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Characterizing Functions based on Ontological Models from an Engineering Point of View

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Abstract. The purpose of this paper is to characterize some definitions of function in engineering and philosophy from an engineering point of view. To do this, this paper firstly discusses some fundamental kinds of function based on ontological distinctions. Next, based on them, we characterize our definition with justifications from the engineering view and present an ontological model of artifact function along the product life-cycle. Then, we try to characterize a philosophical definition of biological organs using the model. Next, we discuss function of a non-biological (non-organic) natural thing. Lastly, we characterize functions of an artifact, a biological organ and a non-biological natural thing based on another ontological model along the evolution of creatures.

Keywords. an ontology of function, functions of artifacts, biological organs, and natural things, interoperability of functional knowledge

Introduction

This paper discusses some ontological issues on functionality. Much research has been carried out on the notion of function in several research areas. In engineering design [1]-[6], artificial intelligence [7]-[10] and value engineering [11], representation of artifact function for computer-supported design has been investigated. In philosophy [12]-[17], what is function of mainly biological organs has been extensively discussed.

The problem here is that there are many definitions of function without clear relationship among them [4][6][15]. Especially, there is a large gap between definitions of functions in engineering and those in philosophy. For example, in engineering, Umeda *et al.* define a function as "a description of *behavior* abstracted by human through recognition of the behavior in order to utilize it" [3]. In this definition, a function is directly related with a physical process performed by an artifact when it is used. The perception similar to this can be found in many definitions in engineering (e.g., [2][5][7][8]). On the other hand, in philosophy, a function is typically a special feature of a thing [15]. For example, in the causal-role function analysis [13] and ICE theory [17], a technical (artifact) function is regarded as a special kind of capacity to be ascribed to an artifact. Thus, according to the former definition in engineering an artifact *performs* a function, while an artifact *has* a function as a property or a function is *attributed* to an artifact according to the latter definition in philosophy. Then, we could say "a function exists *outside* an artifact" according to the former *or* "a function

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exists *inside* an artifact" according to the latter. As you see, there are large ontological gaps between them, even if we compare two definitions of artifact functions only.

In this paper, we aim at characterizing some definitions of function in engineering and in philosophy based on two ontological models of functions. The consideration is made from an engineering point of view based on our long experiences in ontological research on function in engineering design. The authors have established a suite of ontologies of artifact function and an ontology-based functional modeling framework for engineering design [18]-[21]. The framework has been successfully deployed in some manufacturing companies [20]. Those practical experiences provide real engineering basis for the consideration in this paper.

We first discuss some ontological distinctions and fundamental kinds of function based on our previous consideration [20]-[24] with comparisons to some definitions of function in the literature. Next, Section 2 characterizes our definition of artifact function [20][22][24] using those kinds of function and explains its justifications from the engineering point of view. In addition, we present an ontological model of artifact function proposed in [23], which is a macroscopic temporal model along a product life-cycle. Then, in Section 3, we try to account a philosophical definition of function of biological organs proposed by Johansson *et al.* [25] by extending (and specializing) that model. We also make a comparison between our definition and the definition of function in Basic Formal Ontology (BFO) [26]. In addition, Section 4 discusses functions of non-biological (non-organic) natural things and then compares our view with the definition of artifacts proposed by Borgo and Vieu [27]. Lastly, we characterize those functions of artifacts, biological organs and non-biological natural things based on another ontological model of function along the evolution of creatures.

Our motivations for information systems to clarify the notion of function and the relationships among definitions of function are an explicit viewpoint for describing functional knowledge in the information systems and its interoperability [21]. In practice, engineers tend to describe functional knowledge such as functional decomposition [2] based on an implicit perception of function in an ad hoc manner [20]. As a consequence of inconsistency of the implicit perceptions, it is difficult to share and reuse the functional knowledge. Moreover, the interoperability between functional knowledge based on different definitions of function in the literature is difficult due to the lack of the clear relationship among those definitions. Thus, the ontological investigation in this paper will contribute toward providing engineers some differentiated viewpoints for consistent functional modeling. The clarification of relationship among several definitions in the literature contributes to interoperability.

1. Ontological Distinctions of Function

In this section, we discuss some fundamental kinds of function based on ontological distinctions of function. Those distinctions except that between function and behavior discussed in Section 1.2 are orthogonal to each other. The target of the discussion here is mainly function of artifacts[2], while the similar distinctions can be made for biological organs and non-biological natural things as discussed later.

[2] In this paper, we regard an artifact as a physical object that exists in the spatial-temporal space and consists of devices (components) as a system based on a device-oriented ontology [20][24]. We use term 'device' for both artifacts and components. We treat not the artistic aspect but only the physical and functional aspects of an artifact. We discuss our view on artifacts in Section 4.

1.1. Actual Function and Capacity Function

As discussed in the introduction, one of the large differences between the definitions of functions in engineering and those in philosophy is when and where a function exists. In many definitions in engineering (e.g., [2][5][7][8]), a function is directly related to a process performed by an artifact when the artifact is used. On the other hand, in many definitions in philosophy, a function is a special feature of an artifact [15] and what the artifact has or is ascribed to an artifact.

For distinctions of these two senses of function, in this paper, we call the former *actual function*. We regard the latter sense of function as a *capacity to perform the actual function* and then we call the latter *capacity function.* There are deep ontological differences between them. A capacity function is a thing (property) that a device *has* (or is *ascribed* to a device), *exists inside* the device, and is *dependent* on the device. On the other hand, an actual function is a thing that a device *performs (cannot have)*, exists *outside* the device and is *less dependent* on the device. A capacity function is based on a set of appropriate properties (e.g., physical attributes, structure, geometry and material) for realization of the corresponding actual function. A capacity function represents a possibility to perform an actual function and thus is potential and hidden in a device. Then, it is induced by a user at the use phase according to context of use (as discussed in the next sub-section). Thus, when we say “a device has a function”, the function referred to is a capacity function.

In philosophy, Boorse [28] makes a similar distinction in terms of a “weak function statement” and a “strong function statement”, which roughly correspond to the actual function and the capacity function, respectively. The distinction between *function* and *functioning* in [25] is also similar and they roughly correspond to the capacity function and the actual function. The capacity function is also similar to the notion of *disposition* in [25]. We will revisit these topics in Section 3.

As an exceptional definition in engineering design, Hubka and Eder [1] define functions as follows: “The function is a property of the technical system, and describes its ability to fulfill a purpose, namely to convert an input measure into a required output measure under precisely given condition.” In this definition, a purpose represents intended effects as output effects, while a function is the *ability* for an internal task of the technical systems. Thus, the purpose and the function in their definition [1] roughly correspond to the actual function and the capacity function, respectively.

1.2. Function and Behavior

For the actual function performed by an artifact, the distinction between function and *behavior* is important. In both engineering and philosophy, this distinction is extensively discussed. In many definitions in engineering, a function is defined as behaviors *intended* by a user (and/or designer) and is regarded as a subset of behaviors. Such the intention-relatedness is captured in the literature as “aims-means” [1], “means and ends” [8], F-B relationship [3] and in value engineering [9].

We capture an actual function based on context-dependency. We define *behavior of a device* as the changes in the attribute values of the operands which the device affects [20][24]. When a behavior type is identified as the behavior of a device, its instances can play different functions (as *roles* as discussed below) according to teleological contexts, which we call *function contexts (FC)* and we will discuss in Section 1.3. For example, when we identify “to exchange (transfer) heat” as the behavior type of a heat exchanger, which is described as temporal changes of the temperatures of the fluids, an instance of the heat-exchange behavior type can play either of the following functions; (1) "to give heat" function when the heat exchanger is used as a heater with a turbine in a power plant, (2) "to remove heat" function when it is used as a radiator with an engine in a car.

Thus, we define an *actual function* as "a role played by a (device-oriented) behavior in a teleological (function) context" [20]. We call this just 'function' as discussed in Section 2. A role concept cannot be defined without a context and the existence of a role concept depends on the existence of the context [29]. Strictly speaking, a function is a composite of a function-role concept and the behavior playing the function-role concept, which is a kind of a thing called a role-holder [29]. Thus, a function is not a selected behavior. Based on the definition, we say that "a behavior plays a function role". If a device performs a behavior and the behavior plays a function role in a context, then the device plays a *function-performer role* in the context.

In some philosophical considerations [13][17][28], function is regarded as a role, though the role is played by a function-performer. According to the categorization of definitions of function in [15], our definition is a kind of 'goal-contribution theory' in 'recent past backward-looking reductionist category', because our definition is 'goal-directed' (see the next subsection) and we need 'reach back into history as far as the establishment of the goal' [15]. The general characteristics of roles have been extensively investigated such as 'externally-founded', 'anti-rigid' and 'dynamic/ multiple' [29][30]. We have shown that function satisfies those generic characteristics [20]. On the other hand, in [2][5][7], function is not distinguished explicitly from behavior based on the intention-relatedness. Some researchers distinguish purpose from function (e.g., [31][32]), whereby the purpose represents a human-intended goal. Chandrasekaran and Josephson discuss an environment function as an effect on the environment [9]. While the effect of the function in our definition is local within the device performing the function, the environment function and the purpose capture the effects on the environment or human perception, which are consequences in causal or enabling relations of the local effect. Borgo *et al.* [33] investigate a formal account of the definitions of function and behavior in [9].

1.3. External Function and Component Function

An artifact performs an actual function when it is used externally by a user. A component in a system performs such a function that contributes to the whole goal of the system. We distinguish these functions as *external function* and *component function* according to the distinctions of the function context as explained below.

The *external function* is performed by the largest and outermost device as the whole system under an *external function context* which depends directly on the user's intention, i.e., how the artifact is used by a user externally. By the word "external" here, we mean that its *context* is *external* to the device when the device is seen as the whole system. Thus, all the performances of external functions are directly intended by a user[3]. An artifact has generally some capacities to perform the external functions (i.e., capacity functions) as discussed in Section 1.1. Among those possible functions, an external function is performed according to a specific user's intention. For example, a screwdriver can be used for performing a screwing (exerting rotational force on a

[3] Note that the success of the actual function and its validation by a user are different problems.

screw) function or a hitting (exerting linear force on something) function using the tail part of the screwdriver. Some of such capacities are intentionally designed by the designer, as discussed in the next section.

The *component function* is performed by a component embedded in a system under a *system function context* which is determined by a *functional structure* in which the system's whole function is hierarchically achieved by a sequence of (relatively finer-grained) components' functions. The functions of the heat exchanger discussed above are examples of this type. When the heat exchanger is embedded in a power plant, under the system function context which consists of the whole function "to convert heat energy to electricity" and the functions of other components in that plant, the heat-exchange behavior plays "to give heat" as the component function. Such a functional structure is called "degree of complexity" [1], function decomposition [2], or function achievement relation [20]. The causal-role function analysis [13] also captures the relationship between the whole function and the component functions as contribution. The constituent function [34] also is similar to the component function.

This distinction is related to the issue of what a function depends on. The external function depends primarily on a user's intention (I-goals [24]), while a component function depends directly on a functional structure of the system. For an artifact, the possible component functions are determined by a designer. When it is used, component function actually performed is selected according to the external function of the system based on the user's intention. In this sense, the actual component function of an artifact *indirectly* depends on the user's intention as well. For a biological organ in an organism, as we will discuss in Section 3, its component function contributes to the function of the organism as the whole system in the same manner as that of an artificial component. It depends *only* on the functional structure of the system, because there is no external use of the system. Based on this same nature, we can separate the user's intention from the system function context of the component function and thus we could regard that the component function depends on the system (NI-goals [24]). Note that an actual function (either component or external function) depends not only on its context but also on a behavior and a device's capacity (capacity function).

Vermaas and Houkes emphasize that functions are features that are ascribed by agents to artifacts relative to use plans and human beliefs on capacity [17]. Our external function context depends on such a "use plan," though such agent's beliefs are implicit in our definition. Garbacz points out that a function is a state of affairs, which represents a connection between objects and processes [35]. Our definition tries to define the connection in terms of the context from the device-oriented point of view.

1.4. Essential Function and Accidental Function

The function context is categorized also according to whether it is essential to a specific device or not. In the example of the screwdriver discussed above, the screwing external function is intended by its designer. The screwdriver is designed and manufactured (i.e., is made to exist) for performing this function. Such an external function is regarded as an *essential external function* under a *designed function context*. On the other hand, the hitting function of the screwdriver is intended *not* by the designer *but only* by the user. Such an external function is regarded as an *accidental external function* under an *accidental use function context*. This distinction is relative with respect to a device. For example, the screwing function could be performed by a key as its accidental function. The hitting function is an essential function of a hammer. As discussed in Sections 3 and 4, the external functions of a physical entity which is not intentionally designed (e.g., biological organs and non-biological natural things) are regarded as *accidental*.

Whether a component function embedded in a system is regarded as essential or accidental depends on the equality of the functions of the component between *function*$_1$ intended by a designer of the component and *function*$_2$ intended (used) by a designer of the system. Usually, the *function*$_2$ is the same as the *function*$_1$ and then is essential[4]. If not, the *function*$_2$ is regarded as *accidental* to the component. For example, slurry containing diamond powder is manufactured for improving cutting efficiency. However, in a cutting machine, the slurry is also used for cooling the cutting blade. In such a case, from the viewpoint of the intention of the designer of the slurry as a component, the slurry performs a cooling function as an accidental component function. If there is no designer of a system (e.g., an organism), its component functions can be regarded as *essential* as discussed in Section 3, because they are developed in nature (e.g., by natural evolution). If there is a designer of a system and no designer of a component (e.g., an artifact has a natural thing as its part), the component function of the component is regarded as *accidental* in the same manner of the external function.

In the discussion above, the actual function of a device is discussed. Both essential and accidental functions require the device's capacity to perform the function. We call the capacity function to perform an essential actual function of a device as an *essential capacity function*. For an accidental actual function, we call an *accidental capacity function*. For an essential actual function of a device, the physical properties necessary for the capacity to perform that function are intentionally designed by a designer and are manufactured. An accidental capacity function of a device is not intended but potentially inheres in the device. When an appropriate context and appropriate inputs for the corresponding accidental actual function are given to the device, that accidental capacity function is induced and is exhibited as an actual function. In the example of the screwdriver, the screwdriver has the screwing essential capacity function and the hitting accidental capacity function based on its shape and hardness.

1.5. Actual function and Specification of Function

So-called *required function* in engineering design exists in nature as a *specification of function*, which specifies what type of actual functions is required to be realized in spatiotemporal space at the use phase. By specification, we here mean a *proposition* that specifies a thing in the real world[5] [36] independently of whether it is explicitly written or not. Before designing, an instance of the *required function at design phase* is usually given as a part of a design requirement. Before using, a user intends an instance of the *required function at the use phase* as an implicit (not-written) instance of specification of function.

The capacity function also has the sense of *specification* that specifies what type of actual functions the device can perform at the use phase, though it has the sense of 'possibility' as well. In the same manner, we can consider *specifications of device, behavior and function context.* A specification of a device is typically produced as the result of designing and specifies the physical properties of the device to be manufactured (see Section 2.2).

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[4] We can make other distinctions such as mandatory and optional (supplementary).

[5] Note that class definitions in ontologies are *meta*-specifications, because they include classes which specify specifications. We do not discuss such *meta*-specifications here.

2. A Definition and an Ecological Model from an Engineering Point of View

2.1. A Definition of "Function" from an Engineering Point of View

In this section, we explain justification of our definition of function in Section 1 from an engineering point of view. Firstly, our primary definition of "function" is not a capacity function but an actual function. Its first justification is the importance of *actual effects* and values for users from the engineering viewpoint. In engineering, what type of actual effects a user can obtain is of importance. It is represented as an instance of a specific type (class) of the actual function (e.g., "to give heat").

The second justification is the definition of those types of function. Such a definition (e.g., "giving-heat function" class) refers to a behavior as a role-player (heat-flow between two entities) and a function context as a role context (the teleological focus on the heat-receiving entity). Thus, it is defined as a sub-type of the actual function. Each capacity function cannot be defined without referring to those types of actual functions. For example, the heat-exchanger has two capacity functions which are the capacities to perform the giving-heat actual function and the removing-heat actual function. In addition, the required function in engineering design refers to those types of the actual function in the same manner. In the design phase, there is no *instance* of the actual function to be realized but its *type* exists before almost all designs start[6].

The third justification is from the realization-independence of function. A specific required function can be realized by different artifacts with different physical features. This engineering requirement justifies our definition of functions as an actual function detached from artifacts.

As a consequence, the existence of an instance of an (actual) function is *dynamic.* It exists dependently on a specific function context such as a user's intention and its existence is supported by a realized behavior of a device and the device's capacity to perform the function. This dynamism fits in well with the function's properties; those are, dependence on contexts and realization-independence. On the other hand, the instance of an essential capacity function exists during the whole period of the device's existence (we will examine this topic in Section 4). Thus, its existence is *stable*. This difference is the result of the detachment of function from a device.

Our definition of function includes accidental functions as well as essential functions. An accidental use is distinguished from a (proper) function in many philosophical writings (e.g., [12][15][16]). Such accidental use is called "function-as." We regard an accidental effect as a function if it is recognized in a specific function context. If not, it is a behavior. The first justification for our use of the term 'function' here is the effect-oriented definition from the engineering viewpoint. As actual effects, an essential function and an accidental function can have the same intended effect for users[7]. The second justification is that our primary definition of function is an actual function, which is different from the capacity function inhering in a device which is mainly discussed in philosophy.

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[6] One might think so-called innovative design invents a new type of function. We think many of such designs invent not a type of function but a new *way of function achievement* ("how to achieve a function") [20] for an existing type of function or new application of an existing function to a different operand. This is a benefit of our detachment of function from the way of function achievement [20].

[7] By the "same effect", we here mean the same type (class) of the function. The level of optimization of function's performances such as efficiency, accuracy and reliability is different between that of the essential function and that of the accidental function.

2.2. An Ecological Model of Function

We have proposed an ontological model of artifact function along a product life-cycle [23]. This section briefly overviews that model which is called an *ecological* model of function. Figure 1 shows its portion. It shows macroscopic temporal changes of the individuals (instances) of function and function-related concepts where the time flows from left to right. Each of Figure 1(a), (b), (c) ... shows a thing that appears at a *phase* in a time interval or at a time point. The transition between those phases (depicted as a dark-gray arrow) is made by an activity such as designing, manufacturing and use.

As the first phase (a), the *specification* (in the sense discussed in Section 1.5) of a *function context* of anticipated use and that of an *actual function* to be realized are given as a part of the design requirement. The latter is called the *required function at the design phase*. At the phase (b) after the designing activity, there are the *specifications* of a function and a device, which are determined for satisfying the design requirements and are to be realized in the real world. The former is called *specification function*, which satisfies the required function in the successful design.

The manufacturing activity is to make a device to exist in the real world at the phase (c) according to the specification of the device. The device has (at least) an *essential capacity function*, which satisfies the specification function in the design result. In addition, a device can have other accidental capacity functions as the derived (and unintended) results of the designing and the manufacturing.

Figure 1(d) shows a situation where a user intends to realize a specific function in a specific *external function context*. The intended specific function is represented as a *specification of function* and is called a *required function in the use phase*.

As shown in Figure 1(e), when a device is used in the intended function context and the device has the capacity to perform a function satisfying the required function in the use phase, the device performs a behavior instance and the behavior plays the actual function instance as a role in the function context. This is a result of a user's activity to select such a device that has a capacity function which can satisfy the required function. The capacity function is either essential or accidental to the device. When the device is broken and then loses the capacity function (or when the capacity is insufficient due to the wrong selection), the actual function disappears. If the lost capacity function is essential, it might sometimes affect the device's identity as discussed in Section 4.

This ecological model of function explains what kinds of function (discussed in Section 1) exists in what phase in the product life-cycle. It clarifies the relationships among those kinds of functions. Please refer to [23] for the detail. Using this model, we can characterize functions of biological organs and non-biological natural things as discussed in the following sections.

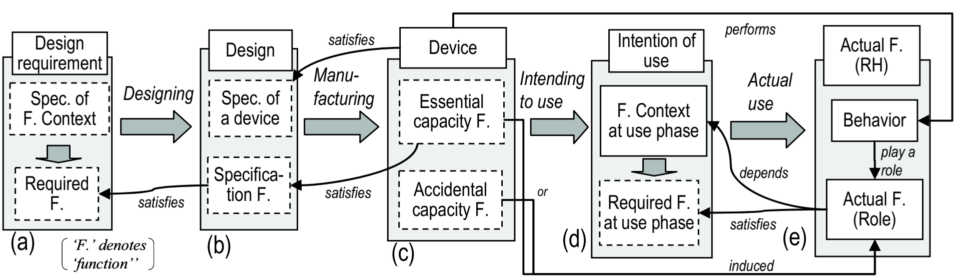

Figure 1. An ecological model of function

3. Characterizing a Philosophical Definition of Function of Biological Organs

In philosophy, function of biological organs has been extensively investigated [15]. Typically, a function of a biological organ inheres to the organ (called a *function bearer*) and is an *objective non-relational property* as pointed out in [37]. The differences between functions of biological and artificial functions are extensively discussed in the book of [37]. Here we try to characterize a philosophical definition of biological function by Johansson *et al.* [25] using the model discussed thus far.

Johansson *et al.* define a function of a biological organ as “a disposition to act in a certain way to contribute to the realization of [a ...] larger function on the part of that whole organism which is its host.”[25] This definition can be represented as a special case of the model of artifact function presented in Section 2 with extensions of the definitions introduced in Section 1 in which the function performer is generalized from an artifact to a physical entity without intentional designing/manufacturing. Figure 2 shows the example of a heart. The function of the heart, “to increase pressure of the blood”, is performed (realized) in the *system function context*, that is, the functional structure of the blood circulation system (and of the body as the whole). Its performance relies on the heart’s capacity to perform that function. This is the same as that of a pump embedded in a fluid circulation system. Thus, the notions of “function” and “functioning” defined in [25] roughly correspond to the *capacity function* and the *actual function*, respectively, There is, however, neither designer’s intention nor *external function context* based on user’s intention of external use. Thus, we can classify the function in this definition as *essential and component capacity-function*. In the case of biological function, in addition, the system function context is fixed to the organ and does not change. Thus, the relationship between the organ’s capacity function and the actual function performed by the organ is *static* unlike the component functions of engineering artifacts. This seems to be one of the reasons of the definition of function as a capacity function, which makes sense in the case of biological function.

We, however, think that the biological organs can perform *external functions* as well. For example, a heart can perform a sound-making (heart sounds) function as an external function under the context of medical diagnosis whereby a medical doctor listens to heart sounds. This function is regarded as *accidental*, because there is no designer’s intention for external use of the biological organ. Many philosophers reject this as a function of a heart (e.g., [12]). We would also reject it under their definitions. As discussed in Sections 2.1, our justification for the acceptance of the sound-making as an accidental external function of a heart is the effect-oriented viewpoint of engineering. Moreover, the typical discussion of the rejection in philosophy is about

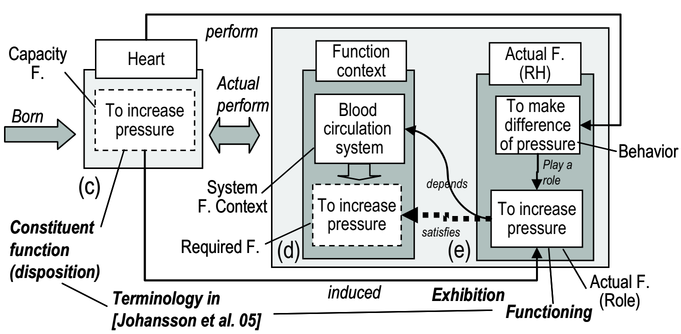

Figure 2. A model of biological function

component functions of the heart, which we do not discuss here. In addition, we do not discuss external function of the *organisms* (e.g., human) as the whole system.

Arp and Smith recently propose a sophisticated definition of functions including both artifact function and biological function in BFO [26]. According to that paper, a (generic) function is a *realizable entity* (“realizable dependent continuant”), which has a *realization*(s) as a process in which its bearer is participant. The realization occurs in virtue of the bearer’s physical makeup, which that bearer possesses because of how it came into being. An artifact function is defined under this generic definition as such a function that the bearer’s physical makeup for the function is realized by intentional designing and manufacturing to function in a certain way and the function bearer does indeed reliably function in that way. This definition of function is also similar to the *capacity function*, while its realization corresponds to the *actual function*. This definition of artifact function roughly corresponds to the *essential capacity function* and does not include the *accidental function*. The definition includes the notion of reliability, though we think that the reliability is a relative issue of optimization of the function’s performance and thus our definition of function does not include the reliability. In [26], a biological function also is redefined under that generic definition. That definition includes the component function only in the same manner as the above.

4. Artifact Function and (non-biological) Natural-thing Function

In this paper, we intuitively regard an artifact as “a physical thing that is intentionally designed and manufactured based on intention about function to be used”. Usually, an engineering artifact is based on designer’s intention about function to be used by potential users. Thus, this view of an artifact is not based on the user’s intention at the use phase but the designer’s intention at the design phase. As discussed in Section 1.4, an artifact is designed and manufactured for performing its essential actual function and thus it has appropriate physical properties as the corresponding essential capacity function. When the artifact loses its essential capacity function permanently, the artifact is not regarded as the same subtype of artifacts any more[8]. Thus, for an artifact, having the essential capacity function is an *essential property* of the artifact. By the *essential property* of a thing, we here mean such a property that provides the thing’s *identity* [36]. For example, the essential property of a screwdriver is to have the screwing capacity function. When a screwdriver loses this capacity permanently, it is not regarded as a screwdriver anymore. Note that the actual performance of an essential function (as an actual function) is *not* an essential property of an artifact. Even if a screwdriver is used for hitting a nail as an accidental function, we can say that it is still a screwdriver.

We can consider a function of a natural thing[9], which is neither intentionally designed nor manufactured for use[10]. When a physical thing is regarded as a natural

[8] Malfunction of an artifact can be defined with respect to its *specification function* (defined in Section 2.2) determined by a designer. We think there are the following three cases of malfunction according to the levels of the loss of capacity; (1) the artifact’s capacity to perform a function is *insufficient*, so that the level of the performance of an actual function (e.g., the output temperature of a heating-function) is insufficient with respect to the specification, (2) the capacity is *temporarily lost*, so that the artifact temporarily cannot perform an actual function of the same type required in the specification, and (3) the capacity is *permanently lost* (e.g., an artifact is fatally broken and thus it cannot be repaired). Only in the last case (3), the artifact loses its identity and thus ceases to belong to the same subtype of artifacts. In the case (1) or the case (2), malfunctioning artifacts keep its identity and remain belonging to the same type.

[9] We exclude biological things, organic things and living things from the natural things discussed here.

thing and it is used under a teleological intention, it is regarded as that it performs an *accidental external function*. For example, let us consider a situation where a pebble as a natural thing is used by a user as a paper-weight. In our view, the pebble performs the "to exert vertical force on a piece of paper" function as an accidental external actual-function. The pebble potentially has a capacity to perform that function as an accidental capacity function based on its weight and the shape of its bottom. It is induced by the use as a paper-weight. It is regarded as *accidental*, because there is no designer's intention for external use as a natural thing. It is impossible to enumerate all the capacity functions of a natural thing like the accidental capacity functions of an artifact.

Next, let us consider a situation where an agent cuts the bottom of the pebble and then make its surface flat, intending to make the pebble to hold the paper stably (i.e., with intention to improve performance of the pebble's function). Thus, if we can regard that cutting act as a manufacturing activity, we can regard that manufactured pebble as an artifact, which has the exerting-force function as its *essential* function. In this case, there is no explicit design phase but we can regard that an implicit design activity has been done simultaneously with the manufacturing activity.

Lastly, let us consider a situation where an agent selects a pebble with a flat bottom from many natural pebbles in a dry riverbed. This act is regarded not as a manufacturing activity but as a selection activity to select an appropriate function-performer based on the required function at the use phase. This is the same as the act performed in the transition from the phase (d) to the phase (e) in the model for artifacts shown in Figure 1. For example, a user can select either a screw driver or a key for the screwing function. Thus, in this situation, the selected pebble is not an artifact but a natural thing, which can perform the function as an accidental function.

Borgo and Vieu deeply investigate an ontological definition of 'artifact' [27]. In their definition, an artifact is the result of "intentional acts" of an agent called a *creator*, which are selection of a physical object and attribution of some capacities to it. In the example of the pebble, by those *creator*'s acts, a paperweight made of a pebble comes into existence. According to their definition, even if a user only selects an object and attributes a capacity to it, the object can be regarded as an artifact (like the example of "a piece of coal to write on a board" in [27]). In this case, it is based on the user's intention at the use phase (the phase (d)) and the capacity[11] (the phase (c)) in our model shown in Figure 1. Their definition includes the case where a designer is the *creator* of artifacts as well ("a commercial pen"), though the designing process includes other important activities besides the intentional selection and the capacity attribution.

Our view on artifacts requires designer's intention (the phases (a) and (b)), a designing activity and a manufacturing activity (the phase (c)) as well as the user's intention. It captures the change inherent in a thing, which is made by intentional designing/manufacturing activities. This observation leads us to a distinction between two kinds of the notion of an artifact, say, a *weak artifact* which can be recognized even if there is only the user's intention and a *strong artifact* which requires the designer's (and manufacture's) intention as well. We might be able to consider that it is a terminological problem which of them is called just an 'artifact'.

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[10] Our goal here is neither to define notions of artifact and natural thing nor to define the designing and manufacturing activities that change a natural thing to an artifact. We discuss functions of them, when a physical thing is regarded as an artifact or a (non-biological) natural thing.

[11] In [27], the capacity is *attributed* to an artifact by an agent. The artifact does not always have the capacity in reality. Precisely speaking, our capacity function represents a real capacity that an artifact has.

In addition, there is notion of 'product' which is similar to an artifact. We regard a product as "a produced or manufactured thing". It is a role played by an output (resultant) thing of the manufacturing activity. An artifact plays the product role in the context of the manufacturing activity. The notion of artifacts in this paper depends on a designing activity and a manufacturing activity with designer's intention. Thus, the context of the notion of a product is narrower than that of an artifact.

Note that the term 'product' has different meanings such as 'for sale' and 'to be offered to a market'. Indeed, WordNet defines two senses; "commodities offered for sale" and "an artifact that has been created by someone or some process". Our view corresponds to the latter sense. Borgo and Vieu define 'product' based on 'exchange purpose' which has wider sense than the former sense 'for sale' [38].

5. Characterizing Functions along the Evolution of Creatures

In this section, we try to explain the differences among the definitions of functions of artifacts, biological organs and non-biological natural things discussed thus far. Our approach is to characterize those differences based on an ontological model along the evolution of creatures using the ontological distinctions discussed in Section 1.

In the pre-human era, there were only the *component functions* under the *system function context*, because there was no external use of biological organs. As discussed in Section 3, the relationship between the *actual function* and the *capacity function* is static in a biological system. Such core notion of function at this era roughly corresponds to the philosophical definitions of biological organs in [25][26], where a function is defined as the *essential and component capacity-function*.

In human era, humans *use* a physical thing externally with an intentional goal. Thus, the notions of the *external function* based on the external use, *the required function at the use phase* and the *accidental function* appeared in this era. Using these notions, we can represent intentional use of a non-biological natural thing and its function as *accidental external function*. The function in the case where a user is a creator of an artifact in the definition of an artifact in [27] roughly corresponds to the notion of function at this era. The function context of a component function of a sub-part of the non-biological natural thing is a functional structure which is the same as that of the biological system. The whole goal of the functional structure of the biological system, however, inheres in itself, while that of the non-biological natural thing in the external use depends on the intention of an external user. Therefore, although definition of biological function as a kind of *essential and component capacity-function* makes sense in pre-human era, it is not successful in explaining *accidental and external function* that appeared in the human era.

Moreover, in order to improve quality of the performance of the functions, humans started to do the designing activity and the manufacturing activity under their intentions of use. At this phase, the notion of the *required function at the design phase* and the *specification function* in engineering design came into existence. In our view, the notion of an *artifact* appeared based on such designer's intention. Our functional model presented in Section 2 includes all these notions.

In this model, we understand that the notion of function has evolved along with the evolutional history of creatures. We can characterize the functions of biological organs and of non-biological natural things in external use at the initial and intermediate eras in the evolutional process for the artifact function at the last era.

6. Concluding Remarks

In this paper, aiming at clearer understanding of the notion of function, we pointed out ontological differences of some definitions of functions of an artifact, a biological organ and a non-biological natural thing. It is based on ontological models using the fundamental kinds of functions with the ontological distinctions. Using them, some important differences and their relationships were explicated.

Our aim here is not standardization of definition of function but interoperability of different definitions of function. For this, we had proposed some upper-level types of function as a reference ontology of function [21]. The kinds of function in this paper are more fundamental and will be integrated into the reference ontology.

Of course, we do not claim that the ontological distinctions in this paper are sufficient for explaining all the differences among functions of an artifact, a biological organ and a non-biological natural thing. The contribution of this paper is to point out some important distinctions from the engineering point of view. There are other important aspects for the difference [16] such as the social aspect in artifact function [38] and the evolutional aspect for biological organs (e.g., reproduction). Lastly, a formal account of the distinctions like that in [33] is expected.

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