \text{ActionRole}(x)$

(D14) $\text{PaperKeepingInstrumentRole}(x) =_{\text{def}} \text{CPT}(x) \wedge \forall y,t(\text{classifiesAt}(x,y,t) \rightarrow \exists z,t'(\text{PaperKeeping}(z) \wedge \text{isInstrumentOfAt}(y,z,t')))$

(T13) $\text{PaperKeepingInstrumentRole}(x) \rightarrow \text{InstrumentRole}(x)$

(F4) $\text{DiagnosingAgentRole}([\text{AgentOfDiagnosing}])$

(F5) $\text{PaperKeepingInstrumentRole}([\text{InstrumentOfPaperKeeping}])$

Having introduced these concepts of participation roles we can formalize our notion of *capacity*. As stated above we consider that a *Capacity* represents a state of capacity (or a potential) which is temporally borne by (available to) an entity; we therefore assimilate it to a *State* (A7). This *Capacity* is proper to the entity bearing it (A8). Within the domain of *States*,

³⁴ The same relationships for temporal classification and subsumption were introduced by (Masolo *et al.*, 2004) in their formalisation of *social roles*.

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we specifically focus on potentials enabling the participation of entities (according to different modes) in *Actions*. These potentials are exercised by the entities during their participation in *Actions* (in other words the achievement of these *Actions*). The *enablesToFulfill* (A9) relationship is the link between the *Capacity* and the participation role or, more precisely, a conceptual description of this role. Axiom (A10) translates the fact that a *Capacity* to play a role in an *Action* is also a *Capacity* to play a more abstract role, in the sense of a taxonomy of *ActionRoles* (e.g. a capacity to sing in tune is a capacity to sing). Depending on the exact characteristics of these roles, different kinds of *Capacities* can be defined: *CapacityToPerformAction*³⁵ (D15), *CapacityToEnableAction*³⁶ (D17). In turn, these *Capacities* can be specialized (D16)(D18), and give rise to a taxonomy of *Capacities* (T14-15).

(A7) $\text{Capacity}(x) \rightarrow \text{ST}(x)$

(A8) $(\text{Capacity}(x) \wedge \text{bearsAt}(y,x,t) \wedge \text{bearsAt}(z,x,t)) \rightarrow y=z$

(A9) $\text{enablesToFulfill}(x,y) \rightarrow \text{Capacity}(x) \wedge \text{ActionRole}(y)$

(A10) $(\text{enablesToFulfill}(x,y) \wedge \text{subsumes}(z,y)) \rightarrow \text{enablesToFulfill}(x,z)$

(A11) $\text{Capacity}(x) \rightarrow \exists y(\text{ActionRole}(y) \wedge \text{enablesToFulfill}(x,y))$

(D15) $\text{CapacityToPerformAction}(x) =_{\text{def}} \text{Capacity}(x) \wedge \exists y(\text{AgentRole}(y) \wedge \text{enablesToFulfill}(x,y))$

(D16) $\text{CapacityToPerformDiagnosing}(x) =_{\text{def}} \text{Capacity}(x) \wedge \exists y(\text{DiagnosingAgentRole}(y) \wedge \text{enablesToFulfill}(x,y))$

(T14) $\text{CapacityToPerformDiagnosing}(x) \rightarrow \text{CapacityToPerformAction}(x)$

(D17) $\text{CapacityToEnableAction}(x) =_{\text{def}} \text{Capacity}(x) \wedge \exists y(\text{InstrumentRole}(y) \wedge \text{enablesToFulfill}(x,y))$

(D18) $\text{CapacityToEnablePaperKeeping}(x) =_{\text{def}} \text{Capacity}(x) \wedge \exists y(\text{PaperKeepingInstrumentRole}(y) \wedge \text{enablesToFulfill}(x,y))$

(T15) $\text{CapacityToEnablePaperKeeping}(x) \rightarrow \text{CapacityToEnableAction}(x)$

Lastly, we address the ascription of *competences* and *functions* by agents to entities. These assignments can be regarded as belief states with a conceptual content. We therefore again resort to *Concepts* to represent *ideas* according to which *entities are in such or such a particular state of capacity* (*Capacity*) and we define *Competences* and *Functions* as *ConceptsOfCapacity* (D19) classifying *CapacitiesToPerformAction* (D20)(F6) and *CapacitiesToEnableAction* (D21)(F7), respectively. Concerning the ascription *per se* and in order to simplify our modelling and avoid defining states of belief, we introduce a primitive quaternary relationship *hasCapacityForAt* (A12), meaning that *the Agent a ascribed the Capacity c to the Endurant e during the Time Interval t*. Depending on the type of *ascribed ConceptOfCapacity*, *Agentives* (D23) are thus distinguished from *FunctionalObjects* (D25). To then distinguish between different categories of *FunctionalObjects*, we next define the ascription of a function by the members of a society (D26) and by a single agent (D27).

(D19) $\text{ConceptOfCapacity}(c) =_{\text{def}} \text{CPT}(c) \wedge \forall y,t(\text{classifiesAt}(c,y,t) \rightarrow \text{Capacity}(y))$

³⁵ As indicated in section 2.2 and when clarifying the notion of *capacity* as part of the definition of *competence*, the terms “knowledge” and “know-how” are used as synonyms to refer to these capacities. The fact that the concepts of “knowledge” and “know-how” are usually treated as states (states of knowledge) strengthens our decision to model capacities as states.

³⁶ This concept literally represents the entity’s capacity when able to help to perform a kind of action, which corresponds to the common definition of state of functioning. We therefore consider that the terms “state of functioning” and “functioning” refer synonymously to this concept.

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- (D20) $\text{Competence}(c) =_{\text{def}} \text{CPT}(c) \wedge \forall y,t(\text{classifiesAt}(c,y,t) \rightarrow \text{CapacityToPerformAction}(y))$
(T16) $\text{Competence}(c) \rightarrow \text{ConceptOfCapacity}(c)$
(F6) $\text{Competence}([\text{CapacityToPerformDiagnosing}])$
(D21) $\text{Function}(f) =_{\text{def}} \text{CPT}(f) \wedge \forall y,t(\text{classifiesAt}(f,y,t) \rightarrow \text{CapacityToEnableAction}(y))$
(T17) $\text{Function}(f) \rightarrow \text{ConceptOfCapacity}(f)$
(F7) $\text{Function}([\text{CapacityToEnablePaperKeeping}])$
(A12) $\text{hasCapacityForAt}(e,c,a,t) \rightarrow \text{ED}(e) \wedge \text{ConceptOfCapacity}(c) \wedge \text{Agent}(a) \wedge \text{T}(t)$
(D22) $\text{hasCompetenceForAt}(e,c,a,t) =_{\text{def}} \text{hasCapacityForAt}(e,c,a,t) \wedge \text{Competence}(c)$
(D23) $\text{Agentive}(x) =_{\text{def}} \exists c,a,t(\text{hasCompetenceForAt}(x,c,a,t))$
(D24) $\text{hasFunctionForAt}(e,f,a,t) =_{\text{def}} \text{hasCapacityForAt}(e,f,a,t) \wedge \text{Function}(f)$
(D25) $\text{FunctionalObject}(x) =_{\text{def}} \exists f,a,t(\text{hasFunctionForAt}(x,f,a,t))$
(D26) $\text{hasSocialFunction}(e,f) =_{\text{def}} \exists a,t(\text{hasFunctionForAt}(x,f,a,t) \wedge \text{SC}(a))$
(D27) $\text{hasPrivateFunction}(e,f) =_{\text{def}} \exists !a,t(\text{hasFunctionForAt}(x,f,a,t))$

4.3. Artefacts

To achieve the objective of formally defining the concepts of *artefact* and *technical artefact*, we perform a two-step process: we first distinguish between entities resulting from actions from those which are the outcome of mere happenings. This means that our strategy amounts to classifying entities according to the origin of their existence by relying on the intentional nature of the originating event³⁷. By adopting this same strategy, within the class of entities resulting from an action of production, we identify entities which are intentionally designed for some reason and which are successfully produced.

Thus, we begin by introducing entities whose existence results from simple happenings *HappeningConsequent* (D28) or from actions *ProducingConsequent* (D29) by singularizing the action to a *Production* (A13). The disjunction of the two classes of *Consequents* (T18) results from the disjunction of *Happenings* and *Actions*. Within the domain of *HappeningConsequents* we can situate *ExperimentalArtefacts* (A14) (without seeking to fully characterize them) as resulting from an unintended creation which parasitizes the results of an experiment.

- (D28) $\text{HappeningConsequent}(x) =_{\text{def}} \exists y,t(\text{HAPP}(y) \wedge \text{isConsequentOfAt}(x,y,t))$
(A13) $\text{Producing}(x) \rightarrow \text{ACT}(x)$
(D29) $\text{ProducingConsequent}(x) =_{\text{def}} \exists y,t(\text{Producing}(y) \wedge \text{isConsequentOfAt}(x,y,t))$
(T18) $\text{HappeningConsequent}(x) \rightarrow \neg \text{ProducingConsequent}(x)$
(A14) $\text{ExperimentalArtefact}(x) \rightarrow \text{HappeningConsequent}(x)$

We continue by specializing the *ProducingConsequents* class according to two semantic axes. Depending on the agent of the action of production (i.e. a human or a non-human animal) we can distinguish between *ArtificialObjects* (D30)(T19) and *AnimalConstructs* (D31)(T20-

³⁷ Another strategy would have been to introduce the Aristotelian opposition between *natural* objects and *artificial* objects (in the sense of objects produced by human). Even though this distinction makes it easy to define human artefacts (as specific artificial objects), it is not appropriate for accounting for animal constructs – some of which are artefacts (within the meaning of intentionally produced entities) but not artificial objects. One can see that this difficulty is related to the particular status granted by this opposition to human constructions that are "cut off" from nature, which is more difficult (or indeed impossible) to do with non-human animal constructions: a bird's nest or a termite mound are integral parts of nature!

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21) (according to the common definition (cf. (Gould, 2007)) within which one can find “artefacts” according to the sense we are going to use here. Next, depending on the existence or absence of a prior intention of production, *Artefacts* (D33)(T23) are distinguished from *Non-TargetedObjects* (D34)(T24). To define *Artefacts*, we first introduce *SuccessfullyProducing* (D32), which are necessarily deliberate actions - *DLBACT* (T22). We take advantage of this opportunity to define the *author* (in general) of an entity as the *Agent* of a production, the consequence of which is the entity (D35). The *intentional author* of an *Artefact* is defined as the *Agent* of the act of successful production from which the *Artefact* results (D36). Lastly, by accounting for the fact that the production of *Technical Artefacts* goes hand in hand with the ascription of a *Function*, we define *Technical Artefacts* as an *Artefact* that is necessarily a *FunctionalObject* (D37). Depending on whether this ascription is social or private, we then define *SocialArtefacts* (D38)(A15) and *PrivateArtefacts* (D33)(A16).

- (D30) $\text{ArtificialObject}(x) =_{\text{def}} \exists y,z,t' (\text{Producing}(y) \wedge \text{Human}(z) \wedge \text{isConsequentOfAt}(x,y,t) \wedge \text{isAgentOfAt}(z,y,t'))$
(T19) $\text{ArtificialObject}(x) \rightarrow \text{ProducingConsequent}(x)$
(D31) $\text{AnimalConstruct}(x) =_{\text{def}} \exists y,z,t' (\text{Producing}(y) \wedge \text{Animal}(z) \wedge \neg \text{Human}(z) \wedge \text{isConsequentOfAt}(x,y,t) \wedge \text{isAgentOfAt}(z,y,t'))$
(T20) $\text{AnimalConstruct}(x) \rightarrow \text{ProducingConsequent}(x)$
(T21) $\text{AnimalConstruct}(x) \rightarrow \neg \text{ArtificialObject}(x)$
(D32) $\text{SuccessfullyProducing}(x) =_{\text{def}} \text{Producing}(x) \wedge \text{SCFACT}(x)$
(T22) $\text{SuccessfullyProducing}(x) \rightarrow \text{DLBACT}(x)$
(D33) $\text{Artefact}(x) =_{\text{def}} \text{ED}(x) \wedge \exists y,t' (\text{SuccessfullyProducing}(y) \wedge \text{isResultOfAt}(x,y,t))$
(T23) $\text{Artefact}(x) \rightarrow \text{ProducingConsequent}(x)$
(D34) $\text{Non-TargetedObject}(x) =_{\text{def}} \text{ProducingConsequent}(x) \wedge \neg \exists y,t' (\text{SuccessfullyProducing}(y) \wedge \text{isResultOfAt}(x,y,t))$
(T24) $\text{Artefact}(x) \rightarrow \neg \text{Non-TargetedObject}(x)$
(D35) $\text{isAuthorOf}(x,y) =_{\text{def}} \exists z,t' (\text{isAgentOfAt}(x,z,t) \wedge \text{Producing}(z) \wedge \text{isConsequentOfAt}(y,z,t'))$
(D36) $\text{isIntentionalAuthorOf}(x,y) =_{\text{def}} \exists z,t' (\text{isAgentOfAt}(x,z,t) \wedge \text{SuccessfullyProducing}(z) \wedge \text{isResultOfAt}(y,z,t'))$
(T25) $\text{isIntentionalAuthorOf}(x,y) \rightarrow \text{isAuthorOf}(x,y)$
(D37) $\text{TechnicalArtefact}(x) =_{\text{def}} \text{Artefact}(x) \wedge \text{FunctionalObject}(x)$
(D38) $\text{SocialArtefact}(x) =_{\text{def}} \text{Artefact}(x) \wedge \exists f (\text{hasSocialFunction}(x,f))$
(A15) $\text{SocialArtefact} \rightarrow \text{TechnicalArtefact}(x)$
(D39) $\text{PrivateArtefact}(x) =_{\text{def}} \text{Artefact}(x) \wedge \exists f (\text{hasPrivateFunction}(x,f))$
(A16) $\text{PrivateArtefact} \rightarrow \text{TechnicalArtefact}(x)$

As a consequence of this modelling, two categories of *FunctionalObjects* are considered (see Fig. 4): entities which can be either natural or artificial (like *Paperweights* (D40)(T26)) on one hand and those which are *Artefacts* (*SocialArtefacts*, to be more precise) and *ArtificialObjects* (like *Staplers* (D41)(T27)) on the other.

- (D40) $\text{Paperweight}(x) =_{\text{def}} \text{hasFunction}(x, [\text{InstrumentOfPaperKeeping}])$
(T26) $\text{Paperweight}(x) \rightarrow \text{FunctionalObject}(x)$
(D42) $\text{Stapler}(x) =_{\text{def}} \text{Artefact}(x) \wedge \text{hasSocialFunction}(x, [\text{InstrumentOfPaperStapling}]) \wedge \text{ArtificialObject}(x)$
(T27) $\text{Stapler}(x) \rightarrow \text{SocialArtefact}(x)$

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As with participation roles, this way of defining *Artefacts* boils down to (i) specializing the concept *Endurant* with a new taxonomy and (ii) considering entities having both a kind and fulfilling one or more functions.

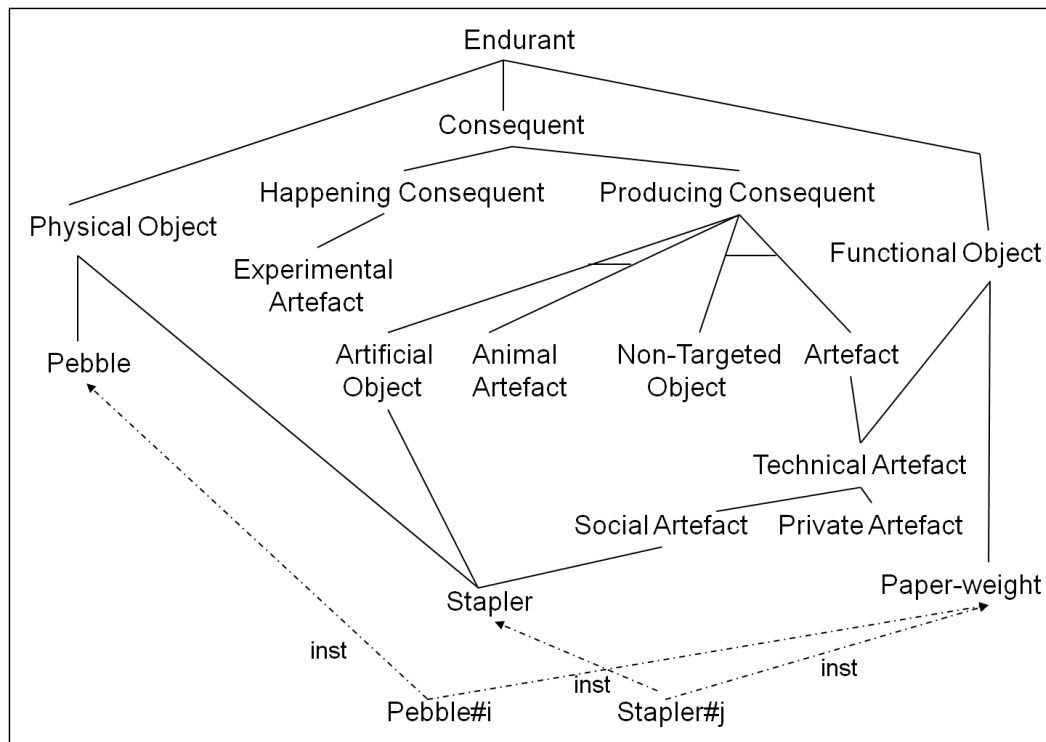


FIG. 4 – *Pebble#i* has for kind *Pebble* and fulfils the function of *Paperweight* ; *Stapler#j* has for kind *Stapler* and fulfils the function of *Paperweight*.

5. Comparisons

As noted in the Introduction, our work was prompted by the fact that existing ontologies do not include a substantial treatment of artefacts. The only notable exception is the recent proposition by (Borgo & Vieu, 2006, 2009) of a formal ontology of artefacts by extension of the DOLCE ontology. We start by comparing our two proposals, which leads us to identify a main difference in terms of the number of objects whose existence is recognized (5.1). In relation to this question of the number of existing objects and their nature, we then draw on current metaphysical theories which confer artefacts with a distinct ontological status (5.2).

5.1. Borgo and Vieu's ontology of artefacts

Borgo and Vieu (B&V) (2006, 2009) have recently laid the foundations of a formal ontology of physical artefacts by specializing (as we do) the DOLCE ontology. These authors suggest giving artefacts full ontological status by conferring them with the essential property of having been intentionally “created”. The act of creation in question corresponds to the “selection” of a physical object (e.g. a pebble) so that the latter becomes an artefact (e.g. a paperweight). The artefact created during selection of the physical object is *constituted* (as defined in DOLCE) by the latter (e.g. the paperweight artefact is *constituted* by the physical object that is a pebble).

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According to B&V, physical objects possess capacities/dispositions assimilated with values taken on by a particular *Quality* (as defined in DOLCE), the *Capacity*. The artefact inherits the *Qualities* of the physical object (notably its *Capacity*) and also possesses new, "selected" capacities assimilated to the values of a particular *Quality*, the *Attributed Capacity*.

Although the B&V ontology specializes the same foundational ontology as ours, one can note several significant differences between the two ontologies of artefacts.

Firstly, B&V consider three entities: the artefact, the (purely) physical object constituting the artefact and the quantity of material constituting the physical object, when we only consider the first and last entities. More exactly, we consider the artefact and the physical object to be a single entity, whereas B&V consider them to be two co-localized entities. We have thus adopted a more reductionist modelling strategy³⁸, in line with the approach already used to model participation roles (discussed in section 4.1). Likewise, when a quantity of matter is itself an artefact (e.g. a quantity of matter produced to serve as a contrast agent in radiology), we consider only a single entity, whereas B&V consider two entities.

Secondly, it should be noted that B&V use the term "artefact" where we use "functional object". According to B&V, the act of creating the artefact ("selection") corresponds to a mental act of ascribing a function to a physical object. In fact, since the property of having been physically and intentionally produced is not necessary for a functional object, B&V's analysis does not consider the intentional creation of the physical object. In our ontology, this creation corresponds to the ascription of a property to an existing object. In so doing, we believe that they are distancing themselves from the common definition of an artefact. Moreover, it appears to us to be counter-intuitive to consider that a mental act gives birth to a new physical object (even though, according to B&V, the artefact is not truly "new" because its physical properties are inherited from the object that constitutes it). In contrast, our notion of artefact is dependent on it having been physically and intentionally produced. Moreover, in line with (Bloom, 1996) and (Thomasson, 2007), we take into account a number of constraints concerning the conceptual content of the intention in question (these constraints are however not part of our current axiomatization, for the latter doesn't include a theory of intentions).

Thirdly, a difference lies in the way in which one accounts for the notions of *capacity* and *function*. As a starting point, B&V adopt the notion of capacity considered by Cummins in his functional analysis (B&V, 2006, p. 7):

Now, what are capacities? We take this notion from Cummin's work on functions [Cummins, 1975]. His behavior-based approach avoids both etiological account of function often given in philosophy of biology and the intentional approach adequate only for artefacts. We do take into account the intention of the agent in the creation event, but characterize, as Cummins does, the purpose, use or function of the artifact in agent-independent ways.

According to B&V, physical objects inherently possess capacities or dispositions that exist independently of any agents' intention. To account for this, they extended DOLCE by introducing a particular *Quality* (the *Capacity*) whose value is equivalent to all the behaviours/dispositions that an object is capable of expressing at a given time (e.g. my ballpoint

³⁸ Vieu, Borgo & Masolo (2008) provide an in-depth discussion *reductionist vs multiplicative* modelling strategies in relation to artefacts and roles, along with the degree of use, maturity and the respective advantages and disadvantages.

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pen currently has the *Capacity* to write finely in black when placed on a paper). When ascribing a function to a physical object (and in line with Cummins' system analysis), a "functional capacity" is identified by the role that this capacity plays vis-à-vis the capacity of a system encompassing the agent-user and the artefact. To account for this functional capacity, the *Artefact* thus produced (and which is constituted by the physical object) also possesses an *Attributed Capacity* whose timeless values depend on the agent's intention.

Fundamentally, and as far as we can judge from the current state of ontology formalisation (because the attributed capacities' dependencies on the agents have not been formalized by B&V), the considered notions are rather similar. The respective distinctions between *capacity* and *function* (in our approach) and between *capacity* and *attributed capacity* (accordingly to B&V) are comparable. However, they differ in that a capacity is assimilated by B&V to a disposition (in general), whereas by rooting our notion of function in a theory of action, we constrain the functional capacity to be a capacity of the artefact that has the role of an instrument in an action. In terms of form (i.e. formalization of the notions), we note a difference in the respective approaches; B&V introduce *Qualities*, whereas we introduce *States (of capacity)*. However, since the *Qualities* of objects whose values vary over time can correspond to *States* of these same objects (e.g. my ballpoint pen is currently in a state in which it can write finely in black), this difference appears to us to be something of a technicality.

Thus, in summary, B&V's ontology currently focuses on functional objects by adopting a broad notion of functional capacity and by setting aside the property of intentional production of the artefact (judged to be non-essential). By doing so, B&V's inventory of existing objects differs from ours because they further consider that the physical object constitutes the artefact.

5.2. A detour via metaphysics

The above-noted difference between the two ontologies concerning the number of existing objects prompted us to look at how metaphysical theories deal with this issue. Before examining these positions, one should note (as does (Elder, 2007, p. 33)) that most contemporary metaphysicians exclude artefacts from their ontological inventory. Only a small proportion of metaphysicians have attributed full ontological status to artefacts (as we have already seen with the notion of *copied object* according to (Elder, 1995)).

Baker's ontology of artefacts focuses on technical artefacts which are specially designed to achieve a practical objective (2004, 2008). According to Baker, artefacts are typically *constituted* by aggregates of entities: a hammer is therefore *constituted* by an aggregate made of an elongated piece of wood and a piece of metal into which the piece of wood can be inserted. The hammer object exists, in addition of the aggregate of the two pieces, as a specific assembly of this aggregate. Grandy (2007) has a different view and notes in this respect that many artefacts are expected to be disassembled and reassembled regularly – for the purposes of cleaning, maintenance, transport, etc - and argues in favour of the persistence of the artefact object throughout these various operations. According to (Grandy, 2007), artefact creation thus corresponds to the initial assembly of the parts to form a whole with a specific, expected function. Next, during the artefact's lifetime, it may very well exist as a distributed physical object whose components are spatially disconnected. Grandy considers that only the artefact

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and its parts exist: there is no need to attest to the existence of an aggregate object. The inventory of objects drawn up by Elder (2007, 2008) is otherwise different because he denies the existence of any entity which is co-localised with the artefact (notably a quantity of matter constituting the artefact) and prefers *substances* (Elder, 2008)).

As we have seen, by starting from a common position that acknowledges the separate existence of an artefact, the various inventories of existing objects are very different. Although we are unable here to detail the arguments justifying the adopted positions, we can summarize our ontology's position in a few words. In line with Grandy and Elder but in contrast to Baker (and thus B&V), we do not consider any aggregate or physical object *constituting* the artefact. In our view, the artefact alone exists and entertains a whole/parts relationship with its components. Thus, the hammer's shaft and head are components or functional part of the hammer and, in turn, are also artefacts – they have been intentionally designed to fulfil the respective functions of a shaft and a head. We further consider (in line with DOLCE) that the three artefacts are each *constituted* by certain quantity of matter.

However, one should note that regardless of the considered relationship (parthood or constitution), none conceptually accounts for the link between the hammer's structure and its function; this remains a challenging problem for ontologies of artefacts (Houkes & Meijers, 2006). In particular, none of these relations can explain the fact that the handle's shape enables it to be held easily by a human and manipulated so that force can be applied to an object via the tool's head. This situation highlights the progress that remains to be made in extending existing ontologies of artefacts.

6. Conclusion

In the present article, we first proposed a novel conceptual framework by drawing together a set of basic notions which we believe are required to account for the general nature of artefacts. This framework is rooted in the common philosophical notion of an artefact and refines it by relying on recent philosophical and psychological theories on this theme.

According to our framework, an artefact is defined as a particular possessing an internal essence (be it physical or social) and the property of having been intentionally and successfully “produced”. In the current version of our ontology, the term “produced” is a catch-all for a set of actions ranging from creation of a new object (its design and making) to the transformation of an existing object. Within the domain of artefacts, technical artefacts have functions - proper or accidental - which gives them (at least) a triple nature. Our chosen notion of function refers to an artefact's capacity to play the role of instrument in actions of a certain kind. The whole conceptual framework is thus firmly anchored in a theory of actions.

Furthermore, we have linked this conceptual framework to the foundational DOLCE ontology by specializing the latter's concepts and relations. The formalization makes use of individuals reifying concepts. We therefore come out of the framework of the first order logic and the expressive and reasoning skills of standard languages used for the Semantic Web (such as OWL-DL). A version of the ontology specified in OntoSpec (a language based on the semi-

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informal method of the same name (Kassel, 2005)) is available³⁹. A simplified version specified in OWL-Lite is currently being used in the NeuroLOG project.

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7. References

- Baker, L.R. (2004). The ontology of artifacts. *Philosophical Explorations*, 7(2), 99-111.
- Baker, L.R. (2008). The shrinking difference between artifacts and natural objects. *APA Newsletters*, 7(2), 2-5.
- Bloom, P. (1996). Intention, history, and artifacts concepts, *Cognition*, 60, 1-29.
- Bloom, P. (2007). Water as an Artifact Kind. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 150-156). Oxford University Press.
- Borgo, S., & Vieu, L. (2006). From Artefacts to Products. In *Proceedings of the second Workshop: Formal Ontologies meet Industry (FOMI 2006)*, Trento (Italy).
- Borgo, S., & Vieu, L. (2009). Artifacts in formal ontology. In A. Meijers (Ed.), *Handbook of the Philosophy of the Technical Sciences* (Vol. 2: Artifact ontology and artefact epistemology). Elsevier.
- Burek, P. (2007). Ontology of functions: A domain-independent framework for modelling functions. *PhD thesis*, Institute of Informatics, University of Leipzig, Germany.
- Chandrasekaran, B., & Josephson, J.R. (2000). Function in device representation. *Engineering with Computers*, 16(3/4), 162-177.
- Cummins, R. (1975). Functional analysis. *The Journal of Philosophy*, 72(20), 741-765.
- Elder, C.L. (1995). A different kind of natural kind. *Australian Journal of Philosophy*, 73(4), 516-531.
- Elder, C.L. (2007). On the Place of Artifacts in Ontology. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 33-51). Oxford University Press.
- Elder, C.L. (2008). Against Universal Mereological Composition. *Dialectica*, 62, 433-54.
- Fortier, J.-Y., & Kassel, G. (2004). Managing Knowledge at the Information Level: an Ontological Approach. In *Proceedings of the ECAI'2004 Workshop on Knowledge Management and Organizational Memories* (pp. 39-45), Valencia (Spain),
- Franssen, M. (2006). The normativity of artefacts. *Studies in History and Philosophy of Science*, 37, 42-57.
- Gangemi, A., & Borgo, S. (Eds.). (2004). Proceedings of the EKAW'04 Workshop on Core Ontologies in Ontology Engineering, Northamptonshire (UK), Retrieved from <http://ceur-ws.org> (Vol-118).
- Gould, J.L. (2007). Animal Artifacts. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 249-266). Oxford University Press.
- Grandy, R.E. (2007). Artifacts: Parts and principles. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 18-32). Oxford University Press.
- Griffiths, P.E. (1993). Functional Analysis and Proper Functions. *British Journal for the Philosophy of Science*, 44, 409-422.
- Hilpinen, R. (1992). On Artifacts and Works of Art. *Theoria*, 58, 58-82.

³⁹ On the *Connaissances* group's web site (<http://www.laria.u-picardie.fr/IC/site/?lang=en>) under the heading "ontological resources for the OntoSpec methodology".

A formal ontology of artefacts

- Hilpinen, R. (2004). Artifact. *Stanford Encyclopedia of Philosophy*, Retrieved from <http://plato.stanford.edu/entries/artifact/>.
- Hornsby, J. (2004). Agency and Actions. In H. Steward & J. Hyman (Eds.), *Agency and action* (pp. 1-23), Cambridge University Press.
- Houkes, W., & Meijers, A. (2006). The ontology of artefacts: the hard problem. *Studies in History and Philosophy of Science*, 37, 118-131.
- Houkes, W., & Vermaas, P.E. (2004). Actions versus functions: A plea for an alternative metaphysics of artifacts. *The Monist*, 87(1), 52-71.
- Kassel, G. (2005). Integration of the DOLCE top-level ontology into the OntoSpec methodology. LaRIA Research Report 2005-08, 2005. Retrieved from <http://hal.ccsd.cnrs.fr/ccsd-00012203>.
- Kroes, P. (2001). Technical Functions as Dispositions: a Critical Assessment. *Techné*, 5(3), 1-16.
- Kroes, P. (2003). Screwdriver Philosophy; Searle's analysis of technical functions. *Techné*, 6(3), 22-35.
- Kroes, P., & Meijers, A. (2006). The dual nature of technical artefacts. *Studies in History and Philosophy of Science*, 37, 1-4.
- Lando, P., Lapujade, A., Kassel, G., & Fürst, F. (2008). An ontological investigation in the field of computer programs. In J. Filipe *et al.* (Eds.): ICSOFT/ENASE 2007, *Software and Data Technologies* (vol. 22, pp. 371-383), Communications in Computer and Information Science, Springer-Verlag Berlin Heidelberg.
- Levinson, J. (1993). Extending art historically. *Journal of Aesthetics and Art Criticism*, 51, 411-423.
- Levinson, J. (2007). Artworks as artifacts. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 74-82). Oxford University Press.
- Margolis, E., & Laurence, S. (Eds.) (2007). *Creations of the Mind: Theories of Artifacts and Their Representation*, Oxford University Press.
- Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A., & Schneider, L. (2003). The WonderWeb Library of Foundational Ontologies and the DOLCE ontology. *WonderWeb Deliverable D18, Final Report*, vr. 1.0.
- Masolo, C., Guizzardi, G., Vieu, L., Bottazi, E., & Ferrario, R. (2005). Relational Roles and Qua-Individuals. In *Proceedings of the AIII Fall Symposium on Roles, an interdisciplinary perspective*, Hyatt Crystal City, Arlington, Virginia.
- Masolo, C., Vieu, L., Bottazzi, E., Catenacci, C., Ferrario, R., Gangemi, A., & Guarino, N. (2004). Social roles and their descriptions. In D. Dubois, C. Welty & M.-A. Williams (Eds.), *Proceedings of the Ninth International Conference on the Principles of Knowledge Representation and Reasoning* (pp. 267-277), Whistler, BC, Canada.
- Millikan, R.G. (1984). *Language, Thought, and Other Biological Categories*, Cambridge, MA: MIT Press.
- Mumford, S. (1998). *Dispositions*. Oxford: Oxford University Press.
- Pacherie, E. (2000). The content of intentions. *Mind and Language*, 15, 400-432.
- Pacherie, E. (2008). The phenomenology of action: A conceptual framework. *Cognition*, 107, 179-217.
- Searle, J.R. (1983). *Intentionality*. Cambridge University Press.
- Searle, J.R. (1995). *The Construction of Social Reality*. New York: Free Press.
- Sowa, J.F. (2000). *Knowledge Representation: Logical, philosophical, and computational foundations*, Brooks/Cole.
- Steimann, F. (2000). On the representation of roles in object-oriented and conceptual modelling. *Data and Knowledge Engineering*, 35, 83-106.
- Temal, L., Dojat, M., Kassel, G., & Gibaud, B. (2008). Towards an ontology for sharing medical images and regions of interest. *Journal of Biomedical Informatics*, 41, 766-778.
- Temal, L., Lando, P., Gibaud, B., Dojat, M., Kassel, G., & Lapujade, A. (2006). OntoNeuroBase: a multi-layered application ontology in neuroimaging. In *Proceedings of the 2nd Workshop Formal Ontologies Meet Industry: FOMI 2006* (pp. 3-15), Trento (Italy).
- Thomasson, A.L. (2003). Realism and human kinds. *Philosophy and Phenomenological Research*, LXVII(3), 580-609.
- Thomasson, A.L. (2007). Artifacts and human concepts. In E. Margolis & S. Laurence (Eds.), *Creations of the Mind: Theories of Artifacts and Their Representation* (pp. 52-73). Oxford University Press.
- Vermaas, P.E., & Houkes, W. (2006). Technical functions: a drawbridge between the intentional and structural natures of technical artefacts. *Studies in History and Philosophy of Science*, 37, 5-18.

A formal ontology of artefacts

Vieu, L., Borgo, S., & Masolo, C. (2008). Artefacts and Roles: Modelling Strategies in a Multiplicative Ontology. In Proceedings of the 5th International Conference on Formal Ontology in Information Systems (FOIS 2008), Saarbrücken (Germany).

Weir, A., Chappel, J., & Kacelnik, A. (2002). Shaping of hooks in New Caledonian crows. *Science*, 297, 981.