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General Ontology of Artefacts

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1. Introduction

In Knowledge Representation, the term "ontology" refers to any information artifact that consists of an interpreted vocabulary to describe a certain domain and a set of explicit assumptions regarding the meaning of the vocabulary words (Guarino [1998]). This is, by now, a truism that sound ontological analysis clarifies the structure of knowledge within a certain domain and enable knowledge sharing between different domains (cf. Chandrasekaran [1999]). Other applications of ontologies in computer science involve: natural language processing, automatic extraction of knowledge from texts, organisational knowledge management (cf. Studer et al. [1998])

Ontologies form a wide spectrum with simple catalogs and glossaries on one side and rich logical theories on the other (Smith [2001]). When a sophisticated knowledge structure is required, much richer systems are applied, which are called foundational (upper-level, top-level) ontologies. Foundational ontologies are specialised logical theories not limited to particular domains. Thus, they comprise only very general concepts, e.g. the concepts of property, event, process, etc. When applied to a particular problem, any foundational ontology needs to be augmented with notions specific to the domain of interest. Indeed, these ontologies aim at providing a universal framework that can be tailored to any application domain; in this way they deliver a reliable tool for information sharing and exchange in all areas.

Usually, it is claimed that the advantages in applying foundational ontologies cover (at least) the following aspects:

- Foundational ontologies reduce the risk of misinterpretation of data and terminology (Guarino [1998]).
- Foundational ontologies make information sharing more reliable (Guarino [1998]).
- Foundational ontologies contribute to interoperability of information systems (Guarino [1998]).
- In the case of incompatible semantic models, foundational ontologies provide a platform for meaning negotiations (Masolo [2003]).

On the other hand, ontologies are trustworthy only if based on a careful and detailed ontological analysis, which must be coupled with a rigorous logical characterisation.

The following theory of artefacts is an ontological analysis of the engineering notion of artefact (and related notions) that is partially formalised in the language of set theory. The result is to be interpreted as a foundational ontology for engineering. As such, the theory is capable to facilitate the construction of a model for any domain of technical artefacts.

The structure of this report is as follows. The next section is devoted to comparison of different theories and models of technical devices from engineering design. Ins section 3, I summarise one of the most mature philosophical theory of artefacts. Finally, I present my own analysis.

2. Artefacts in Engineering Design and Artificial Intelligence

It is most trivial to say that engineering design focuses on theoretical issues of how to represent and reason about technical artefacts (devices, products, technical systems, etc.). Indeed, there exist various approaches and theories in which the notion of artefact and the related notions are dealt with. Because detailed description of each of these systems is clearly beyond the scope of this report, I present here only several classifications thereof. Thereby, I intend to make it possible for ther reader to grasp a general picture of the field.

First, I will present some general classifications. The domain of engineering models of technical artefacts may be organised along the following lines:

(i) with respect to the *origin*/*motivation* of a theory:
 (a) purely technological,
 (b) praxeological,
 (c) logical, e.g.

(ii) with respect to the *logical status* of a theory:
 (a) free text,
 (b) structured text (definitions, axioms, theorems),
 (c) formal language (variables, compositionality),
 (d) axiomatic system (formal language+axioms).

(iii) with respect to the *scope* of a theory:
 (a) general (i.e. applicable to any kind of artefact),
 (b) domain-specific.

(iv) with respect to the *methodological focus* of a theory:
 (a) pragmatic,
 (b) apragmatic.

(v) with respect to the *conceptual depth* of a theory:
 (a) total (i.e. aim to grasp all relevant aspects of artefacts),
 (b) partial (aim to grasp only some relevant aspects of artefacts).

Table 1 contains descriptions of some paradigmatic engineering theories of artefacts. The abbreviations used are explained in Table 5 below.

	ORIGIN			LOGICAL STATUS				SCOPE		FOCUS		DEPTH	
	technology	praxeology	logic	free text	structured text	formal language	axiomatic system	general	specific	production	product	total	partial
A-Design	+			+					+	+			+
Axiomatic Design Theory	+				+			+		+		+	
CONGEN	+					+		+		+	+	+	
DeKleer	+					+			+		+	+	
DwO	+					+		+		+		+	
EFDEX	+				+			+			+		+
EngMath	+					+		+			+		+
FBRL	+							+					
FBS	+				+			+			+	+	
FR	+					+		+			+	+	
FTA			+				+	+			+		
Functional Basis	+			+				+			+		+
Galle					+			+		+		+	
Gasparski		+			+			+		+		+	
Kitamura and Mizoguchi	+					+		+			+	+	
NIST Design Repository	+			+				+			+		+
Pahl and Beitz	+			+				+		+		+	
Reconciled FB	+							+			+		+
Roy	+					+		+		+	+	+	
Theory of Technical Systems	+ +			+				+		+	+	+	
YMIR	+			+				+			+	+	

Table 1

It is a far from trivial observation that only some theories of artefacts contain models of artefacts, i.e. abstract representations thereof. Among such theories we can draw three types of distinctions:

(i) with respect to the *number of dimensions* of the model of artefacts postulated by a theory:
   (a) two-dimensional
   (b) three-dimensional
   (c) four-dimensional

(ii) with respect to the *logical power* of the model postulated by a theory:
   (a) purely representational (i.e. no inference rules)
   (b) inferential (axioms+inferential rules)

(iii) with respect to the *expressivity* of the language of the theory:
   (a) first-order logic
   (b) set theory
   (c) other languages

Table 2 shows how these distinctions work.

	DIMENSIONS			POWER		EXPRESSIVITY
	two	three	four	representation	inference	
CONGEN		Fr/B/Fun		+	+	classes (SHARED object model)
DeKleer		S/B/Fun		+	+	set theory and arithmetic
EFDEX		B/Fun/M		+	+	classes
EngMath		S/B		+		mathematics (functional analysis)
FBRL	B/Fun			+		natural language
FBS		S/B/Fun		+		natural language + diagrams
FR (earlier)		S/B/Fun		+		(elementary) set theory
FR (later)			S/B/M/Fun	+		(elementary) set theory
Houkes and Vermaas	S/Int			+		natural language
Kitamura and Mizoguchi (earlier)	B/Fun			+	+	FBRL
Kitamura and Mizoguchi (later)		S/B/Fun		+	+	natural language+FBRL
Roy		S/B/Fun		+	+	classes
Theory of Technical Systems			S/O/B/Fun	+	+	natural language
YMIR		Fr/S/B		+		natural language (language of network models)

Fr – form (shape, dimensions, internal spatial relations, tolerances, surfaces)
S – structure (ports, components, links, couplings, external spatial relations)
B – behavior
O – organ
Fun –function
M – mode of deployment (environment constraints, instructions of use)
Int – intention

Table 2

It is evident from these comparisons that only some theories attempt to provide a full picture of artefactual entities. The majority of them focus on selected aspects of artefacts, among which design enjoys a widespread popularity. Let me now classify engineering theories of design.

(i) with respect to the *intended domain* of a theory

  (a) theories of designing

    1. total

    2. partial

      - theories of conceptual design
      - theories of detail design

  (b) theories of design product

(ii) with respect to the *illocutionary force* of a theory

  (a) descriptive (i.e. answer the question: what are actual designs?),

  (b) proscriptive (i.e. . answer the question: what are good designs?)

  (c) advisory (i.e. . answer the question: how to assist in creating designs?).

	Intended domain			Illocutionary force		
	Process		**Result**	**Descriptive**	**Prescriptive**	**Advisory**
	Total	**Partial**				
A-Design		conceptual design		+		+
Axiomatic Design Theory	+				+	
CONGEN		conceptual design		+		
DwO	+		+	+		+
EFDEX		conceptual design				+
Gasparski	+			+		
Hilpinen		authorship/ co-authrorship relations				
Houkes and Vermaas	+			+		
Hybrid Model			+		+	
Kitamura and Mizoguchi		conceptual design				+
Pahl and Beitz	+			+	+	
Roy	+					+
Theory of Technical Systems	+			+	+	
YMIR			+	+		

Table 3

Another popular issue in engineering design is device functionality. Here I will present only two classifications:

(i) with respect to the *expressivity* of a theory:

(a) taxonomies of function, e.g. Functional Basis

(b) models of functions:

- with the relation of being a subfunction of a function,
- with the relation of being a function of an artifact,
- with the relation of being achieved in a way,
- with the relation of being a function with respect to a view,

(ii) with respect to *ontological categorisation* of functions:

(a) qualitative, e.g. Theory of Technical Systems

(b) relational, e.g. Pahl and Beitz

(c) procesual, e.g. FBS

(c) mixed

(d) other, e.g. abstraction of task.

	Expressivity						Categorisation
	Taxonomy	**Model**					
		Subfunction	**Function of**	**Metafunctions**	**Achievement**	**View**	
CONGEN		+	+	+	+		-
DeKleer							*what a device does*
EFDEX		+		+	+		purpose abstraction of behavior
FBRL	+		+			+	interpretation of behavior under a goal
FBS		+				+	abstraction of behavior
FR	+		+		+		(intended) behavior
Functional Basis	+	+	+				change of flow
Houkes			+				-
Kitamura/Mizoguchi (earlier and later)	+	+		+	?		-
NIST Design Repository	+	+	+				change of flow
Pahl and Beitz	+	+					relation between input and output change of flow
Reconciled FB	+						change of flow
Roy et al.		+	+	+			abstraction of task
Theory of Technical Systems	+		+			+	capability task
YMIR						+	specification of behavior

Table 4

All engineering models and theories of artefacts convey substantial amount of expertise and provide with valuable insights into the nature of real-world devices. Still, if one wants to apply them to increase semantic interoperability between different information systems, then the prospects for their usefulness look rather dim. The main issue here is to overcome ambiguous and incompatible conceptual schemas they employ. It is a rule rather then an exception that the most crucial notions are defined in an informal, and sometimes even sloppy, way. For instance, let us focus on definitions of function and behaviour we find in these schemas.

- In general, ***function is what a*** design ***is going to do***, while ***behaviour is how*** a design will do it. (Zhang et al. [2001])
- The intermediate point between structure and function is behaviour. Structure is what the device is, and ***function is what the device is for***, but ***behavior is what the device does***. (DeKleer [1984])
- Thus, structure is *what is*, ***behaviour how does***, ***function what does*** and ***purpose why does*** or *what for*. (Rosenman et al. [1998])
- By „Function“ we mean an abstract formulation (or definition) of a task that ***is independent of any particular solution***. (Roy [2001])
- The function of a device is a description of what the device does in the environment […]. Therefore, the function of a component ***is dependent on the device (i.e. context) in which it is embedded***. (Kumar et Upadhyaya [1998])
- Behavior representation of a component is the necessary and sufficient information for simulating states of the component in a system. Parameters which represent the state of the component and constraints or causal relationships among them are included in the behavior representation. Next we can recognize an intended desirable state for each of components in a system. We call the state a goal. Lastly, with necessary information, we can interpret the behavior of a component under its goal. […] We call such interpretation result as function. (Sasajima [1995])

Even if we aim just to compare these different approaches, our task is not easy because the terms by means of which these notions are defined are either ambiguous or unclear. B. Chandrasekaran, who is one of the senior researchers in this field, recently claimed that such definitions increase instead of decrease confusion (see Chandrasekaran [2005]).

The second shortcoming of these approaches seems to be inadequacy. Except for few theories, such as Theory of Technical Systems, engineering models of artefacts are biased toward design and manufacturing activities. Subsequently, other aspects of the artefactual world are neglected. For instance, we could obtain hardly any information how and why artefacts are used. Other psychological and sociological issues are not addressed either.

Abbreviation	Source	Description
A-Design	Campbell et al. [1999]	Agent-Based Approach to Conceptual Design in a Dynamic Environment
Axiomatic Design	Suh [1998]	axiomatic theory of design
CONGEN	Gorti et al. [1998]	software architecure
DeKleer	De Kleer [1984]	theory of electrical circuits from qualitative physics
DwO	Liang and O'Grady [1998]	theory of design from object-oriented perspective
EFDEX	Zhang et al. [2001]	Knowledge-Based Expert System for Functional Design of Engineering Systems
EngMath	Gruber and Olsen [1994]	mathematical ontology of engineering descriptions
FBRL	Sasajima et al. [1997]	function and behaviour representation language
FBS	Umeda et al. [1990]	theory of artefacts described in terms of structute, behaviour, and function
FR earlier	Chandrasekaran [1994] Chandrasekaran and Josephson [1997]	formal theory of artefacts and artefact functionalities
later	Chandrasekaran and Josephson [2000] Chandrasekaran [2005]	formal theory of artefacts and artefact functionalities
FTA	Tzouvaras [1993] Tzouvaras [1995]	formal theory of artefacts
Functional Basis	Szykman et al. [1999]	taxonomy of flows and functions
Galle	Galle [1999]	semi-philosophical theory of design activity
Gasparski	Gasparski [1978]	praxeological theory of design activity
Hybrid Model	Salustri and Venter [1992]	formal theory of design
Kitamura and Mizoguchi earlier	Kitamura et al. [2002]	non-formal ontology of artefacts in the FBRL language
later	Kitamura and Mizoguchi, [2003]	non-formal ontology of artefacts in the FBRL language
NIST Design Repository	Szykman et al. [2000]	formal model of artefacts from object-oriented perspective
Pahl and Beitz	Pahl and Beitz [1996]	general theory of design activity
Reconciled FB	Hirtz et al. [2001]	taxonomy of flows and functions
Roy	Roy et al. [2001]	general theory of artefacts
Theory of Technical Systems	Hubka and Eder [1988]	general non-formal theory of artefacts
YMIR	Alberts [1994]	general theory of artefacts from network models perspective

Table 5

4. Artefacts in Philosophy

Artefacts enjoy a modest presence in philosophy today. Usually they enter the philosophical *agora* not because of their own sake but because of problems related to some other kind of entities. For instance, artefacts are mentioned quite often in discussions on the notion of function in philosophy of biology. Thus, instead of comparing few existing philosophical conceptions of artefacts, I will present one of the most elaborated proposal by Randall Dipert.[1]

Dipert defines the notion of artefact in the following series of definitions.

(Instrument) An object x is an *instrument* with respect to property-set X for agent y and goal z just when:

(i) x has properties from X and is believed by y to have such properties,

(ii) properties from X are means of attaining z and are believed by y to be such means,

(iii) y has used x intentionally in order to achieve z. (Dipert [1995], p. 121)

Loosely speaking, an instrument is an object that was contemplated by some agent as useful for attaining some goal and that was used in the contemplated capacities.

(Tool) An object x is a *tool* with respect to property-set X for agent y_1 and goal z just when:

(i) x has properties from X and is believed by y to have such properties,

(ii) some agent y_2 intentionally modified or deliberately left alone all of the properties from X in order to better achieve z and this is believed so by y_1,

(ii) y_1 intentionally used x because of beliefs about the intentionally-increased efficacy produced by y_2 of x through properties from X (p. 123)

Loosely speaking, an instrument is an object that was intentionally modified to be useful for attaining some goal and that was used in the contemplated capacities.

(Artefact) An object x is an *artefact* with respect to property-set X_1 for agent y_1 and goal z just when:

(i) x is a tool with respect to property-set X_2 for an agent y_1 and goal z,

(ii) X_2 contains properties intentionally modified by some agent y_2

[1] Other philosophical approaches are presented in Hilpinen [1993], Houkes and Vermaas [2004], Simons [1996].

(iii) y_1 believes that y_2 intentionally modified properties from X_2 in order that an agent come to believe that x is a tool for an agent with respect to X_2 and z,

(iv) y_1 comes to believe that properties from X_2 are tool properties and that properties from X_1 communicate this in virtue of the apprehension of properties X_1 in a certain way. (p. 129)

According to this account, artefacts are such objects that „communicate" to their users that they are tools.

Dipert also provides a detailed description of the process of artefact production. An agent who created an artefact must have started with a sort of rule-guided deliberation in which he pondered over a spectrum of possible objects to be produced. Then, he must have chosen one of these objects because its properties seem to him to be desirable. His choice involves a desire to achieve a certain state of affairs and an intention to realise that state. The process of production of the chosen object is a result of this intention provided that the relation between the agent and the reality is of the appropriate sort (Dipert [1993], p. 44-45).

Dipert holds that artefacts are what they are due to the past beliefs of their users. If x is an artefact, then its characteristic features *qua* artefact are fixed by the past beliefs and actions of some agents. The actual physical nature of x is not crucial in this respect:

What is important and interesting about actions and artifacts […] has nothing to do with their physical nature. An event in a space-region is not an action of certain sort because of physical properties within that region. Likewise, an artifact is not an artifact because of any physical properties of that entity considered as a presently existing physical object. (Dipert [1993], p. 133)

In other words, whether some entity is an artefact does not depend on the properties possessed by this entity, but on (past) beliefs of some agents.

Despite a number of important philosophical insights, Dipert's theory of artefacts is not well suited for the domain of technical devices. First, the notions he employs are not related in any way to the real-world processes of artefact design and manufacture. Secondly, Dipert tends to overemphasise the historical aspect of artefacts and disregard their physical dimension. Thirdly, we do not find any constraints on the beliefs due to which objects acquire a status of artefacts. Consequently, we are not in a position to eliminate such weird cases of artefacts as talismans. Fourthly, such issues as modelling device behaviours and functions are not addressed in this approach.

5. Artefacts as four-dimensional objects

A theory of artefacts I present below is the result of philosophical reflection on engineering models of technical artefacts, which reflection takes into account methodological considerations from ontological research in Knowledge Representation and Artificial Intelligence. The present report presents a fairly embryonic version of this approach, whose substantial parts are not yet formalised.

5.1. Methodology

Artefacts are methodologically awkward entities. One of the problems they pose is exceptionally troublesome as it occurs at the very beginning of every conceptualisation of the realm of artefacts. I bear in mind the following classificatory problem: which objects are, and which are not artefacts? Admittedly, *particular* answers abound. Hammers, cars, and sculptures are artefacts. Electrons, human beings, and icebergs are not artefacts. Nonetheless, philosophers' attempts to give a *general* answer remain unsatisfactory. It is still debatable whether definitions, songs, computer programs, or political parties are artefacts.

Pieter Vermaas and Wybo Houkes have recently suggested a methodological strategy of developing theories of artefacts (cf. Vermaas and Houkes 2003: 263-265). I transformed their proposal into a heuristic defined by 1.

(1) (i) Start with the phenomenology of non-controversial examples of artefacts!
- (ii) Generalise the phenomenology!
- (iii) Expand your generalisation from (ii) into an axiomatic system!
- (iv) Derive the consequences from the axioms!
- (v) Compare those consequences with the phenomenology!
- (vi) If, but only if, you detect any *serious* divergences at step (v), repeat the whole procedure modifying step (i), step (ii), or step (iii)! Otherwise, you have at your disposal a tentative theory of artefacts.

The liberal attitude motivating step (vi) comes from my pessimistic belief to the effect that the domain of artefacts (if we include therein both works of art and technical artefacts) is so diversified that it is impossible to provide any general account concordant with all our reliable beliefs about artefacts. My overall epistemological attitude bears a close resemblance to the methodology of ontology of the material world employed by Theodore Sider:

> One approaches metaphysical inquiry with a number of beliefs. Many of these will not trace back to empirical beliefs, at least not in any direct way. These beliefs may be particular, as for example the belief that I was once a young boy, or they may be more general and theoretical, for example the belief that identity is transitive. One then develops a theory preserving as many of these ordinary beliefs as possible, while remaining consistent with science. There is a familiar give and take: one must be prepared to sacrifice some beliefs one initially held in order to develop a satisfying theoretical account. But a theoretical account should take ordinary beliefs as a whole seriously, for only ordinary beliefs tie down the inquiry. (Sider 2001: xvi)

It is a crucial assumption of the four-dimensional ontology of artefacts that it primarily concerns artefact-types and not artefact-tokens (instance-level artefacts). I follow here the Aristotelian cliché to the effect that there is no science about particulars as particulars: *non datur scientia de individuo ut individuo* (*Ethica Nicomachea* 1080b, *De anima* 417b). As Randall Dipert observed some time ago (Dipert 1993: 16, 36), we should speak rather about artefactual aspects of objects than about artefacts themselves. The notion of artefact-type is used here to gather such artefactual aspects of objects. In what follows when I use the term 'artefact', I will refer to artefact-types unless otherwise explicitly stated.

5.2. Formal Tools

In the course of the exposition, I will need two formal tools. First, I presuppose a simple account of inference. In order to serve this need, I will apply the notions from the standard theory of consequence. The details of the theory might be found in (Wójcicki [1984]). I believe that it is in principle feasible to define the consequence operation C determined by the rules of inference we use when we reason about artefacts. In the case of technical artefacts, C should contain at least a causal logic associated with some temporal logic. In particular, C satisfies the following axioms:

(2) (i) $X \subseteq \mathsf{C}(X)$,

(ii) $X \subseteq Y \rightarrow \mathsf{C}(X) \subseteq \mathsf{C}(Y)$,

(iii) $\mathsf{C}(\mathsf{C}(X)) \subseteq \mathsf{C}(X)$,

(iv) if $\varphi \in \mathsf{C}(X)$, then $\exists Y \subseteq X$ [Y is finite and $\varphi \in \mathsf{C}(Y)$].

The second formal tool is a formal ontology of objects and states of affairs. Very roughly speaking, one may say that, as the former are ontic counterparts of proper names, so the latter are ontic counterparts of sentences. To put it in a different way, while proper names are linguistic representations of objects, sentences are linguistic representations of states of affairs. Thus, that the Eiffel Tower is made of steel is a state of affairs and the Eiffel Tower is an object.

In order to be more specific, I will employ some ideas from the formal ontology of the Polish philosopher Roman Ingarden (cf. Ingarden [1965]). Simplifying slightly the issue, one might say that Ingarden distinguishes two different ontological categories of states of affairs: real and intentional. A *real state of affairs* may be defined as a part of the ontic range an object. For instance, if this shaft in front of me is one meter long, that the shaft is one meter long is part of the ontic range of the shaft since the property of being one meter long inheres in the shaft. Similarly, that a valve controls a flow of water and that Mary's car burnt into flames are states of affairs. Knowing that a state of affairs is part of the ontic range of an object, I know what the object is like, or in what process it takes part, or in what event it occurs. If a state of affairs *x* is a part of the ontic range of an object *y*, I will say that *y occurs in x*.

As for intentional states of affairs, Ingarden says that due to its content every representational state of mind determines an intentional state of affairs. Derivatively, due to its meaning every declarative sentence determines an intentional state of affairs. For example, if John thinks that the Eiffel Tower is made from glass and he discusses with a friend what is the impact of this fact on the safety of public transport in Paris, then they both refer to the same entity, but because this belief is false, no real state of affairs corresponds to it. Intentional entities, including intentional states of affairs, function as intermediate entities between mind (or language) and reality. As real objects occur in real states of affairs, so intentional objects occur in intentional states of affairs. The category of intentional states of affairs cannot be reduced to the category of sentences because two different sentences may determine the same intentional state of affairs, but one of these sentences may cease to exist without the intentional state of affairs ceasing to exist. For a similar reason, the former category cannot be reduced to the category of representational states of mind.

What is then the relation between the realm of real states of affairs and the realm of intentional states of affairs? Assume that an intentional agent formulates a sentence or entertains a belief. If the sentence (belief) is true, the intentional state of affairs determined by that sentence (belief) m i r r o r s some actual state of affairs (i.e. some *fact*) in the ontological universe. Ingarden adds that the intentional state of affairs and its actual counterpart share the same content, but differ in the mode of existence: actual states of affairs exist autonomously and intentional states of affairs exist heteronomously. He explains: to exist autonomously is to have its ontic ground in itself, and to exist heteronomously is to have its ontic ground in something else. For example, the intentional state of affairs that the Eiffel Tower is made from glass has its ontic ground in the aforementioned John's belief. If the sentence in question is contingently false, the intentional state of affairs created by the sentence could mirror some actual state of affairs in the ontological universe. Modifying Ingarden's position, I call the actual portions of reality that can be mirrored by the intentional states of affairs and the respective possible portions *real states of affairs*. Both the state of affairs that the Eiffel Tower is made from steel and that the Eiffel Tower is made from glass are real states of affairs. If a sentence one forms is necessarily false, then by definition there can be no actual state of affairs that the intentional state of affairs created by that sentence could mirror. The entity that the Eiffel Tower is made from empty sets is not a real state of affairs in that sense.

If a representational state of mind or a declarative sentence determines an intentional state of affairs that corresponds to some real state of affairs, I will say that the state of mind or the sentence represents this real state of affairs. I will also say that the respective intentional state of affairs represents the actual state of affairs. Similarly, I will say that intentional objects represent real objects.

I supplement Ingarden's theory with the relation of parthood between states of affairs. Being parts of ontic ranges of objects, states of affairs may be parts of one another. The state of affairs that this shaft is one meter long is part of the state of affairs that this shaft is a one meter long steel shaft. The state of affairs that John is an accountant is part of the state of affairs that he is an absent-minded accountant. Generalising, the state of affairs that p is part of the state of affairs that p and q. However, there are also non-conjunctive cases of parthood. For example, the state of affairs that John's car burnt into flames is part of the state of affairs that it burnt into flames after it hit the curve.

The expression '$\mathrm{Occ}(x, y)$' will mean that an object x occurs in a state of affairs y (or that y is a part of the ontic range of x). The expression '$x'' y$' will mean that a state of affairs x is part of a state of affairs y.

The formal theory of states of affairs is defined by axioms 4-8, and 10 below. Since these axioms constitute fairly weak characteristics of the respective notions, the resulting theory might be classified as a *minimal ontology of states of affairs*. All axioms are to hold both for real and intentional entities.

Given the relation of occurrence we may define the notions of object (3(i)) and of state of affairs (3(ii)):

(3) (i) $\mathrm{Obj}(x) \equiv \exists y\, \mathrm{Occ}(x, y)$.

(ii) $\mathrm{Soa}(x) \equiv \exists y\, \mathrm{Occ}(y, x)$.[2]

The following two axioms express the categorical constraints on objects and states of affairs.

(4) $\mathrm{Obj}(x) \equiv \neg \mathrm{Soa}(x)$.

(5) $x'' y \rightarrow \mathrm{Soa}(x) \wedge \mathrm{Soa}(y)$.

Following Roberto Casati and Achille Varzi, I assume the lexical principle to the effect that any relation of parthood is a partial order (Casati, Varzi 1999, p. 33). I express this principle by the axioms 2.4-2.6:

(6) $\mathrm{Soa}(x) \rightarrow x'' x$.

(7) $x'' y \wedge y'' x \rightarrow x{=}y$.

(8) $x'' y \wedge y'' z \rightarrow x'' z$.

The expression '$x<y$' will mean that a state of affairs x is a proper part of a state of affairs y.

(9) $x<y \equiv x'' y \wedge x \neq y$.

It follows that the proper parthood is irreflexive, asymmetric and transitive.

Given the metaphor of ontic range it appears obvious that if a state of affairs x is part of a state of affairs y and an object z occurs in x (i.e. x is part of the ontic range of z), then z also occurs in y:

(10) If $x'' y$, then $\forall z\, [\mathrm{Occ}(z, x) \rightarrow \mathrm{Occ}(z, y)]$.[3]

5.3. Other Primitives

Without any further explanation, I will speak about agents, intentional agents, and communities of intentional agents. An *agent* is an object that is able to bring it about that some state of affairs is the case. An *intentional agent* is an agent who has some beliefs and

[2] Although the minimal ontology of states of affairs refers to two kinds of entities: objects and states of affairs, the ontology i s n o t a many-sorted theory. Subsequently, all variables ranges over the same set of entities.

[3] Since in this paper I use my theory of states of affairs only as a tool to grasp the ontological properties of artifact designs, I do not compare it with other formal accounts of states of affairs. I decided not to employ these accounts either because the complexity of their formalism is too high for the present purposes (e.g. Barwise and Perry [1983]) or because they involve more philosophical commitments than my minimal proposal (e.g. Armstrong [1997]). This does not mean that I think these other approaches might not be used for the present purposes.

some wishes. An intentional agent x *knows* that y is the case iff x rationally believes that y is the case. If x rationally wishes y to be the case, then x knows what it would be for y to be the case. An intentional agent is *rational* iff her beliefs and wishes are rational. An intentional agent x *communicates* to an intentional agent y that z is the case if x brings it about that y believes that z is the case. A *community of intentional agents* is such collection X of intentional agents that (i) the members of X believe that they belong to X, (ii) the members of X do not wish not to belong to X, and (iii) they communicate to each other that they have some beliefs and wishes. In what follows, I will speak about purpose ascriptions made by such communities. A community X of intentional agents *ascribes y as a purpose of z* iff (i) some members of X believe that y is a purpose of z, (ii) they wish other members of X to have the same belief, and (iii) the former are able to bring it about that the latter believe that y is a purpose of x. An analogous definition may be formulated for the relation: a community X of intentional agents *ascribes y as an instruction of use for z*.

Consequently, besides the notion of consequence operation and the notions of state of affairs and object (as defined above), the four-dimensional approach takes for granted the following notions as primitives: '*x* (*rationally*) *believes that* a state of affairs y is the case', '*x* (*rationally*) *wishes* a state of affairs y to be the case', '*x brings it about that* a state of affairs y is the case', '*x is able to bring it about that* a state of affairs y is the case'.

5.4. Towards Formal Ontology of Artefacts

Following the heuristic defined in (1), I begin with a short description of a technical artefact. The example has been chosen for its simplicity and intuitive appeal.

On a train, John writes a philosophical paper on his laptop. He bought it since he believes that the most fruitful ideas come to his mind while he travels. He saw it many times that other people make notes on a train. His fellow philosophers advised him that this very brand of laptop would best serve his needs. John considers his laptop a reliable device since he was told that it has been designed on the ground of the up-to-date know-how in computer science. He has barely any idea about its design, but he does not encounter any serious problems with it since he has carefully read the manual and knows its instructions of use. Sometimes he uses it as a paperweight but he does not believe that this is a proper function of his laptop.

Now I will generalise this phenomenology (cf. 1.1(ii)), bearing in mind the lessons learned from research in engineering design. Artefacts are entities produced on purpose. We produce artefacts in order to achieve by means of them some aims we find important. We produce them on the ground of their designs, which are supposed to make our production more efficient. We produce artefacts and construct their designs referring to some background knowledge relevant for this kind of artefacts. This knowledge is supposed to guarantee that artefacts help us to achieve the aims for which they were produced, or at least it is supposed to make it more probable that we achieve those aims. We may achieve those aims if we follow the instructions of use determined by artefacts' designs and the respective background knowledge. Subsequently, I submit here a view to the effect that any artefact should be characterised with respect to four dimensions: teleological (i.e. purposes), intentional (i.e. design), epistemic (i.e. background knowledge), and operative (i.e. instructions of use).

Investigating the nature of artefacts in the context of engineering design, we may pose two types of questions. One type concerns ontological issues: what is an artefact?; what is the difference between behaviour and function?; etc. The other type concerns representational issues: What is the most effective way of representing artefacts?; How to render the difference between behaviours and functions?; etc. For obvious reasons, I will keep these types of problems separate.

Teleological dimension

The most suitable candidate for the ontological category of purposes is the category of state of affairs. To be more precise, *x* is a *purpose of y* if *x* is a state of affairs and there is some intentional relation between *x* and *y*. If *y* is an artefact, then a purpose of *y* is a state of affairs *x* intentionally ascribed to *y*. At first sight, a purpose may be ascribed to an artefact by a user of the artefact, or by its designer(s), or by a community of intentional agents, which includes the designer(s)[4] and the users of the artefact. However, if an individual user of an artefact were in a position to determine the purposes of the artefact, then contrary to our common sense beliefs such ascriptions would not be ontologically stable nor socially communicable. Furthermore, the important distinction between proper and accidental purposes would then disappear. On the other hand, if the designer(s) of an artefact were in a position to determine all purposes of the artefact, then contrary to our common sense beliefs it would not be possible for the users of the artefact to invent its new purposes. Consequently, I contend that purposes are ascribed to artefacts by communities of intentional agents.

Being an artefact is then a social fact, and as such is relative to a community of intentional agents. The collective process of purpose ascriptions might be described roughly as follows. A designer of an artefact *x* interprets her product saying what *x* is for. Saying that, she either addresses the request that was explicitly expressed to her or comes up with *x* adver-

[4] For a theory of collective authorship, see (Hilpinen [1993].

tising it as a means to serve such and such needs. Both kinds of elucidations are assessed by x's initial users or/and by experts in the domain of knowledge relevant for x (see below). The former simply use it and examine what needs x actually serves. The latter evaluate the designer's declaration against their expertise. The users or/and the experts determine to what extent (if to any) the designer was right in her declaration and, in some cases, what other purposes x might also serve. Other intentional agents either imitate the former or trust the latter. In this way, the community of intentional agents establishes what purposes x actually has.

Since artefacts are not made in vain, I claim that a community of rational agents ascribes to every artefact it uses a purpose for which the artefact is produced. In order to keep the ontological problem apart from its representational counterpart, I will use the Times New Roman typeface when I address the former and `the Courier New typeface` when I address the latter. Let $\mathtt{L}_A$ be a language to speak and reason about artefacts. Then the set S_A contains all states of affairs represented by sentences from $\mathtt{L}_A$.

Let 'Purpose(x, y, z)' means a real state of affairs x is a purpose of an artefact y in community z. Respectively, let a set `Use`(x, y)$\subseteq \mathtt{L}_A$ contain sentences that represent the purposes of x in y. Since it turns out that being social entities, artefacts are relative to communities of agents, I will represent the former by means of binary predicate 'Art': Art(x, y) means that x is an artefact in a community y.

(11) Art(x, y) → Obj(x) ∧ Obj(y).

(12) Art(x, y) → ∃z Purpose(z, x, y).

(13) Art(x, y) → `Purpose`(x, y)≠∅.

The following two axioms introduce categorical constraints on arguments of Purpose and `Use`.

(14) Purpose(x, y, z) → Soa(x) ∧ Art(y) ∧ Soa(z).

(15) `Purpose` (x, y) → Art(x) ∧ Obj(y).

Intentional dimension

Artefacts are deliberate products of rational agents. When Smith produces an artefact x, she is supposed to consult the design of x. This seems to be a definitional feature of her action: the design sets apart her action, which is said to be an act of production, from bringing about a state of affairs. For if Smith just brought it about that x exists, but did not refer to anything that might be even roughly described as the design of x, then one might entertain a reasonable doubt whether she actually produced an artefact or even whether her action might be adequately described as an act of production. If you move in a certain planned way, then it is the design of your walking that "decides" that your movements might be classified as, say, a dance, than as a stroll. Moreover, it is usually believed that consulting the design of an artefact increases the prospects for obtaining the purpose for which we produce the artefact. If both Smith and Brown wish to achieve the same purpose y and because of these wishes Smith produces an artefact x_1 and Brown produces an artefact x_2, then if Smith resorts to the design of x_1 and Brown does not resort to the design of x_2, then it is more probable that x_1 makes it easier for Smith to achieve y than that x_2 makes it easier for Brown to achieve y. If both probabilities happen to be equal, then Smith's efforts are likely to be more economical in terms of time, energy, materials, etc., than Brown's efforts.

We produce artefacts referring to their designs. It means that when one produces an artefact x, then either one modifies some object(s) in accordance with the design of x, or, as Dipert rightly observed, one deliberately leaves some of x's features unmodified. In the latter case, the design of x contains the states of affairs contemplated and deliberately left unmodified by the designer(s) of x.

What are designs? I will start with the classificatory problem: What is the ontological category of designs? Being an ordinary object, every artefact has certain properties, takes part in various processes, occurs in events, etc. Thus, if we were asked to characterise some artefact, we might come up with a set of sentences specifying what properties the artefact has, in which processes it takes part, etc. Every such sentence would refer to a state of affairs in which the artefact occurs. For example, specifying one feature of a resistor the sentence 'This resistor has the resistance of 10 kΩ' refers to the state of affairs that the resistor has the resistance of 10 kΩ. The "fusion" of all states of affairs in which an object occurs may be called the ontic structure of object.

Artefacts are products of human activity that involves mental components as its essential factors. Apparently, artefact designs somehow represent artefacts. If one says that x represents y, one might mean by her claim two things. First, she might wish to express the fact that x is an image of (or mirrors) y, in which case it is y that comes first and x is supposed to imitate y. Here, it is x that is evaluated as a faithful or unfaithful representation of y. If x represents y in this sense, I will say that *x represents$_1$ y* and call such relation the relation of *epistemic representation*. Secondly, saying that x represents y she might wish to express the fact that y is an image of (or mirrors) x, in which case it is x that comes first and y is supposed to imitate x. Here, it is y that is evaluated as a faithful or unfaithful representation of x. If x represents y in this sense, I will say that *x represents$_2$ y* and call such relation the relation of *poietic representation*. If x represents$_1$ or represents$_2$ y, I will still say that *x represents y*. Admittedly, claiming that artefact designs represent artefacts I claim that the former represent$_2$ the latter.

Usually there is nothing in the content of a representation of an entity that makes it a representation$_1$ or a representation$_2$ of that entity. It is a user of a given representation that determines that by using the representation either as an epistemic or poietic representation. Moreover, it is not the case that any representation$_1$ may be considered as a representation$_2$; however, any representation$_2$ may become a representation$_1$. In our case it is a community of rational agents that determines which representations are poietic representations of artefacts.

I need two additional qualifications of the relation of representation. I will say that *x truthfully represents y* iff every representational detail of *x* corresponds to some detail of *y*. I will also say that *x adequately represents y* iff every detail of *y* corresponds to some representational detail of *x*.

(16) (i) (At least) some designs truthfully represent$_2$ some artefacts.

(ii) For any artefact *x*, no design adequately represents$_2$ *x*.

Later on 16(i) will be strengthen to the "at most some" condition. 16(ii) accounts for the fact that human designs are products of finite minds that are unable to describe all details of any their products. Consequently, a design of an artefact never specifies the w h o l e ontic structure of the artefact.

Artefact designs are like other representation of reality: they contain both objective and subjective components. An electrical schema is an inscription made of ink or chalk (the objective component of the design) by means of which some rational agent represents$_2$ some electrical device (the subjective component of the design). Generally speaking, designs are physical objects of various kinds (inscriptions, drawings, pictures, sounds, etc.) that are considered by rational agents as representations$_2$ of other physical objects. For any artefact, the objective factor of its design may vary while the subjective factor remains constant. One might represent$_2$ an electrical device by means of a drawing, or a complex inscription, or a series of sounds, but all these physical entities represent$_2$ one and the same artefact. This means that the drawing, the inscription, and the sounds may be considered by a rational agent as such representations$_2$ of the artefact that represent$_2$ it in the same way, i.e. provide the same poietic information on that artefact. Consequently, the following distinction seems to be useful.

(17) An *engineering specification* of an artefact is a physical object considered by some rational agent as a representation$_2$ of the artefact.

(18) A *design* of an artefact is an entity due to which some rational agent considers different engineering specifications as representations$_2$ of the same artefact.

When a rational agent identifies by means of a design x different engineering specifications y_1 and y_2 as representations$_2$ of the same artefact, I will say that y_1 and y_2 (*physically*) *support* x.

The foregoing remarks should make it clear that every engineering specification supports at least one design. Assuming that designing is a rational activity I stipulate that the relation of support is a function, i.e. no engineering specification supports more than one design.

The design of an artefact determines what the artefact is like, i.e. it determines in which states of affairs the artefact is involved.[5] This claim presupposes that artefact designs have a proposition-like structure, i.e. it presupposes that in principle any design might be supported by some complex inscription (i.e. a mereological sum of sentences).[6] Obviously, designs are not (sums of) sentences because when a designer constructs a design, she need not formulate any sentence and a great number of actual designs are not (and presumably will not be) supported in this way. However, since it is sufficient for a sentence to exist if there exists the language of which this sentence is part, I assume that for any engineering specification there exists a mereological sum of sentences, which sum supports the same design as the specification. This assumption is not as strong as it looks if we concede that drawings or charts are (or consist of) *sui generis* sentences.

Subsequently, what are designs? It is easy to notice that designs are neither engineering specifications nor mereological sums of engineering specifications. As for the former claim, a lot of designs are supported by more than one engineering specification, none of which has the privileged position of being t h e engineering specification of a given artefact. Secondly, you can multiply engineering specifications, e.g. by photocopying them, without multiplying designs. Thirdly, you can change or even destroy an engineering specification without changing the design that is supported by the engineering specification. As for the latter claim, since a mereological sum of a set of objects changes if you change one of its members, we cannot change an engineering specification without a change in any sum of engi-

[5] The precise meaning of this claim is explained by the following implication: if a design of an artifact determines that the artifact is such and such, then it is the case that the artifact is such and such. The claim d o e s n o t entail the converse of that implication. At present I neglect the distinction between ‘is such and such’ and ‘is designed to be such and such’.

[6] Mereology is the general formal theory of the parthood relation (cf. Casati [1999]). It has been successfully applied in a number of domains in Knowledge Representaiton and Artificial Intelligence (see e.g. Guarino [1997], Menghini [2001])

neering specifications to which this engineering specification belongs. Consequently, if designs were mereological sums of engineering specifications, then any change in any engineering specification would be a change of design. For a similar reason a design cannot be identified with a (distributive) set of engineering specifications.

I claim that designs are intentional states of affairs. What does this claim mean? Assume that a rational agent has designed an artefact. I argued above that

(i) the resulting design represents$_2$ (part of) the ontic range of the designed artefact,

(ii) there is a mereological sum of sentences supporting that design.

Every sentence from the sum referred to in (ii) creates an intentional state of affairs. Every such state represents a part of the ontic range referred to in (i). Let X be the set of these intentional states of affairs. Because of the unity of the designer's intentions, the design is also a unified entity. Given the above theory of states of affairs, the simplest way to represent the latter unity is to require that the design be (the state of affairs that is) the least upper bound of X with respect to $''$.

(19) For every artefact x, there exists a non-empty set $X \subseteq S_A$ such that the least upper bound of X is a design of x.

How many designs does an artefact have? At first sight, it seems that the answer is straightforward: Every artefact has exactly one design. Observe however that an artefact may be part of another artefact and a design of the latter may not specify all details of the former. A diode is a part of a power supply. The design of the diode that is part of the design of the power supply specifies only two parts of the diode: the anode and the cathode. Still, a more detailed design of the diode, for instance the design you may find in a handbook on general electronics, mentions also a semi-conductor junction between the anode and cathode. Consequently, the diode has at least two designs. Consider also another case. Assume for the sake of an example that political organisations are artefacts. The design of the European Union mentions the Republic of Poland as its part and the provinces of Poland as parts of Poland. Nevertheless, the design does not mention the local communes of Poland as parts of the EU. Still, the design of the Republic of Poland, which is determined by the current administrative Polish law, mentions these communes as parts of Poland. Subsequently, it appears that ordinary parlance allows us to admit different designs of the same artefact. Strictly speaking, in their professional activities artefact designers seem to represent$_2$ one artefact by means of different representations$_2$. One, usually the most specific, representation$_2$ is created before the artefact is produced, other, less specific, representations$_2$ are created when the artefact is used as a component of or tool for other artefacts. The fact that the most specific design is not deployed in the latter case is not a contingent matter, but is a consequence of the bounded rationality involved in engineering practice. In most cases of technical artefacts, if a design *x* of an artefact contained the most specific designs of the components of the artefact, *x* would be extremely complex representation. If, but only if, engineers were intentional agents with unlimited cognitive capacities, they might afford to neglect the complexity of their products. Later on I will also show that the fact that one artefact has more than one design makes it possible to draw a useful distinction between artefact tokens and artefact types.

Given my identification of designs with intentional states of affairs, the most adequate approximation of the relation of specificity between designs is the relation of proper parthood between states of affairs.

(20) A design *x* is *less specific than* a design *y* iff $x<y$.

I claim that the set of all designs associated with a given artefact has its greatest and least element with respect to $<$. The existence of the former guarantees that every artefact is uniquely determined by its design as far as its physical structure is concerned. The existence of the latter guarantees that there is an objective rationale for artefact tokens identification. Let me explain the latter claim in more detail.

Your new laptop has some dead pixels on the display. You want to reclaim it, so you visit the technical support unit. When you hear there that that laptop on the shelf is the same as your laptop, you will not start complaining that the technical support breaches the law of indiscernibility of the identicals. You presume that they mean that your laptop is a copy of that laptop on the shelf. We know that artefacts exist, so to speak, in copies. What we do not know are the conditions under which one artefact is a copy of another artefact.

It turned out that your second laptop is even worse than the first one. You have to replace one part after another. When does the laptop on your desk cease to exist because of this replacement process? We know that in the course of time artefacts undergo various changes. What we do not know are the conditions under which artefacts preserve their identity in time or cease to exist.

These and similar problems are more tractable if reformulate them in terms of artefact tokens and artefact types. Then, instead of pursuing the question when one artefact is a copy of another artefact, we pursue the question when one artefact token is a token of the same artefact type as another artefact token. For example, the question ‘Is my laptop a copy of that laptop on the shelf?’ is substituted with the question ‘Is this artefact token of a laptop a token of the same artefact type as that artefact token of a laptop?’ Instead of pursuing the question under what conditions artefacts endure in time, we pursue the question when an object is a token of a given artefact type. For example, the question 'Does my laptop survives (i.e. preserves its identity despite of) the replacement of its battery *B* with a new battery *B*'?' is substituted with the question 'Will the replacement of *B* with *B*' in this artefact token result in the change of its artefact type?' or with the question 'Is this artefact token with the old battery *B* of the same artefact type as that artefact token with the new battery *B*'?'

An artefact token is an artefact in the ordinary sense of the word. Artefact tokens are physical entities located in space and time. It is artefact tokens that we use as writing tools. They have certain properties, participate in processes, and occur in events. One artefact token may be a copy of another. Given the ontological framework sketched above, one may say that artefact tokens are real objects and their ontic ranges consist of real states of affairs. On the other hand, an artefact type is an abstract object like a universal. An artefact type gathers the features common to a group of artefact tokens. Artefact types are not located in space or time, therefore you cannot write philosophical papers with them; nonetheless, artefact types are useful. When I am to learn about the significant features of some artefact token, I may limit my investigation to the features specified by the artefact type of this token. When I notice that two artefact tokens *x* and *y* are similar in the relevant respects, I may express my observation saying that *x* is of the same artefact type as *y*. When I wish to make a general observation about a group of artefact tokens, I may express it saying that the respective artefact type exhibits the observed regularity. In short, artefact types represent artefact tokens. Given the ontological framework sketched above, one may say that artefact types are intentional objects.

It should be now obvious that the most specific design of an artefact exhaustively determines the ontic range of the respective artefact type, but the artefact tokens are not thereby completely determined. However, we must not identify the ontic ranges of artefacts types with the most specific designs. Since we should allow for the fact that some artefact tokens malfunction, we must not say that two artefact tokens are tokens of the same artefact type only if their ontic ranges are represented by the same most specific design. Even if an artefact token loses some features specified by its most specific design, the token may still keep its artefact type. We ought to ground the identity of artefact tokens in less specific designs and the most natural candidates are the respective least specific designs. If every artefact has its least specific design, then we may say that two artefact tokens are tokens of the same artefact type if their ontic ranges are represented by the same least specific design. Consequently, I will identify the ontic ranges of artefact types with the least specific designs of artefacts.

Now we are in a position to solve our initial puzzles, i.e. the puzzle of copies and the puzzle of replacement. A physical object *x* is an *artefact token of an artefact type y* iff the least specific design of y represents$_2$ part of the actual ontic range of x. When x is an artefact token of y, y will be called an *artefact type* of x. A physical object x_1 *is a token of the same artefact type as* a physical object x_2 iff there is an artefact type of which both x_1 and x_2 are tokens. Observe that if the relation of being an artefact token of is a function (i.e. if x is an artefact token both of an artefact type y_1 and of an artefact type y_2, then y_1=y_2), then the relation denoted by the expression '... is of the of the same artefact type as ...' is transitive.

Consequently, my laptop is a copy of that laptop on the shelf iff there is the least specific artefact design that represents parts of the ontic ranges of both laptops. My laptop preserves its identity as long as its least specific design represents some part of its ontic range, i.e. if the least specific design represent some part of the ontic range of the laptop with *B*' in place of *B*, then the laptop survives the replacement of *B* with *B*'. On the other hand, if the design at issue represents no part of the ontic range of the laptop with *B*', then the replacement process puts an end to the laptop.

Let the expression 'design(x, y)' abbreviate the expression 'a states of affairs x is a design of an object y'. Since designs are intentional states of affairs, the intended domain of the following formal theory of designs contains only intentional entities: intentional objects and intentional states of affairs.

Any design is supported by an engineering specification. I claim that for any design, at least one of such specifications is identical to or may be faithfully translated into a set of sentences (from L_A). The symbol '`design`(x)' will denote the set of sentences that constitute the translation of one of the support of a design of x.

I claim in this paper that designs are (intentional) states of affairs representing objects.

(21) design(x, y) → Soa(x) ∧ Obj(y).

The most specific design of an artefact x will be called the *full* design *of* x and the least specific design will be called the *minimal* design *of* x. The fact that x is the full design of y will be denoted by "Design(x, y)". The fact that x is the minimal design of y will be denoted by "design$_0$(x, y)".

(22) (i) $\mathrm{Design}(x, y) \equiv \mathrm{design}(x, y) \wedge \forall z\, [\mathrm{Design}(z, y) \rightarrow z'' x]$,

(ii) $\mathrm{design}_0(x, y) \equiv \mathrm{design}(x, y) \wedge \forall z\, [\mathrm{Design}(z, y) \rightarrow x'' z]$.

By 'Design(x)' and 'design$_0$(x)' I will denote, respectively, the full and minimal design of x. Similarly, the singletons `Design`(x) and `design`$_0$(x) will represent, respectively, the full and minimal design of x.

23 is the conclusion of the foregoing argument.

(23) $\mathrm{Art}(x) \rightarrow \exists y_1, y_2\, [\mathrm{Design}(y_1, x) \wedge \mathrm{design}_0(y_2, x)]$.

It follows from (22) and (23) that the full design of x and the minimal design of x are unique, therefore I will denote them by, respectively, $\mathrm{Design}(x)$ and $\mathrm{design}_0(x)$.

The notion of minimal design is the objective ground for artefact identification. This entails that if x is an artefact type, then the minimal design of x is part of every state of affairs in which x occurs:

(24) $\mathrm{Occ}(x, y) \wedge \mathrm{design}_0(z, x) \rightarrow z'' y$.

The above axioms do not guarantee that artefact designs are not circular. There are at least two kinds of circularity at stake. The first one is more straightforward. Both artefacts and non-artefacts may occur in artefact designs, but on pain of infinite regress I assume that no artefact occurs in its own design.

(25) $\mathrm{Design}(x, y) \rightarrow \neg \mathrm{Occ}(y, x)$.

25 does not proscribe the design supported by the sentence 'The hammer x consists of the haft y and …', but it does proscribe the design supported by the sentence 'The hammer x consists of the hammer x and …'. Incidentally, notice that 25 establishes the special sense of the expression 'A design of an artefact determines the ontic range of the artefact'. Namely, if x is a design of y, then x does not specify in what states of affairs y occurs but specifies the states of affairs in which occur those objects which compose y.

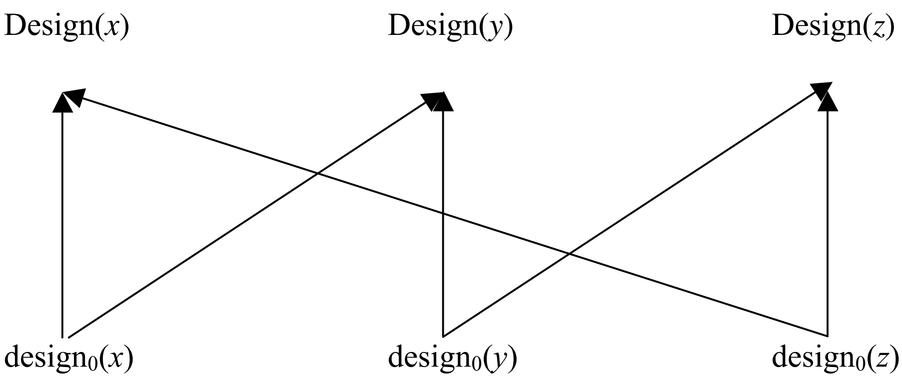
The second type of circularity is more complex. Assume that a design of an artefact x is less specific than a design of an artefact y and a design of y is less specific than a design of x. If we conceded that all artefacts have exactly one design, such a case would be excluded by the asymmetry of the relation of being less specific than (i.e. relation <). However, since we allowed that some artefacts may have more than one design, the situation depicted below is possible.

$$\begin{tikzcd}
\mathrm{Design}(x) & \mathrm{Design}(y) \\
\mathrm{design}_0(x) \arrow[u] \arrow[ur] & \mathrm{design}_0(y) \arrow[u] \arrow[ul]
\end{tikzcd}$$

In this case it seems that x is a proper part of y (because a design of x is a proper part of a design of y) and y is a proper part of x (because a design of x is a proper part of a design of y), which conclusion is absurd. In order to exclude such cases I introduce axiom 26:

(26) $\mathrm{design}_0(x)<\mathrm{Design}(y) \wedge \mathrm{design}_0(y)<\mathrm{Design}(x) \rightarrow x=y$.

Of course 26 does not eliminate all cases of design circularity. For instance, 26 allows for the following situation:



However, in order to exclude all such cases we need either introduce denumerably many axioms or resort to a second-order theory.

The identification of the minimal designs with the ontic ranges of artefact types entails that artefacts types with the same minimal designs are identical. Needless to say, if two artefact types have the same non-minimal design, then they are identical as well. So if y_1 and y_2 are artefact types, then the following claim is valid:

(27) $\mathrm{Design}(x, y_1) \wedge \mathrm{Design}(x, y_2) \rightarrow y_1=y_2$.

The purposes of an artifact do not determine uniquely its design since artifacts made according to different designs may serve the same purpose, but it might be argued that the design of an artifact determines uniquely its purposes (as ascribed to it by a community of rational agents).

(28) $\mathrm{Design}(x_1)=\mathrm{Design}(x_2) \rightarrow \forall y\ [\mathrm{Purpose}(y, x_1, z)\equiv\mathrm{Purpose}(y, x_2, z)]$.

(29) $\mathtt{Design}(x_1)=\mathtt{Design}(x_2) \rightarrow \mathtt{Purpose}\ (x_1, y)= \mathtt{Purpose}\ (x_2, y)$.

In what follows, I will use two auxiliary notions:

(30) (i) $\mathrm{design}(x) := \{y\colon \mathrm{design}(y, x)\}$,

(ii) $\mathtt{design}(x) := \{\mathtt{design}(x)\}$.

Epistemic dimension

The third element of my conceptual model of artefacts is background knowledge. When Smith designs some artefact, her designing is not a chaotic sequence of independent actions. Her designing forms a relatively compact structure of actions linked together by her conceptual decisions based on some background knowledge. The information she refers to does not determine her action exhaustively, but the more influential impact it exerts, the less accidental the resulting design turns out to be. Similarly, when Brown produces the artefact designed by Smith, Brown is guided by information from some source of information. The "sum" of information from both sources will be called the *background knowledge relevant for* a given artefact. Perhaps the term 'knowledge' might be misleading here since I mean by it an unordered collection of information to which a designer(s) or a manufacturer(s) of an artefact implicitly or explicitly refers. The background knowledge relevant for an artefact x contains not only general theorems about the nature of objects of the same kind as x, but also practical rules of thumb relevant for the production of x. For example, the practical experience of a potter also falls under this broad notion of knowledge. The majority of artefacts we use are designed and manufactured on the ground of vague psychological and sociological observations concerning our desires, fears, preferences, beliefs, etc., but we may generically determine the content of the relevant background knowledge by using labels: mathematics, quantum chemistry, physiology of hearing, etc. W. Vincenti shows in Vincenti [1990] that any sufficiently mature branch of engineering grows in the course of time its own specific body of knowledge.

I will represent the background knowledge relevant for an artefact x by a set $\mathtt{Knowledge}(x)$ of sentences from L_A.

(31) $\mathrm{Art}(x, y) \rightarrow \mathtt{Knowledge}(x) \neq \varnothing$.

It seems plausible to assume that the background knowledge is a theory with respect to the consequence operation $\mathtt{C}$. I define an auxiliary extension of $\mathtt{C}$:

(32) $\mathtt{C}_{K(x)}(X) := \mathtt{C}(X \cup \mathtt{Knowledge}(x))$.

Of course, our new consequence operation must be consistent (with respect to $\mathtt{C}$). Moreover, since we are interested in communities of rational agents, I stipulate that $\mathtt{Purpose}(x, y)$ be $\mathtt{C}_{K(x)}$-consistent with $\mathbf{Design}(x)$ (i.e. that the set $\mathtt{Purpose}(x, y) \cup \mathbf{Design}(x)$ be $\mathtt{C}_{K(x)}$-consistent):

(33) $\mathtt{C}_{K(x)}(\mathtt{Purpose}(x, y) \cup \mathbf{Design}(x)) \neq L_A$.

The background knowledge relevant for an artefact x is determined uniquely by a design of x.

(34) If $\mathtt{Design}(x_1) = \mathtt{Design}(x_2)$, then $\mathtt{Knowledge}(x_1) = \mathtt{Knowledge}(x_2)$.

The states of affairs represented by $\mathtt{Design}(x)$ characterise the static features of x, but the set $\mathtt{C}_{K(x)}(\mathtt{Design}(x))\backslash\mathtt{C}_{K(x)}(\varnothing)$ represent the dynamical features of x. In particular, the latter describe (the patterns of) x's causal interactions with other objects.

Finally, observe that in general the purposes of an artefact do not determine its full design or the respective background knowledge. Usually we may achieve our aims by different means.

Operative dimension

The last element of my conceptual model is instructions of use. As a rule, artefacts do not help us in achieving our aims merely by themselves, but we must "set them in motion." Even those more automatic devices, such as mixers or washing machines, require from their users some actions. In addition, more sophisticated artefacts as pieces of music "work" only if their "users" are properly disposed or behave in a special way. Some artefacts, such as household appliances, are accompanied by explicit sets of instructions, others such as books or paintings, are to be used according to some implicit strategies. If you fail to follow the instructions of use for an artefact, you will presumably not achieve the aims for which you make use of that artefact. Obviously, every complete set of instructions for an artefact does not completely characterise all details of the artefact's use.

As in the case of designs, I distinguish a *technological instruction of use* from a *philosophical instruction of use*. The former is usually a sentence in the imperative mood, the latter is the ontic representation of the declarative counterpart of that sentence. The sentence 'Press the power shot button in intervals of at least 5 seconds!' is a technological instruction associated with the state of affairs that some y presses the power shot button in intervals of at least 5 seconds, which is a philosophical instruction of use.

Introducing technological instructions of use we usually have two aims. First, they are to guarantee that a user of an artefact and the artefact itself meet certain conditions, i.e. the respective states of affairs in which the user and the artefact occur are among the artefact's philosophical instructions of use. Secondly, the technological instructions of use are to guarantee that the "surroundings" of the artefact are of the prescribed kind. Most artefacts are environment sensitive, that is, they work in accordance with their user's wishes only if they are used in the specific conditions of environment. When one exploits a given artefact, one should guarantee that objects (possibly including other intentional agents) in its neighbourhood have certain features. The respective states of affairs in which these objects occur are also among philosophical instructions of use.[7]

Since I speak about artefacts used by communities of rational agents, therefore it is reasonable to assume that it is the designer(s) who formulates the instructions of use for such artefacts. Sometimes, however, it may happen in the course of time that some users modify these instructions (by deleting or adding a new item) when they notice either that the artefact in question does not achieve one of the aims they ascribe to it or that some instruction of use may be substituted by another instruction if the latter is more easier for them to bring it about. Subsequently, I contend that it is a community of rational agents that eventually ascribes instructions of use to artefacts, but I also contend that it is an designer(s) of an artefact who plays a decisive role in this process.

Thus, I surmise that it is feasible to recast the technological instructions related to an artefact in a community by means of the predicate 'Use'. Use(x, y, z) means that a state of affairs x is a (philosophical) instruction of use for an artefact y in a community z. A set $\mathtt{Use}(x, y)\subseteq L_A$ will contain the linguistic representations of these states of affairs.

(35) $\mathrm{Art}(x, y) \rightarrow \exists z\ \mathrm{Use}(z, x, y)$.

(36) $\mathrm{Art}(x, y) \rightarrow \mathtt{Use}(x, y)\neq\varnothing$.

(37) $\mathrm{Use}(x, y, z) \rightarrow \mathrm{Soa}(x) \wedge \mathrm{Art}(y) \wedge \mathrm{Soa}(z)$.

(38) $\mathtt{Use}(x, y) \rightarrow \mathrm{Art}(x) \wedge \mathrm{Obj}(y)$.

It is obvious that $\mathtt{Use}(x, y)$ is $\mathtt{C}_{K(x)}$-consistent with $\mathtt{Purpose}\ (x, y)\cup\mathtt{Design}(x)$.

(39) $\mathtt{C}_{K(x)}(\mathtt{Purpose}\ (x, y)\cup\mathtt{Use}(x, y)\cup\ \mathtt{Design}(x))\neq L_A$.

The instructions of use must also satisfy the *feasibility constraint* to the effect that a user of an artefact should be able to follow its instructions of use:

(40) If x is an instruction of use for an artefact y with respect to a user z, then z is able to bring it about that x is the case.

The instructions of use for an artefact x are uniquely determined by the design of x and the background knowledge for x or only by the design of x:

(41) $\mathrm{Design}(x_1)=\mathrm{Design}(x_2) \rightarrow \forall z\ [\mathrm{Use}(z, x_1, y)\equiv\mathrm{Use}(z, x_2, y)]$.

(42) $\mathtt{Design}(x_1)=\mathtt{Design}(x_2) \rightarrow \mathtt{Use}(x_1, y)=\mathtt{Use}(x_2, y)$.

Definition of artefact

[7] It seems to me that the notion of instruction of use plays here the same role as the notion of mode of deployment in the Functional Representation approach (cf. Chandrasekaran and Josephson [2000], p. 171).

The general idea behind the notion of instruction of use is that if we follow all prescribed commands, then an artefact produced according to its design will help us to achieve the aims for which it was produced (and we are in a position to ascertain that fact if we have access to the relevant background knowledge):

(43) $\mathtt{Purpose}(x, y) \subseteq \mathrm{C}_{K(x)}(\mathtt{Design}(x) \cup \mathtt{Use}(x, y)) \setminus \mathrm{C}_{K(x)}(\varnothing)$.

43 delimits the purposes a community of rational agents may ascribe to artefacts. It also shows how the present framework deals with the crucial distinction between proper and improper purposes of artefacts. The former are represented by set $\mathtt{Use}(x, y)$ and the latter are represented by $\mathrm{C}_{K(x)}(\mathtt{Design}(x) \cup \mathtt{Use}(x, y)) \setminus (\mathrm{C}_{K(x)}(\varnothing) \cup \mathtt{Purpose}(x, y))$.

The four-dimensional ontology defines an artefact type as a quadruple consisting of its purposes, design(s), background knowledge, and instructions of use. More precisely speaking,

(44) $\mathrm{Art}(x, y) \equiv \exists z\, \mathrm{Purpose}(z, x, y) \wedge \exists z\, \mathrm{design}(z, x) \wedge \mathtt{Knowledge}(x) \neq \varnothing \wedge \exists z\, \mathrm{Use}(z, x, y)$.

Likwise, an artefact type within a community y is represented as a quadruple $\langle \mathtt{Purpose}(x, y), \mathtt{design}(x), \mathtt{Knowledge}(x), \mathtt{Use}(x, y) \rangle$.

5.6. Further work

Although the above results provide a general picture of the world of artefacts, they are too general to be applicable. In particular, we lack an analysis of the notion of device function and the related notions (e.g. the notion of behaviour). Besides, if we want to evaluate the adequacy of these considerations, we should check them against some particular domain of artefacts. These issues will be the subject of the further study within this project.

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