From Physical Artefacts to Products

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Abstract. The central activity of industries is to produce and sell products. Although we all share a common understanding of what a product is, there is no formal definition of this concept which is satisfactory from an ontological viewpoint and could serve as a departure point for enterprise integration. To fill this gap, we look at the notion of product from the perspective of foundational ontology: we concentrate on the industrial meaning with particular attention to the manufacturing domain, that is, we consider products as physical artefacts that are the result of intentional activities.

The paper provides a first formalization of this notion relying on the concept of artefact as developed within the framework of the DOLCE ontology. In this framework, an artefact is created when an entity (the constituent of the artefact) is selected by an agent for some purpose or intentional use; this act of the agent (the creator) brings out the artefact, which is necessarily co-localized with the constituent and is characterized by a new type of quality dubbed *selected capacity*. Thus, our approach to characterize the concept of product (as well as some related notions) consists in searching for a specialization of the ontological notion of artefact which is satisfactory for the industry domain.

Introduction

This paper arises from the increasing interest in the knowledge representation area toward the description of general notions and from the evident need of better formalization of the general concepts central to the economic and the industrial domains. Both researchers and industrial practitioners, for different reasons and following different goals, have become aware of the limits of *ad hoc* modeling (like in the case of expert systems) and have recognized the crucial role of semantics in conceptual modeling. The need for a well-founded and philosophically justified characterization of concepts, terms, and relations gave rise to the search for new approaches among which particular success has the research area now identified as *(applied) ontology*.

Generally speaking, the term ontology has several meanings. This is not the place to discuss this notion in details; here it should suffice to keep in mind the clear distinction between the research domain of applied ontology (a knowledge representation area concerned with modeling methodologies and techniques in application domains like industry, medicine or civil engineering) from the metaphysical discipline that goes back to (at least) Aristotle and that has influenced most of western philosophy. Nonetheless, applied ontology has strong connections with the philosophical approach because, although the overall goal is quite different, it relies on general principles and philosophical considerations to justify the adopted knowledge structures.

In this paper we are interested in ontological systems, hereafter called *ontologies*, that satisfy two major requirements: they must be *formal* and *foundational*. These terms need

some clarification. Roughly, an ontology is formal if it is expressed in a logic language endowed with clear semantics for instance in model-theoretic terms (as in first-order predicate logic [1]). This choice is of course important for application concerns but, for our goals, it is central because it puts at the center semantic transparency, a key element for interoperability and maintenance. By foundational ontologies we mean those knowledge systems that focus on very general and basic concepts (like object, event, state, quality) and relations (like constituency, participation, dependence, parthood).

In other words, formal ontology is the study of formal (logical) systems which are: *general*, they include the most usable and widely applicable concepts; *reliable*, they are logical theories with clear semantics, a rich axiomatization and careful analysis of formal consequences (theorems); and *well organized*, they are based on philosophical principles whose choice is explicitly motivated and independent from particular domains. In this paper, we will use formal ontology in this general sense.

Among the ontological systems with foundational interest in the literature, just a few present (more or less satisfactorily) these properties: BFO (`http://ontology.buffalo.edu/bfo/BFO.htm`), DOLCE (`http://www.loa-cnr.it/DOLCE.html`), and GFO (`http://www.onto-med.de/en`), but these provide no notion of artefact or product. Other known systems, like OPENCYC (`http://www.opencyc.org`) and SUMO (`http://ontology.teknowledge.com`), include an explicit characterization of the concept of product or of artefact but they are hardly useful to our perspective: the first has no clear stand on foundational issues and the latter introduces these notions very superficially.

Overall, our goal is to present a preliminary formalization of the notion of *product* which, among other things, does justice to properties usually ascribed to them in the manufacturing domain while remaining independent from specific applications. In doing this, we will work within the framework of a specific foundational ontology (DOLCE) and apply a characterization of the notion of artefact that we have provided elsewhere [2]. In turn, our work can be seen as a possible extension of this system and also as a general analysis of the category of products for implementation purposes.

1 Toward a Notion of Product

Roughly, what we want to ontologically characterize are the material entities that in economical terms are labeled *products* or *goods*. The restriction to material entities is important, it shows that our analysis will leave out some kinds of products, in particular services. This choice is crucial because of the deep ontological difference between tangible and intangible entities.

Traditional dictionaries are not very detailed on the entry "product". For instance, the Oxford Dictionary (`http://www.oup.com/`) says that a product is "a thing that is grown or produced, usually for sale" and (in a related sense) "a thing produced during a natural, chemical or industrial process." The first sense matches our intuition with two proviso: we do not use the notion of sale (exchange of money) preferring the larger perspective of just "exchange" which is less restrictive (we are not interested in the commercial perspective to which a product is often related and try to be as general as possible on this aspect); secondly, we exclude biological entities so we do not consider products as the result of a "growing" activity. The second sense of the Oxford Dictionary relies primarily on the meaning of the verb "produce" which, according to this dictionary, is specialized by: to make (naturally or else), to create with skill, to cause result or effect, to prepare.

For a different kind of source, we look at Wikipedia (`http://en.wikipedia.org`) where it is claimed that "in marketing, a product is anything that can be offered to a market

that might satisfy a want or need" and adds "it is the complete bundle of benefits or satisfactions that buyers perceive they will obtain if they purchase the product. It is the sum of all physical, psychological, symbolic, and service attributes." From this characterization it seems that the same product token is a different entity for different agents since the definition involves the perceptions, desires and needs of the (potential) buyer. We will not follow this subjective approach here.

WordNet (`http://wordnet.princeton.edu`) reports two senses that are relevant to us: "commodities offered for sale" and "an artifact that has been created by someone or some process." Regarding the first, we have already said that the possible exchange of money (selling) is not relevant for a product to be such, what is important is the exchange purpose. The latter sense presents products as a kind of artefacts which has been created by an agent or a process. The verb "to create" has several meanings in WordNet (to make, to cause, to become, to bring into existence, to manufacture) and our formal treatment will help in understanding how this expression should be understood.

Finally, we look at another source more ontologically oriented: the Enterprise Ontology (`http://www.aiai.ed.ac.uk/project/enterprise`). Here product stands for "the ROLE of the good, service, or quantity of money that is: offered FOR SALE by the VENDOR –or– agreed to be exchanged [...]".[1] A note follows this text: "There is possible confusion with the use of the term 'product' when referring to something produced/manufactured but which is not sold (i.e. an intermediate product internal to a manufacturing process). It may become necessary to introduce two terms for this, such as 'Market Product' and 'Manufactured Product'." Clearly, here an entity is a product only if there is a vendor — i.e., some agent who intends to exchange it.

This concludes our brief overview of the different meanings (and peculiarities) that characterize the term "product" in different domain sources. From this overview, we retain the following features: products are artefacts meant to be exchanged, and are often, although not necessarily, the result of a processing activity. In what follows, we concentrate on our formal ontology approach to arrive at a definition of product which is ontologically coherent and motivated within the chosen ontology framework.

2 The ontological framework

As said already, we are concerned with the representation of products as special types of artefacts. The study of artefacts has attracted the attention of researchers from different domains, from engineering to philosophy, from psychology to linguistics. Notwithstanding this wide interest, most foundational ontologies do not include a category of artefacts. This is probably due to contingent aspects (most formal ontologies have been proposed only recently and are still under development). However, it should be noticed that the lack of widely accepted characterizations of this notion in the literature makes it hard for the ontologist to provide a formalization.

This is not to say that there is no other definition of artefacts in formal ontology. However, with the exception of the two ontologies mentioned above (OPENCYC and SUMO), as far as we know the other ontological definitions of artefact are limited by constraints specific to some application domain.

Our next step is to formalize a notion within the DOLCE ontology. We begin by quickly introducing this ontology.

[1] Terms in uppercase are those formally defined in the ontology.

2.1 A quick introduction to DOLCE

The Descriptive Ontology for Linguistic and Cognitive Engineering, DOLCE [3], concentrates on *particulars*, that is, roughly speaking, objects (both physical and abstract), events, and qualities. It does not attempt to provide a taxonomy of properties and relations and these are included in the system only if deemed crucial in characterizing particulars. DOLCE adopts the distinction between objects (like scissors and refrigerators) and events (like cutting and cooling); it includes a useful differentiation among individual qualities, quality types, quality spaces, and quality values; and it relies on a very expressive language, namely first-order modal logic. These features are sufficient to model many physical objects and seem promising for our study of artefacts.

DOLCE, which is influenced by natural language and cognitive studies, adopts a *multiplicative approach*, that is, it assumes that different entities can be co-localized in the same space-time. For example, a drilling machine and the amount of matter that consitutes it are captured in DOLCE as two distinct entities (as opposed to different aspects of the same entity). The reason lies on the different set of properties that these entities enjoy: the drilling machine ceases to exist if a radical change of shape occurs (e.g., when it has crashed and cannot be repaired) while the amount of matter is not affected (the change of spatial properties, like shape or connectedness, is irrelevant for the identity of an amount of matter). For a different example (discussed at length in the philosophical literature), consider a statue made of clay. DOLCE models the statue and the clay as different entities which share the same spatial (and possibly temporal) location. This allows us to capture the strong intuition that a scratched statue has changed (since scratched) and yet it is the same statue it was before. In DOLCE this is possible since the statue itself might not be affected by (minor) scratches, but the clay (which is the constituent entity of the statue) does because amounts of matter cannot loose some parts.

The category of *endurant* collects entities like a "car" or material like "some plastic", while events like "making a hole" and "moving a steel block" are in the category of *perdurant*. The term 'object' itself is used in the ontology to capture a notion of unity or wholeness as suggested by the partition of the class "physical endurant" into the classes "amount of matter" (whose elements are (an amount of) gold, air etc.); "feature" (a hole, a boundary); and "physical objects" (a hammer, a human body). See Figure 1. Some categories are informally described in section 2.2. Note that the terminology adopted departs sometimes from the usage in the knowledge representation area since it has been affected in part by philosophical literature.

Both endurants and perdurants are associated with a bunch of *qualities*. These entities and their evaluation are crucial in DOLCE and the distinction between *individual qualities*, *qualia*, and *quality spaces* has been set with the aim of capturing common sense in a coherent and consistent way.

Individual qualities like "the color of my pen" *inhere in* specific individuals, that is, "the color of my pen" is different from "the color of your pen" no matter how similar the two endurants are. These qualities can change through time since "the color of my pen" can match color *red* today and color *rose* tomorrow. Differently from individual qualities, qualia are not entity dependent. An example of a quale is a specific color, e.g., red. Intuitively, these entities are obtained by abstracting individual qualities from time and from their hosts. If the color of my pen and the color of your pen match the same shade of red, then they have the *same* (color) quale. In this sense, qualia represent perfect and "objective" similarity between (aspects of) objects. Quality spaces correspond to different ways of organizing qualia. They are motivated by "subjective" (context dependent, qualitative, etc.) similarity between (aspects

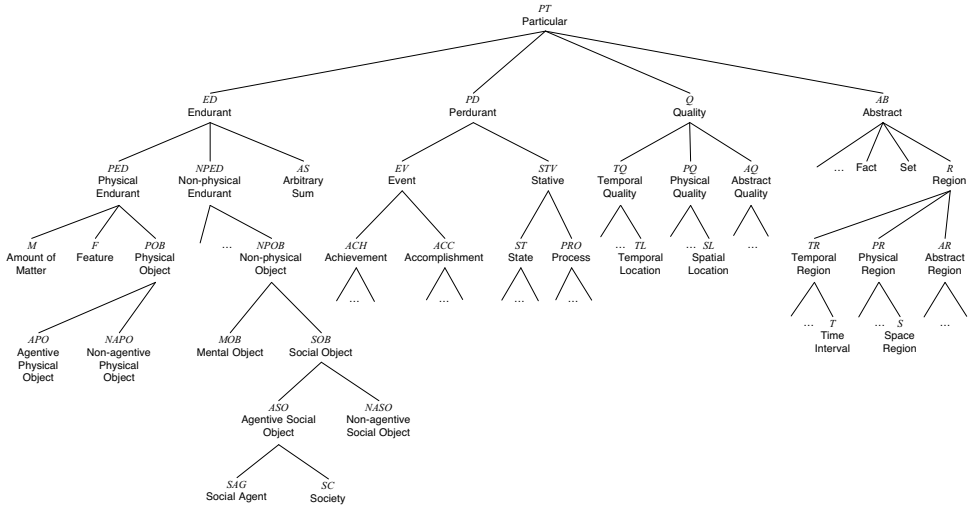

Figure 1: Taxonomy of DOLCE basic categories (from [3]).

of) objects. By means of spaces, a structure can be imposed on qualia (for example, a geometry, a metric, or just a topology) and this makes it possible to differentiate several quantitative and qualitative degrees of similarity.

The actual list of qualities of an entity depends on the specific entity and does not concerns us here. To provide some examples: shape and weight are usually taken to be qualities of physical endurants while duration and direction are qualities of perdurants. However, these examples are not enforced by the ontology itself which is indeed neutral on the topic.

2.2 Some Categories and Relations in DOLCE

Several categories of Figure 1 will be used to characterize artefacts and products. Here we skim through some of them (including some relations) as an informal introduction to DOLCE's terminology. In parenthesis we report their formal names as used in the next sections. The interested reader can find in [3] the formal system and a more detailed discussion.

We begin with the general notion of "endurant" (ED). This category collects those entities that are *wholly* present at any time they are present, for instance a car or an amount of water (contrast these with a football game). Physical endurants (PED) are the endurants located in space-time, e.g., a hammer as opposed to a poem. This latter entity is classified among the non-physical endurant ($NPED$). The term "object" is used to capture a notion of wholeness. Thus we distinguish amounts of matter (M), for instance some gold, from physical objects (POB), e.g., a car. Regarding agency, non-agentive physical objects ($NAPO$) are physical objects to which one cannot ascribe intentions, beliefs or desires (like a product or a ticket). A person is an agentive physical object (APO), so distinguished from a company which is a social agent (SAG). Agents can also be collectives, like a group of people. Among social entities, social systems have their own category called "society" (SC).

Perdurants (PD) are, informally, entities that are only partially present at any time they are present. In this category we find football games as well as device productions. These entities have temporal parts (like the first half of the game) as well as spatial parts (the event restricted to a half of the football field during the game). Note that endurants are not parts of perdurants, rather they *participate* in them (the relation is called PC).

A different type of entities find place in the individual quality category (Q). As discussed

above, individual qualities can be seen as instantiations of basic properties of endurants or perdurants (shape, weight, duration, electric charge; usually qualities can be perceived or measured). The term 'individual' is used to mark the essential relationship between an entity and its own qualities. Every endurant (or perdurant) comes with its physical (or temporal) qualities. Recall that qualities are particulars in DOLCE so they should not be confused with properties (universals).

Finally, the interdependence between entities is captured through relationships. For instance, expression $qt(q, x)$ reads "q is an individual quality of x". As we know, qualities are associated to quality spaces and the position an individual quality has in a space is called a quale. We write $ql(r, q, t)$ to mean "r is the quale of the endurant's quality q during time t" while $ql_T(t, x)$ stands for "t is the quale of the temporal quality of x". (Note the temporal parameter in $ql(r, q, t)$. If we want to evaluate "John is 5 feet tall", we have to make explicit when this sentence is stated since John may change his height over time. Relation $ql_T(t, x)$ captures duration and it's used to formalize, e.g., "the game lasts one hour".) Each set of qualia provides, informally, equivalence classes over a type of individual qualities. For instance, the same weight quale is associated to all the individual qualities (relative to weight) that are indistinguishable. Two entities that have their individual weight qualities associated to the same quale (in the space of weights) are *ontologically indistinguishable* with respect to the weight property, i.e., the property corresponding to that type of individual qualities. Among the remaining relations, we will make use of (general) *parthood* as in "x is part of y", written $P(x, y)$. The relation *being present* states when an entity exists in the world, thus one writes $PRE(x, t)$ to mean that "x is present in the world at time t". We already mentioned *participation*, $PC(x, y, t)$ stands for "endurant x participates in perdurant y during time t". *Constant constitution* captures a strong form of dependence. We write $SK(x, y)$ to mean: "x is constantly (specifically) constituted by y". (Note that this relationship is stronger than the one holding in the above example of the statue and the clay. Indeed using SK the statue would be strictly tied to the very same amount of clay it was made of when it was created.) Finally, we will use the relationship *classification*, written CF, which is formalized in [4]. In this case one writes $CF(x, y, t)$ to state "at time t, x satisfies all the constraints stated in the description defining concept y".

3 Our Notion of Artefact

In order to reach an ontological definition of product, we need to clarify what an artefact is. This task must be understood within the framework provided by DOLCE. What we provide is not a general definition of artefact *tout court*. The term "artefact" in the literature has been associated to a variety of meanings depending on the research domain and on the specific viewpoint of the authors. It might be useless to look for a general definition that captures all these meanings. We focus instead on a quite large class of entities that we commonly label as artefacts without aiming at full generality. First of all, artefacts must be physical endurants, that is, we leave out things like laws, pieces of music and social institutions as well as acts of judgement, performances and wars. These other entities may be considered artefacts as well. Nonetheless, they are not elements of the category we are interested in for this paper. Among physical endurants, we deal with both amounts of matter (like glass and plastic) and physical objects (like a pen, a table, a paper-weight), but do not include features, i.e., dependent entities like the corner of a table or a bump on a road. Furthermore, we leave out biological entities, thus saying nothing of intended babies, cultivated plants and bred animals, and even genetically modified organisms. Within the DOLCE classification, the artefacts we are after

are in the category *amount of matter* or in the category *non-agentive physical objects*[2]. The latter category is quite big and presents a variety of interesting subclasses but, fortunately, we do not need to provide more specialized definitions as it would be necessary to distinguish, say, "devices" from "works of art". Lastly, we insist that we deal primarily with specific tokens and only in a second step with artefact types. The focus on tokens is natural in the DOLCE framework since, as pointed out earlier, this ontology is about particulars.

We adopt the view that artefacts have an ontological status, are characterized by capacities, and are essentially the result of an intentional act [5]. The basic notion of *bare artefact* (generated by the private intention of the creator) is not immediately related to the notion of product since the latter is a specialization of the category of *social artefacts* (or proper artefacts, artefacts that have a social dimension). However, since the definition of bare artefacts is central to understand our intuition of the general notion of artefact and is needed to define social artefacts (the category in which we classify products), below we introduce and constrain the category of bare artefacts to some degree.

In this enterprise we put ourselves within the framework of an ontology of *social reality*. Social reality [6, 7] refers to the part of reality that covers groups of agents and the social relationships therein, actions that are either collective or directed toward a social group, as well as the variety of resulting "social entities", like a contract or a company. Such entities are often dependent on mental attitudes like beliefs or intentions, either individual or collective. Formal ontology dedicated to social reality takes into account all such entities in its domain and attempts at characterizing them by modeling general properties and facts. Ontology of social reality and ontology of mind need to be distinguished with epistemological studies that would account for the ways an agent builds his or her beliefs about reality, for instance to categorize entities. Formal ontology takes for granted an objective[3] point of view on reality, that is, external of any particular agent. This stand justifies the introduction of notions like "intentional selection" or "social artefact", which are important in our approach (a product is an entity that can be socially recognized as such, a property that sits at the core of the legal systems for economy) and put us in a clear position with respect to the philosophical debates that inspired us. Acknowledging the fact that products are (somehow indirectly) grounded on mental attitudes such as the intentions and goals of their creators does not mean that we focus on the epistemological question on how products can be recognized and classified by an agent, as it will become clear in the next sections.

3.1 Bare artefacts

Consider the agent's intentions underlying the creation of an artefact. There are two aspects: the intention to get an entity for some purpose or use, and the intention to physically modify or process some preexisting entity to "produce" the artefact. We focus here on the first one only because we take the second aspect, i.e., being an *artificial* entity, not to be necessary for artefacts: a pebble can make a paper-weight when taken to an office, and a fallen trunk a bench (although one could claim that moving the pebble to your desk counts as some kind of modification, a trunk can be a bench on the very spot where it fell for natural reasons). Since I can start a business of selling paper-weights made of pebbles, it is not necessary for a product to be a processed entity, although important sub-categories like that of manufactured

[2] In particular, here a robot is an artefact in as much as it is not considered as an agent. This choice fits our interest in defining products.

[3] Some ontologies adopt a *cognitive* approach in the sense that the categories of entities and the relations used to represent reality are chosen for their compatibility with those arguably used by humans in their language and/or their conceptions. The cognitive approach does not mean that the facts to be represented are subjective.

products require processing of course. In addition, *residues*, such as sawdust, are intentionally processed but not intentionally selected for any use. Artefacts are, *in nuce*, entities created for some purpose, some use, where "created" refers to a mental event, not a necessarily a physical one.

We suppose that the paper-weight *cannot* be identified with the pebble.[4] The paper-weight is the result of some agent intentionally *selecting* the pebble and attributing to it some *capacities* for which it counts as a paper-weight (e.g., the capacity to stand firm and hold paper under without damaging it). In other words, the paper-weight is the pebble together with some *selected capacities*. Importantly, there can be a mismatch between the actual capacities of the artefact (the capacities of the selected entity) and its 'selected capacities' (those selected by the creator) as it happens for flawed or malfunctioning artefacts. Note that, in general, the paper-weight starts to exist well after the pebble does; the two objects, although co-localized, may have different lifetimes and are therefore different. The paper-weight is dependent on the pebble, as this specific paper-weight cannot exist without this specific pebble. In fact, the pebble *specifically constitutes* the paper-weight (in particular, they are co-localized).

Now, what are capacities? We take this notion from Cummins's work on functions [8]. His behavior-based approach avoids both the 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 artefact in agent-independent ways. To this end, we use the notion of quality in DOLCE, and assume that both amounts of matter (category M) and non-agentive physical objects, category ($NAPO$) have an individual quality named *capacity*. The capacity of an entity is an individual, just as its color and its weight are. This capacity-quality maps into a quale that is a region (or a set of atomic qualia) in the "capacity space", which can be seen as some sort of functional conceptual space [9]. The quale corresponding to the capacity of an entity at a given time collects the various dispositions [10] or behaviors [11] the entity is able to express at that time. For instance, the capacity of my pen has now the quale of writing finely in black on paper, fitting in my hand, making a certain noise when struck on the table ...

In addition to the capacity possessed by any endurant, artefacts have a *selected capacity*, another quality mapping to qualia in the same capacity space. Capacity and selected capacity differ in the following: the quale associated to the selected capacity does not change with time since it is fixed by the creation event; moreover, this quale is a *set* of regions of the capacity space, since the intended behavior of the artefact needs not be fully specified. For instance, when I want something to write on a board and I select a piece of coal, the value of the selected capacity is only to write on the board and fit in my hand. Therefore, the selected capacity maps into the qualia space in a variety of alternative regions corresponding to different possible writing behaviors, e.g., writing finely in black on the board and fitting in my hand, writing thickly in black on the board and fitting in my hand, writing finely in brown on the board and fitting in my hand, etc. On the other hand, the creator of a pen has probably designed it precisely and therefore chosen a selected capacity which maps to a reduced number of regions or even a unique one. This region, though, is a priori smaller than the capacity's quale region, e.g., the creator of the pen may not have thought about the noise it is able to make when crushed with a rock. Typically, the quale of the artefact's capacity strictly includes one member of the quale of its selected capacity. This does not hold in the

[4]For the sake of clearness, we develop our framework discussing very simplified examples like the pebble and the paper-weight. This choice allows us to easily separate the different ontological aspects we deem crucial. Of course, one can rephrase the discussion talking about more complicated objects like shoes or airplanes at the cost of considerably complicating the presentation.

case of malfunctioning or faulty artefacts: one can create an artefact with a selected capacity's quale that the entity's capacity does not have and perhaps will never have.

Formally, we take a bare artefact to be an element in $M \cup NAPO$ (amount of matter or non-agentive physical object, called for short "material entity" in the remainder). For instance, an amount of glass is an artefact of category *M*, while a paper-weight, no matter out of what it is made, is an artefact of category *NAPO*. A bare artefact x is created by an intentional association of an entity $y \in M \cup NAPO$ and a quality q which is of the type selected capacity, *SelectedCap*. The intentional association that generates the artefact is a special event here called *CreationEv*. To define this we use the *IntentionalSel* (intentional selection) primitive relation which takes as argument an event *e*, a physical or social agent *a* (*APO* or *SAG*), a material entity *x*, a (perhaps complex) material entity *y*, and a quality *q*. *IntentionalSel(e,a,x,y,q)* should be read "*e* is the event of agent *a* intentionally selecting capacity *q* for *y* obtaining the artefact *x*." Bare artefacts are then simply defined as the result of some intentional selection event:

$$BareArt(x) =_{def} \exists e, a, y, q \; IntentionalSel(e, a, x, y, q)$$

The primitive *IntentionalSel* brings a number of assumptions that here we discuss informally only.

The bare artefact *x* is constantly specifically constituted (*SK*) by the material entity *y*.[5] We also assume that the agent and the two material entities participate (*PC*) in the selection event for the time of the event. One consequence is that these three entities are present (*PRE*), i.e., exist, during the event. It is nevertheless somehow arbitrary to say that the artefact *x* exists during the event, one could take it to exist only after it. This choice is not crucial to our approach. Note that *y* does not need to exist before *e*, since *e* could co-occur with a physical creation event, in which case both *x* and *y* are created simultaneously. (see also Section 4.)

Other constraints are needed. First, for a given artefact, the constituting entity and the selected quality are unique, and the quale of the selected quality does not change in time. However, we suppose the same artefact can be selected several times by different agents —for example the same "trunk-bench" in the woods—so the event and the selector are not necessarily unique. Similarly, an entity may constitute several different bare artefacts (successively or at the same time)—for example the same pebble can constitute both a paper-weight and a pestle, although for a given intentional selection event, the artefact and the selector must be unique.

Also, we require selected capacities to be qualities of artefacts only[6] and intentional selections to be $Creation$ events (unless the *same* artefact has already been selected). We impose that there is a $Creation$ event for each artefact, and this makes sure that the artefact does not already exist before the first intentional selection event. The $Creator$ of an artefact is the first selector and is unique as long as there are no simultaneous first intentional selections of the same artefact. Note that further refinements could be necessary for agents such as companies in order to distinguish the creator (the company) from co- or sub-creators like, say, the manager, the designer, the workers processing the material. This can be done introducing more explicitly the intentions of the involved agents, a topic that we do not develop here.

From these constraints, it follows that bare artefacts have the following properties: a bare artefact is an amount of matter *M* or a non-agentive physical object *NAPO* that possesses a (unique) selected capacity with a permanent quale; it is specifically constituted by, thus

[5] This is a simplifying assumption, of course. A more realistic account can be given taking into considerations the essential parts of the artefact through time.

[6] A quality inheres in a unique entity, so given q, there is a unique x such that $qt(q, x)$.

specifically dependent on, another amount of matter or non-agentive physical object; and it is historically dependent on its creator. That is

- $BareArt(x) \rightarrow (NAPO(x) \vee M(x)) \ \wedge \ \exists!q, v(SelectedCap(q) \ \wedge \ qt(q,x) \ \wedge \ \forall t \ (PRE(x,t) \rightarrow ql(v,q,t)))$
- $BareArt(x) \rightarrow \exists y((M(y) \vee NAPO(y)) \wedge SK(x,y) \wedge \forall t(PRE(x,t) \rightarrow PRE(y,t)))$
- $(BareArt(x) \wedge PRE(x,t)) \rightarrow \exists a, t'(Creator(a,x) \wedge PRE(a,t') \wedge t' \leq t)$

3.2 Social Artefacts

Informally, a social artefact is a bare artefact whose selected capacity is recognizable by the members of some society. What we usually call an artefact is not the once-used object like the bench-and-table that I selected out of a fallen tree and used during my last picnic in the woods. Nor an artefact repeatedly but privately used such as the spice-grinder that I selected out of a coffee-grinder. Often, artefacts are recognized as such by agents other than their creators: we buy knives assuming that someone has made them with the purpose of being capable of cutting. This is in particular the case for products. Societies share the knowledge of recognizing many different artefacts, i.e., recognizing the selected capacity in a given entity: pens and knives, glass and flour... so that most of the time there is no need for the creator to explain what their purpose is. As Dipert puts it, a *proper artefact* is in effect an entity for which the selected capacity (Dipert says the creator's intention) is recognizable [5]: we call these social artefacts.

A recognition event has to be distinguished from an intentional selection, as the intention recognized is attributed to someone else, even if unknown. Of course, I may believe to recognize an artefact, i.e., assume the existence of someone having selected a capacity for this entity, and be just wrong. This is an epistemological issue and as such is not a subject for ontological analysis. However, aiming at products, we need to analyze the ontological import of the fact that a given society shares knowledge about some kinds of artefacts. As said earlier, formal ontology of social reality does not aim at analyzing how and on which grounds an agent of this society is able to perform the recognition of a given artefact. Nonetheless, it has to deal with the fact that some artefacts acquire a social status. Note, though, that the *existence* of the artefact is not affected by its having or not the property of being recognizable: social artefacts are essentially bare artefacts.

Recognition, for what concerns us, can be divided in two types. The first type is intrinsically related to the material entity itself (its structure, its physical qualities, its actual capacity, etc.) and to the structure and properties of entities previously encountered. We recognize in this way knives and cars. In the other case, recognition is based on the larger context in which the artefact is. For instance, if we see a pebble (of a certain size) on someone's desk on top of a heap of papers, we will assume that the pebble constitutes a paper-weight, while we do not recognize paper-weights on the sea-shore (but may intentionally select some). Similarly, if we see in a store a bunch of pebbles with a label "paper-weights", we all assume the store is actually selling paper-weights (there are obvious limits to this: a label "paper-weight" on a heap of sand is not enough for the recognition of an artefact since some constraints on the capacity of the material entity must be satisfied). We thus distinguish between (intrinsic) social artefacts and contextual social artefacts.

To ontologically capture such notions, we use a new primitive *Recognizable(q,x,s,t)*, that reads "selected capacity *q* of artefact *x* is recognizable by society (*SC*) *s* at time *t*". The basic constraints on this relation are:

- $Recognizable(q, x, s, t) \rightarrow (BareArt(x) \ \wedge \ SelectedCap(q) \ \wedge \ qt(q, x) \ \wedge \ SC(s) \ \wedge \ PRE(x, t) \ \wedge \ PRE(s, t))$

Constraining further *Recognizable* is not an easy matter if one wants to avoid referring explicitly to agents' mental attitudes. On the other hand, if we do allow doxastic modalities (the modal *belief* operator [12] $Bel_{x,t}\phi$ standing for "x believes proposition ϕ at t"), as well as the arguably simpler primitives *Member* (between a physical agent (*APO*) and a society (*SC*) at some time) and *Perceives* (describing an event of an agent (*APO*) perceiving a physical endurant (*PED*)), we can attempt to define this predicate. The selected capacity *q* of artefact *x* is recognizable by society *s* at time *t* if the artefact and the society are present at t and if whatever member of the society[7] perceiving the entity constituting the artefact believes it is an artefact with the same selected capacity's quale:

$Recognizable(q, x, s, t) =_{def} \exists y, v \ (\exists e, p \ IntentionalSel(e, p, x, y, q) \ \wedge \ ql(v, q, t) \ \wedge \ PRE(x, t) \wedge SC(s) \wedge PRE(s, t) \wedge \forall e', z, t'((Member(z, s, t') \wedge Perceives(e', z, y) \wedge ql_T(t', e') \ \wedge \ t' \subseteq t) \rightarrow Bel_{z,t'} \exists e'', p', y', q' \ IntentionalSel(e'', p', x, y', q') \wedge ql(v, q', t)))$

An (intrinsic) social artefact for society *s* is then a bare artefact whose selected quality is recognizable by society *s* at all times the artefact and the society are present.

$SocialArt(x, s) =_{def} BareArt(x) \ \wedge \ \exists q \ \forall t \ ((PRE(x, t) \wedge PRE(x, t)) \rightarrow Recognizable(q, x, s, t))$

4 Products

The key element that distinguishes products from simple artefacts is the 'exchange purpose'. Let us assume that a predicate $Exchange(e, a, b, x)$ (event e is an exchange of entity x between agents a and b)[8] and the modality $Int_{a,t}\phi$ (agent a intends at t that ϕ holds) have been adequately constrained.

A product is a social artefact such that, during the intentional selection event in which the artefact is created, the creator has the intention of using the artefact in some future exchange, and some agent (who possesses the artefact at the moment, be it the creator, a retailer or an Ebay user) still has the intention of exchanging it. This assumption entails that a given social artefact may be initially a product and then loose and recover this property when it is bought and put on sale again during its existence.[9]

Given a society s, a physical endurant x and a time t, we define x to be a product at t when:

$Product(x, s, t) =_{def} \exists e, a, b, t'(SocialArt(x, s) \ \wedge \ PRE(x, t) \ \wedge \ Creation(e, x) \ \wedge \ ql_T(t', e) \wedge Creator(a, x) \wedge Int_{a,t'} \exists e' b' t'' \ (Exchange(e', a, b', x) \wedge ql_T(t'', e') \wedge t' < t'') \ \wedge \ Int_{b,t} \exists e' b' t'' \ (Exchange(e', b, b', x) \ \wedge \ ql_T(t'', e') \ \wedge \ t < t''))$

As pointed out earlier, products are not necessarily manufactured. Paper-weights selected out of pebbles and gold nuggets sifted out of the river are products when they are meant to be exchanged. In order to characterize the sub-category of manufactured products, we need to introduce another notion, that is, "processing". Roughly, an event is a processing when

[7] There is surely the need to restrict the conditional antecedent to qualified members of the society, thus disregarding babies, drunk people and the like.

[8] In general, in such an event more than one entity is exchanged. Since these other entities are irrelevant to the ontological status of the product x, we leave them implicit in the predicate.

[9] An alternative view, not explored in this paper, is to define products as roles of social artefacts: roughly, a product is an artefact that has (in the intention of the owner) the potential role of exchanged entity in an exchange event.

it modifies some intrinsic qualities (other than location) of an endurant, e.g., its shape or color. Note that a processing is not enough to generate a (manufactured) product. As in the case of the selection of artefacts, it is crucial that the processing is done intentionally. The agent must intentionally physically transform some entity to (perhaps) create a new one. If a manufacturing ontology is adopted, it can be used to specialize this notion further via the concept of "operation" (see [13]). Note that the processing event has to be distinguished from the event of intentional selection, although they are often simultaneous; simultaneity is not necessary but obviously the processing can't occur after the selection. The entity constituting the product coexists with it: it may also be an entity obtained in the processing of some preexisting entity with this latter destroyed in the very same process.

Let us assume that the predicate $IntentionalProc(e, a, x, y)$ —event e is the intentional processing by agent a of entity y to obtain entity x— has been constrained.[10] A manufactured product is then:

$ManProduct(x, s, t) =_{def} Product(x, s, t) \wedge \exists e, e', a, y, z, q, t', t''(ql_T(t', e) \wedge ql_T(t'', e') \wedge IntentionalSel(e, a, x, y, q) \wedge IntentionalProc(e', a, y, z) \wedge \neg t' < t'')$

Thus, we consider a manufactured product to be a product that is constituted by some intentionally processed entity. We now explore related concepts we can capture starting from the above definitions.

4.1 Malfunctioning Products

Our notion of product (and already that of artefact) includes malfunctioning or even failed products. It is rather straightforward to state that a product is malfunctioning at some time t since this amounts to say that the entity does not possess all the capacities selected for it:[11]

$MalFunctioningProduct(x, s, t) =_{def} Product(x, s, t) \wedge \forall q, q', v, v', w((qt(q, x) \wedge qt(q', x) \wedge SelectedCap(q) \wedge Capacity(q') \wedge ql(v, q, t) \wedge ql(v', q', t) \wedge IN(w, v)) \rightarrow \neg P(w, v'))$

This definition is based on the fact that "possessing the selected capacities" means that at least one of the alternative regions in the quale of the artefact's selected capacity is part of the region corresponding to the current quale of the artefact's capacity. Note that we talk of the capacity of the product itself and not of the capacity of its constituent. It is nevertheless natural to assume that a product inherits the capacity's quale of its constituting entity (i.e., the region quale of the product's capacity includes that of the constituting entity):

- $(IntentionalSel(e, p, x, y, q) \wedge Capacity(q') \wedge qt(q', x) \wedge ql(v', q', t) \wedge Capacity(q'') \wedge qt(q'', y) \wedge ql(v'', q'', t)) \rightarrow P(v'', v')$

Note that here we do not mention products explicitly. Indeed, this argument holds for all artefacts. Also, we refrain from requiring the two qualia to be identical. Indeed, creating a new product, say a coin, new capacities are created, e.g., its face value, that the constituent (the metal disk) does not possess.

[10] x and y may be the same entity, if the processing doesn't alter *essential* qualities.

[11] The membership predicate IN is not characterized in DOLCE as of now. We assume here a minimal mereological axiomatization.

4.2 Residues vs Products

We have seen that often an event of intentional selection is related to an event of *physical* processing. This is when a selection generates more than a simple artefact, it also creates the *processed* material entity constituting the artefact. However, not all (intentionally) processed entities yield artefacts and manufactured products, e.g., sawdust.[12] We can define a *residue* as an entity that has been processed and that does not constitute an artefact nor a product because there is no intentional selection made by the agent who performed or activated the processing. Note that, if later an agent intentionally selects capacities for this residue, he will create an artefact or product that has this very residue as constituent. This is what happens when sawdust is sold for its capacity to burn (wood pellets) or to make chipboard.

Using the same primitive introduced above, $IntentionalProc(e, a, x, y)$, we can state

$$Residue(x) =_{def} \neg BareArt(x) \ \wedge \ \exists e, y, a \ IntentionalProc(e, a, x, y)$$

4.3 Product Types

The approach developed so far allows us to characterize a notion of *product type* within DOLCE. Since products are artefacts, i.e., endurants with a particular quality called selected capacity, one can collect products by comparing the values of their selected capacities. Basically, if we want to define a specific category, say *Hammer*, we can isolate the collection of those products whose selected capacities are such that all the regions in their quale include one of those of a generic hammer. That is, if there is such a thing as a most typical hammer, i.e., a product that has been selected for all—but not more—the capacities a hammer must have to be functioning as a hammer, we can use this item as a prototype to define the category *Hammer*. This definition of product type does justice of the intuition that two hammers are two products (tokens) which are 'equivalent' relatively to their selected capacities. Clearly, a network of categories arises by considering the selected qualities of, say, a *carpenter hammer*, that of a *physician hammer*, and so on.

Formally, we use the *classification* (CF) relation. Recall from section 2.2 that $CF(x, y, t)$ stands for "at t, x satisfies all the constraints stated in the description defining concept y".

$$\textit{ProductType}(p, s) =_{def} \forall x, t \ (CF(x, p, t) \rightarrow Product(x, s, t)) \wedge \exists x, t, q_x, v_x(CF(x, p, t) \wedge SelectedCap(q_x) \wedge qt(q_x, x) \wedge ql(v_x, q_x, t) \wedge \forall y, t' \ (CF(y, p, t') \leftrightarrow \exists q_y, v_y(qt(q_y, y) \wedge Product(y, s, t') \wedge SelectedCap(q_y) \wedge ql(v_y, q_y, t') \wedge \forall w_y(IN(w_y, v_y) \rightarrow \exists w_x(IN(w_x, v_x) \ \wedge \ P(w_x, w_y))))))$$

This definition says that all products classified by p have a selected capacity's quale whose member regions all include a region of the quale of some distinguished product (a prototype) within the type. Note that the products do not need to be present at the same time; indeed the type is time-independent since, as we have seen, the value of a selected capacity cannot change in time.

5 Conclusions

In this paper we have ontologically studied the notions of artefact and product by looking at these from the perspective of the DOLCE ontology. Our formalization that defines artefacts to be endurants with a special individual quality and products to be social artefacts that are the intended for exchange provides a first attempt to characterize these concepts in very general

[12] Of course, sawdust itself *is* an artefact when produced intentionally.

and domain independent terms. The approach is based on the introduction of a quality for capacity and a distinguishing quality (called selected capacity) which justifies the special status of artefacts. In this class of entities, a product is any artefact characterized by the intention of the creator to exchange the product at some future time, as a background to the selection event, and for which there is still someone who has the intention to exchange it. Manufactured products are such that the selection event operates over the result of a processing event. Although several of the new primitives we have introduced still require further investigations to obtain a rich axiomatics, this study allowed us to formalize a series of notions (malfunctioning product, residue, product type) which do justice of philosophical distinctions as well as common sense intuitions. As far as we know this approach, which borrows from several discussions in the philosophy discipline and in the knowledge representation field, is new in the literature.

We conclude this paper highlighting a couple of open problems that we think should be addressed to understand the advantages and the limits of our framework.

We have not discussed the conditions for which a product ceases to exist. Since we have to allow for malfunctioning products, it is not totally clear what transformations a product may overcome without disappearing altogether. From the definition, three things are nevertheless clear. First, if its constituting entity ceases to exist, the bare artefact (and thus the social artefact and the product) disappears as well; for example, a lottery ticket may cease to exist if left outside for a while because the action of rain and sun destroys the paper where it is printed. What is left is a new physical object (or perhaps just a heap of powder) but neither the paper constituting the original ticket nor the ticket itself exist anymore. Second, if the society is no longer able to recognize the selected quality, the social artefact and the product (but not the bare artefact) cease to exist. The loss of the property of being socially recognizable may be reckoned from the tentative definition we provided for "Recognizable": it is enough that a (qualified) member of the society is no longer able to recognize its selected capacity. Using another sort of quantifier (*for most* instead of *for all*), this condition could be made more realistic. Finally, if no one has any longer the intention to exchange the social artefact, the social artefact remains but it is no longer a product. This happens all the time: we buy products and then possess only artefacts.

The next issue is that our notion of artefact relies on one important quality space, namely the capacity space. This entity has not been analyzed here and is not well understood yet. It includes functional and contextual aspects in an interesting setting that deserves more attention. Furthermore, it seems necessary to study the dimensions of this space, their relationship and the overall structure if we aim at formalizing properly specific subclasses of manufactured products like that of technical artefacts (devices).

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