# A unifying definition for artifact and biological functions

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**Abstract.** Physical artifacts and biological systems have been studied from a variety of perspectives in different disciplines. These entities show many common characteristics and are investigated using similar notions except for one important aspect: functionality. Notwithstanding many attempts, the search for a unified notion of functionality that could encompass both the functions attributed to natural objects, like biological organisms, as well as those attributed to designed objects, like artifacts, to date has remained an open challenge.

Deepening an earlier characterization of engineering functions, this paper starts with an introduction to the notions of behavior and context, which become the basic blocks for the construction of a general framework for a unified definition of function. The approach distinguishes three types of functional contexts (systemic, user and design) and clarifies the role of goals in defining biological and artifact functions. Finally, it shows that the notion of systemic function, as detailed in the paper, succeeds in comprising both biological and artifact functions. The proposal is evaluated against a collection of desiderata and examples taken from the literature.

Keywords: function, context, role, biological function, engineering function

## 1. Introduction

The notion of function is a useful conceptual tool in clarifying the relationship between physical entities as well as how entities interact with the environment. We can see this in simple objects like chopsticks and chairs and in complex devices like nuclear plants and satellites as well as in the variety of biological, natural and socio-technical systems. Since functions are usually not addressed in isolation, we generally discuss the functions of a class of objects, e.g., grippers, and compare it to that of another class, e.g. hands. However, the relationship between functions and objects is twofold and indeed we seem to use different notions of function depending on the type of objects we study. The typical example is the distinction between artifact functions and biological functions. The artifactual world (that of the artifacts) and the biological world (that of biological systems) are each naturally explained in terms of functions but each seems to require its own particular notion. This fact is not just a curiosity. Today information systems developed for these two worlds cannot reliably communicate since we cannot align core notions like that of function. The unification of the two notions of biological and artifact functions fills this gap leading towards the construction of information systems for domains, like biomimetics and bio-inspired engineering, that necessarily cross the biological vs engineering divide.

The difficulty of achieving a satisfactory single notion of function relies on basic characteristics of the systems to which such a notion should apply. While biological systems are usually loosely characterized as systems of organs (broadly understood) that interact together to achieve some goal; the intuition on artifacts is less clear and conflicting views have been proposed, e.g., see Hilpinen (2011). Fortunately, we do not need to put forward a precise definition of biological system nor of artifact, for our goals it suffices to take a generic (even permissive) view. In particular, we take artifacts to be physical objects that exist by human intervention like cars, pacemakers and space aircrafts. We assume that this human intervention

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is intentional and involves precise reasons for producing those artifacts. Without loss of generality and to further emphasize the contrast with natural entities, below we restrict our attention to *technical* artifacts as introduced in Borgo *et al.* (2014), that is, physical entities that have been selected (typically via a manufacturing process) and that, due to this selection, are expected to behave in a certain way in a given situation.

A preliminary version of the approach discussed in this paper has been presented in Mizoguchi *et al.* (2012). In that work an ontological study of the notion of function has been carried out and a proposal has been presented. In this paper we deepen and improve the proposal, analyze the background assumptions, and discuss its applicability.

Historically, our proposal stems from an informal definition of function focused on engineering artifacts (Kitamura *et al.*, 2006; Kitamura and Mizoguchi, 2010). The attempt to clarify the multiple dependences between function and intentionality in this and other definitions in the literature, led to a revision of that approach. The revision was carried out applying techniques of ontological analysis (Welty and Guarino, 2001) and made evident that the approach could be generalized to cover a much broader class of functions spanning both biological and artifact functions. The application of ontological analysis to intentionality is not original, it has already been exploited in clarifying, e.g., the relationship of intentionality with objects (Vermaas *et al.*, 2011) or with artifacts (Borgo *et al.*, 2014). Our analysis applied to the notions of function, in particular in the framework of Mizoguchi *et al.* (2012), leads us to distinguish at least two uses of intentionality in functional studies. On the one hand, intentionality has to do with the choice of a system as the subject of study. In this case, it occurs in the form of a selection, an act that ideally isolates an entity (typically a complex entity or system) as the context of functional discussion. On the other hand, intentionality has to do with the choice of a behavior and of a state of the entity. In this latter case, intentionality occurs in the form of two selections: *(a)* the selection of some parameter(s) of the relationship between the entity (subject of functional considerations) and the environment; and *(b)* the selection of a desired state (goal) in the interaction between the entity and the environment. The selections *(a)* and *(b)* can be traced fairly well in studies of artifact functions but, generally, are not explicitly addressed when dealing with biological functions. In our opinion, the latter use of intentionality, namely, when intentionality is used to identify the goal, is particularly relevant in all uses of functional talk: the crucial contribution of the notion of goal in theories of artifact functions has an interesting counterpart in theories of biological functions even though this aspect is not usually discussed. This observation leads to reconsider the role of intentionality in artifact and biological functions and to formulate a more general notion of function which abstracts from the specificity of artifacts. Note that in the presentation we insist on viewing this new notion as a generalization of the initial notion of artifact function. The reason is that in this way it is simpler to introduce and motivate the formalization of such a definition and, thus, to make it immediately available to information systems and applications in general.

It turns out that, instead of tackling intentionality itself, one can rely on the derived notion of *desired state* or *goal* (Mele, 2003). Given an (intentional) agent, we take a goal of the agent to be a configuration of the world that the agent prefers or, more precisely, a state which maximizes a strategic interest for the agent. The notions of goal and of agent are central to our analysis and are here taken as primitives: that is, we do not choose a specific meaning nor provide a formalization. Instead, we use them as building blocks for our work. In particular, the notion of agent could here be taken to comprise people, software and even complex systems in general as long as it is understood what a goal for the agent is. Note that our generality leads to consider also agents, e.g. systems, which are not intentional agents. To consistently talk about goals in relation to this large class of agents, we adopt a weak notion of goal, namely, that of *a state to be achieved*. When the goal is the goal of an intentional agent, it will be understood as the agent's desired state as usual. The remaining notions central to our approach, namely, behavior and context, will be analyzed in more details in the paper. These terms are used with quite different meanings in the literature and there is no agreement even on the basics for their characterization. We will thus clarify how they are used in this framework.

The paper is organized as follows. Section 2 introduces the topic via two examples of biological and artifact functions. Section 3 presents the notion of behavior used in this paper and Section 4 distinguishes the three function contexts, namely, systemic, user and design contexts. Section 5 highlights the relevance of behaviors in function contexts and the next section, Section 6, looks at the relationship between systemic contexts and objects, and between user contexts and events. Section 7 gives the unified definition of function. This definition is used to discuss essential vs accidental functions in Section 8 and is evaluated in Section 9 with respect to a list of desiderata. Some scenarios, usually taken as problematic, are explicitly addressed to show how the definition overcomes common criticisms. Section 10 discusses related work, and the last section adds concluding remarks.

## 2. Two examples

An example of a biological function discussed in the literature is the function of the heart in the human body (Wright, 1973). In these discussions, it is claimed that the human heart is an organ that has the function to pump blood throughout the body via the circulatory system supplying oxygen and nutrients to the tissues and removing carbon dioxide and other wastes. An example of artifact function discussed in the literature is the function of a heat exchanger (Forbus, 1988). A heat exchanger is an artifact that has the function to cool or heat realized by transferring heat between two fluids.

In both cases, we talk about the function of an object in a system: the heart connected to the human circulatory system, the device connected to two fluid circulatory systems. Also, in both cases we point to a goal of the function: the tissues have to be supplied with blood rich of oxygen and nutrients while the blood rich of carbon dioxide and other wastes must be taken away from the tissues; the temperature of one fluid system has to be reduced and the temperature of the other fluid system to be increased. One notices in these two examples a similarity across their function descriptions. In particular, both functions depend on a precise context and goal. We can then ask: Is this similarity limited to these specific examples or is it pointing to some general property of functions? If this is a general property, can we leverage from it to discuss a common view on functions?

On the other hand, typically, one is not free to choose a context for a biological function, the function of a biological organ is somehow constrained in the needs of the system to survive. This is clearly not the case for artifact functions since a device does not have survival constraints and can always be used in ways not foreseen by the designer while there is no designer for biological functions. The above questions and the relative difficulties in unifying biological and artifact functions require a suitable framework where functional discussions can be reconstructed and compared. This is the first aim of the paper. To set the framework we begin with the introduction of a few general notions: event, process, behavior and (some types of) context.

## 3. Behavior

Behavior and context are two key notions for our understanding of function, consequently we start our study with their ontological and formal characterization. Admittedly, we focus on the subclass of behaviors and contexts crucial to a development of functional discourse: the precise understanding of behavior and context in general is addressed in part but remains beyond our goals. For a general grounding of the background we adopt, the reader can look at the YAMATO ontology (Mizoguchi, 2010; Borgo and Mizoguchi, 2014) and references therein.[1] Note, however, that the work presented in this paper remains largely independent of the YAMATO ontology, that is, one can apply this framework within other perspectives.

Following YAMATO, we take behavior to be a type of process along the lines of the discussion in Stout (1997) and Galton and Mizoguchi (2009), i.e. a temporal entity that captures what is called an ‘ongoing

[1] http://www.ei.sanken.osaka-u.ac.jp/hozo/onto_library/upperOnto.htm

instantaneous change'. We begin with the basic distinction between events and processes, the notion of behavior will follow. Let us say that an event is, roughly speaking, the happening in a spatio-temporal region, and in this sense a spatio-temporal entity. Consider an event $e$ of a heater that heats an object from temperature $A$ to temperature $B$ during a period of time $T$ where $T = [t_0, t_1]$. While the event $e$ takes place, i.e. during the heating, the object undergoes a continuous change, namely, the continuous increase[2] of temperature, which is what the object *experiences* at each instant from $t_0$ to $t_1$. In natural language one can utter "the heater is heating" at each instant in the interval $T$ to refer to this process at that instant, i.e., to indicate a change which is 'ongoing' at each of those instants. We characterize this change using the terms *ongoing*, since the change happens in time, and *instantaneous*, since at each instant there is an actual change. Such a process should not be confused with the heating event $e$, i.e., the global change from $t_0$ to $t_1$. The latter has temporal extension $T$, while the process has no temporal extension. More precisely, being an instantaneous entity the process has temporal extension zero. Yet, it perdures since it continues to exist at each instant of the temporal interval $T$. In other terms, the process is the continuous change that, instant after instant, builds up the event of a heating during $T$ and, in turn, the event is the combination (the god's view, so to speak) of all the instantaneous changes that happen to the object as time flows from $t_0$ to $t_1$. For another example, consider the difference between your experiencing life (your awareness of being here now, a process) and your life itself. Although the first is present at each instant from your birth to the end of your life, the two are different things. In our terminology, awareness is an ongoing instantaneous experience (since your awareness is present at each instant and at each instant it refers to the awareness at that very instance) and thus it is a process, while your whole life is an event as usually understood.

As said, the notion of behavior discussed in this paper does not refer to behavior in general; it focuses on the behavior of technical artifacts used as devices. A device is an object that plays an agent role and uses some input to produce some output. Useful related notions (actually, roles) are *conduit, operand, medium, input/inlet and output/outlet*.[3] An individual can play multiple roles (Mizoguchi *et al*., 2007) at the same time; for example, a shaft in a car plays a conduit role and a medium role respectively to transfer and to hold torque. Note that in this approach objects can be seen as systems of components (*systemic view*). The idea is that the components of a system interact with each other and these interactions realize a behavior of the system as a whole. A behavior is identified by looking at the changes caused on some operand. In the case of the heating device described in the previous example, the heater's behavior is modeled as a change between the temperature of a fluid (the operand) at the inlet and at the outlet. This view assumes that changes in real life are reducible to changes of physical (observable) qualities.

Scientists, like engineers and biologists, work with a simplified model of the processes in real-life. Since real processes are rich of features and it is hard to build a perfect model, they select some aspects and the relative properties which are relevant for their tasks and ignore the rest. Thus, they actually deal with simplified representations obtained by considering a limited perspective of the ongoing change(s). As we will see in the subsequent sections, such a model of behavior is adequate for understanding functions.

## 4. Function Context

The notion of context is a useful conceptual tool applied in different domains, from psychology and sociology (Rogoff and Lave, 1984), to philosophy and linguistics (Lewis, 1980), from logic and reasoning (McCarthy, 1993; Ghidini and Giunchiglia, 2001) to human-computer interaction (Dey, 2001). Contexts are regularly used and studied in interdisciplinary research (Brézillon *et al*., 2013). Notwithstanding the large interest in the research community, no shared definition has emerged in the literature. It is generally claimed that a context is like an *environment* or a *situation*, though these terms may have quite different connotations (Dey, 2001).

[2]This simply means that at each instant the temperature has a measurable tendency to increase, typically given the first derivative of the temperature function.

[3]These and other notions are detailed in the device ontology presented in Mizoguchi and Kitamura (2009).

Our goal is to investigate the notion of function with respect to a suitable notion of context. We assume that the latter notion is available and use it as a *primitive* element that we specialize into the notion of function context. For this purpose, we informally assume that a context $C$ is a complex entity with (at least) the following characteristics:

1. $C$ existentially depends on (at least) one entity $O$. We highlight this by writing that the context $C$ is *for* $O$. For example, a heating context depends on a heat exchanger artifact, call it $A_e$. We then say that such a heating context is for $A_e$ (and perhaps for other entities as well).
2. For some entity $O$ there exist multiple distinct contexts $C_1, \ldots, C_n$. For example, heating and cooling can be contexts for the same heat exchanger artifact $A_e$.
3. There exists a context $C$ which is context for different entities $O_1, \ldots, O_m$. For example, a school system is the context for both the teachers and the students of that school.
4. A context $C$ for $O$ identifies an entity $S$ consisting of all the objects in $C$, including $O$, and a description of a state (or set of states) of $S$. We call such a $S$ the *support* of $C$. Typically, $S$ is the mereological sum of the entities in the context and in richer cases may include their relationships as well. For example, the support of the cooling context is the sum of the heat exchanger artifact (a radiator) with the connected pipes, pumps, fluids, heat generator(s) etc.
5. Let $C$ be a context with support $S$, then a larger context is a context $C'$ with support $S'$ such that $S$ is a mereological part of $S'$. In short, contexts can be nested. For example, the school context is nested into the education context of some social system.

In summary, we assume that a context $C$ for an entity $O$ is a complex entity that identifies an entity $S$ (the support) which includes $O$. A context $C$ is included in a larger context $C'$ provided the support of the former is a part of the support of the latter. We now introduce function context as a specialisation of the above notion of context.

### 4.1. Function, Systemic and Use Contexts

As this paper deals with the attribution of function to biological and artificial physical objects, in what follows we further elaborate on the above notion of context restricted to physical objects, thus leaving aside abstract entities. Indeed, in the study of physical objects that can perform a function, contexts are introduced to help identifying the physical environment with which these objects interact. More precisely, this restriction amounts to the notion of *(physical) function context*, i.e., contexts that allow to define some function role. Here we also assume that a relation "contributes to" is given, see Borgo and Mizoguchi (2014). This relation applies to two processes and in this paper the second process will always be a process that leads to a state. Thus, the relation "a process A contributes to the process of achieving state B" (or "a process A contributes to state B", for short) stands for the causal relationship that the process A is bringing about the state B as in "the raising of the mist contributes to a state of lack of visibility."

Based on the notion of artifact's behavior introduced in the previous section, we define a function context as follows:

**Definition 1** (Function Context)**.** Given an object $O$, a *function context $C$ for $O$* is a triple formed by a context for $O$, a behavior $B$ of $O$ and a state $G$, called *goal*, such that the goal $G$ is supposed to be achieved by the behavior $B$ [4].

**Definition 2** (Appropriateness between Goals)**.** Fix a function context $C$ for $O$ with goal $G$ and behavior $B$. We say that $G$, specified by $C$, is *appropriate for a goal $G'$*, specified by a function context $C'$ for an object $O'$, if there exists a sequence of distinct contexts $C_1, C_2, \ldots, C_n$ with distinct objects $O_1, O_2, \ldots, O_n$, goals $G_1, \ldots, G_n$ and processes $B_1, \ldots, B_n$ such that (1) $O = O_1$, $O_i$ is part of $O_{i+1}$ (for $1 \leq i < n$), and $O_n = O'$; and (2) $G = G_1$, $G' = G_n$ and the process $B_i$ achieving $G_i$ contributes to the process $B_{i+1}$ achieving $G_{i+1}$.

[4] The notion "being supposed to be achieved" is taken as primitive here. Formally, it can be reduced to the relationship "causally contributes to", which is also used in the next definition of appropriateness between goals. Recall that the "causally contributes to" relation has been partially formalized in Borgo and Mizoguchi (2014).

As discussed in the introduction, "goal" in these definitions does not mean "intentional goal" since no agent might be involved in these contexts. The goal in the definition of function context is simply the state associated with the given context, that is, the state to be achieved. Furthermore, appropriateness of a goal $G$ is always relative to some other (larger) goal $G'$.

There are two basic types of function contexts: systemic function context and use function context.

**Definition 3** (System and its components)**.** A *system* is an entity which consists of two or more identified components and their relationships. The components can be atomic or complex. An *atomic component* is not decomposed further. A *complex component* is itself a (sub-)system. Every system is decomposed into atomic components in a finite number of steps.

Typically, we distinguish physical systems, having only physical components, social systems, having only social components and systems that mix both of them.

**Definition 4** (Systemic Function Context)**.** A *systemic function context $C$ for $O$*, systemic context for short, with support $S$ is a function context such that (1) $S$ is a system, (2) $O$ is a component of $S$, and (3) the goal $G$, specified by $C$, is a state for $S$.

The system $S$ can be fairly simple like a chair understood as the combination of the legs, the seat and the back (including their relationships and structure), or quite complex like the environmental water circulatory system. For example, a systemic context $C$ for a heat exchanger artifact $O$ with a support system $S$ can have as goal "the temperature of the heat-transfer fluid is at most 70°C" to be achieved by a behavior $B$ of the heat exchanger $O$. The support system $S$ consists of $O$, the engine and the other components (and their relationships) like the heat-transfer fluid circuit, the engine and the fluid.

**Definition 5** (Use Function Context)**.** A *use function context $C$ for $O$*, use context for short, with support $S$ and goal $G$ is a function context relative to some fixed event $E$ such that: $(a)$ $S$ is the mereological sum of the participants in $E$; $(b)$ $O$ participates in $E$; $(c)$ an intentional agent (or group of agents) participating in $E$ with a goal $G'$ is selected, where $G'$ and $G$ could identify the same state; and $(d)$ the selected agent in $E$ considers during $E$ the achievement of goal $G$, by an actual behavior of $O$ in $E$, as contributing to the achievement of $G'$.

Note that since $O$ participates in $E$ and $S$ comprises the participants in $E$, then $O$ is part of $S$. From the definitions, in the use context the goal $G$ is appropriate for the goal $G'$ of the selected agent in $E$.

Definition 5 aims to capture the intuition that a use context is a function context in which the behavior is an actual behavior of some participating entity during the event. Since this function context becomes relevant only when an agent participating in the event takes this very behavior as a means to achieve his/her goal (and typically, enforces it), the constraint on agents and their intentionality is justified. For example, consider the event $E$ of an agent with dirty hands opening a door by pushing it with a hammer that she happens to have at reach. The goal of the agent in this event is having the door open and clean (more precisely, as clean as before the opening). Here the support $S$ consists of the component $O$ (hammer), the agent (which here coincides with the hammer user) and all other participants in the event, e.g., the door. The use context $C$ relative to $E$ with respect to $S$ specifies a goal $G$ and behavior of $O$ (say, the goal of having the door open, and the behavior of exerting force to the door by using the hammer as push handle) which is appropriate for the agent's goal in $E$ to have the door open and clean ($G'$).

Looking at the relationship between the component subject to functional ascription and the system to which it belongs, systemic contexts can be structurally divided in *direct* and *general*.

**Definition 6** (Direct Systemic Function Context)**.** A *direct systemic (function) context* is a systemic context where the component $O$ is a part of $S$ and no proper subsystem of $S$ containing $O$ is given.

The definition aims to rule out the case of an element $O$ which is related to $S$ in the context $C$ via some intermediary subsystem of $S$. The general class of systemic function contexts can be characterized as follows:

**Definition 7** (General Systemic Function Context)**.** A *general systemic (function) context* is a finite sequence $C_1, \ldots, C_n$ ($n \geq 1$, $c_i \neq c_j$) of direct systemic contexts such that if $S_i$ is the support system of the direct context $C_i$ with $i < n$, then $S_i = O_{i+1}$, i.e., $S_i$ is the component of the support system $S_{i+1}$ of the direct context $C_{i+1}$.
A general context for $O$ in $S$ is a general context $C_1, \ldots, C_n$ in which $O = O_1$ and $S = S_n$.

Note that any direct context is a general context as well. The counterpart claim is false. Unless otherwise specified, in the following we take systemic functions to be defined using direct systemic contexts.

### *4.2. Design Context*

The design context exists in relation to designed objects, i.e. artifacts that have been designed. In this case, the figure of the designer plays a crucial role since the designer selects some behaviors of the designed object (perhaps indirectly via selecting its properties) as essential for it, and this gives rise to another important class of function contexts.

**Definition 8** (Design Function Context)**.** Given a designed object $O$, a *design function context $C$ for $O$*, design context for short, is a systemic or use context $C$ for $O$ that satisfies the constraints envisioned by $O$'s designer.

The design context is closely related to the use context since in both cases an intentional agent determines which behavior(s) to consider. It is instructive to clarify the relationship between design and use contexts. Assume we are dealing with a designed object, call it $D$. We can distinguish two kinds of use contexts for $D$. In the first case we have an event $E$ which, roughly speaking, satisfies the constraints posited by the designer for a proper use of $D$ and during which the object is used as the designer intended. In this case, use context and design context agree. In the second case, we have an event $E$ which does not satisfy the constraints posited by the designer for a proper use of $D$ or during which the object is used in a way not intended by the designer. In this case, use context and design context disagree.

The specification of these two kinds of use contexts is sometimes identified by the designed object itself in virtue of the properties that make it artifactual.[5] From this brief presentation, it is clear that the design context differs in kind from the systemic and use contexts. For example, if a designer designed an object with the specification of hammering nails into pieces of wood as its use situation, then the designed object is properly identified as (having the essential properties of) a claw hammer. The designed object is then expected to satisfy whatever required by the design context, and the designer's intention determines its function. Yet, the design context does not directly identify a particular event in which the claw hammer functions as such.

We insist that systemic context, use context and design context differ from several ontological perspectives. The first and the second rely on different ontological categories: systemic contexts are centered on the object category while use contexts on the event category. These both differ from the design context since in the latter the actual event is not identified but only constrained. The three are also distinguished since the intentionality source in the use context is a participant to the event, namely the user. The intentionality in the design context comes from the designer which, as such, does not participate in the use situation. Finally, the systemic context makes no reference to intentional agents, and thus here the notion of goal, as previously motivated, is not associated to an agent.

However, it would be too harsh to conclude that systemic and use contexts are unrelated. Together they provide flexible and complementary ways to isolate functional information. For instance, systemic contexts can be used to alternatively capture the core elements of a use context. We can see a use context from the viewpoint of a systemic context by taking the functional object in the use context as the selected

[5]To be more precise, by designed objects here we mean engineering artifacts as described in Borgo *et al.* (2014). A designed object in this sense is an object which undergoes an (intentionally performed) manufacturing phase. Since the manufacturing phase aims to make the object suitable in some use context(s) desired by the designer, by undergoing this phase the object is associated with the specification of such use context(s).

component of the system, the agent (the user) as another component of the system, and the system itself as composed by (at least) the object and the user. The user intention is not part of the resulting systemic context but the goal of the user matches the goal associated to the context. Indeed, in this correspondence the user's goal in the use context is like an operator for the selection of the system context's goal. A use context is a systemic context where the goal of the functional context is identified by the user. A design context is a systemic context where the goal of the functional context is identified by the designer.

## 5. The Relationship between Behavior and Context

The pivoting idea in our definition of function is the following: functions are given by the interplay between behaviors and function contexts. Ontologically speaking, the behavior gives the variety of possible changes for a given object; the function context provides the means to isolate a subset of the possible behaviors by filtering out the input-output that are irrelevant with respect to the context. Finally, these selected behaviors in the given context play a *functional role* as discussed later. In Kitamura *et al.* (2006); Kitamura and Mizoguchi (2010), a technical (actual) function is defined as "a role played by a (device-oriented) behavior in a teleological (function) context". The investigation in this paper exploits, makes formal and generalizes this basic intuition.

The three function contexts seen above lead us to three kinds of functions that we dub *systemic function*, *use function* and *design function*, respectively. In what follows we concentrate on the fairly new notion of systemic context and describe how it brings into the picture the needed information for the function definition.

As said, a systemic context $C$ includes a support system $S$, to be seen as a whole object, with a set of its components or subsystems and their relationships. It also provides one of the system's behaviors and a selection of the subsystems' and the components' behaviors. As anticipated in the description of the general systemic context, the structural relationships between system and components impose further constraints on the selected behaviors: the selected behavior of the system as a whole has to be 'matched' by the behavior of its subsystems and components in the sense that the selected system's behavior is caused (physically or otherwise) by some of the component's and subsystems' selected behaviors. This is formally captured by the notion of appropriateness (Definition 2). We already anticipated that the object performing the function in a systemic context is one of the components while, differently from use and design contexts, there is no intentional agent. This latter point is of primary relevance: in the use context (the design context) the agent (the designer, respectively) brings about the goal, which is intentionally selected by that agent. In the systemic context the goal is provided by the selected behavior of the system.

Let $X,Y,Z,W$ be a set of components and/or subsystems of $S$, the support of a systemic context $C$, such that $X,Y$ and $Z$ cover the input-output relationships relative to the behavior of $S$, see Figure 1. Let $X$ be the target component whose function in the given systemic context is to be determined. By the definition of systemic context, the behavior of S corresponds to the combination of some given behaviors of $X,Y$ and $Z$, and we say that the goal of $X$ specified by $C$ is to *contribute* (possibly with $Y$ and $Z$) to the achievement of the goal $G$ as determined by the selected behavior of $S$.

For a more complex example, let us look at the function of the heart in the human body introduced in Section 2 (Wright, 1973; Wouters, 2005). Figure 2 shows some relationships among behaviors, contexts and functions of the heart. A systemic context ($C_1$) for the heart ($X$) is given with the circulatory system ($S$) as its support system (nodes and links related to the systemic context $C_1$ are shown in solid lines). The heart ($X$), selected as the object whose function is to be determined, is of course a part of $S$. Here we consider two selected behaviors of the heart: "pressuring blood" and "making sound". As discussed in Section 3, we capture the behavior of the heart as changes of some operand between input and output of an object (seen as a black box), e.g., the pressuring-blood behavior identifies a change between the

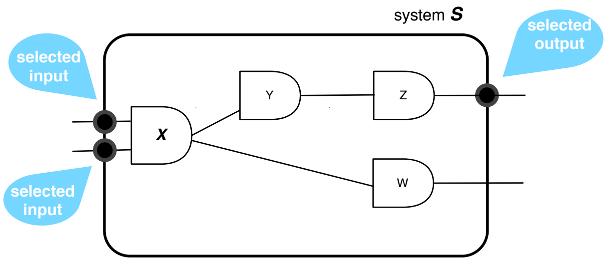


Fig. 1. A system $S$, its components, their connections and $S$'s selected input-output (circled).

pressure of the blood (as operand) at the inlet of the heart and at its outlet.[6] For the sake of the example, let us assume that we have two more components in the circulatory system: the artery subsystem ($Y$) and the kidneys ($W$).

As said, a systemic context provides a selection of behaviors of the system $S$. In this example, the systemic context $C_1$ provides "transferring blood containing oxygen" as a selected behavior of the circulatory system ($S$), which in turn gives a system internal goal to be achieved by its internal components. The systemic context $C_1$ also specifies to have high-pressured blood at outlet of the heart as the goal $G_1$ to be achieved by some behavior of the heart ($X$). The pressuring blood behavior of the heart can achieve this specified goal. Then, the process of achieving this goal contributes to the realization of the selected behavior "transferring blood containing oxygen" via the achievement of the system's internal goal. This is the functional role of "to give pressure" or "pumping blood" which is played by the behavior of pressuring blood. Similarly, the behavior of the artery subsystem ($Y$) plays the functional role of "to let blood pass", which contributes collaboratively with $X$ to the realization of the selected behavior of $S$ in $C_1$.

Next, consider the appropriateness of $G_1$ for $G'_1$, where the latter is specified by $C'$ whose support is the human body $S'$. Beside the circulation system, the human body consists of many parts which require oxygen, e.g., legs and skin shown in Figure 2. If we select as goal $G'_1$ the state in which the oxygen is provided to the organs, the blood circulatory system *contributes* to the achievement of the goal $G'_1$ by transferring blood carrying oxygen. Then, the heart's goal "to have high-pressured blood" ($G_1$) is appropriate for the goal ($G'_1$) "to provide oxygen to organs". Note that the lung's behavior also *contributes* to the achievement of $G'_1$ by taking oxygen into the blood.

Analogously, let the systemic context $C_2$ be like $C_1$ except that the goal $G_2$ of $X$ is the (persistence of the) sound made by the heart, and let us consider its appropriateness for the (persistence of the) body sound goal $G'_2$ relative to the human body $S'$.[7] In Figure 2, the nodes and the links related to the systemic context $C_2$ are depicted in gray-shaded and dotted lines. This time we conclude that the making-sound behavior of the heart, via this goal $G_2$, contributes to the realization of the selected goal $G'_2$ (persistence of body sound) of $S'$[8]. Then, the heart's goal "persistence of heart sound" ($G_2$) is appropriate for the goal "persistence of body sound" ($G'_2$). Finally, note that "to have high-pressured blood", i.e. goal $G_1$ of the heart, is inappropriate for $G'_2$.

As we have seen, the systemic context filters out the components that do not contribute to the system's behavior, e.g. the kidneys $W$ in the previous examples, and preserves only the relevant behaviors of the contributing components (pressuring blood in the first example and making sound in the latter). The component's contribution is mandated by physical laws in the described examples but systemic contexts are

[6]Note that "contracting at a rate" is not a behavior of the heart since it refers to a change of the size of the heart (thus, looking into the black box) and not to a change between input and output. Instead, "contracting at a rate" is how the behaviors blood-pressuring and sound-making of the heart are realized (Kitamura *et al.*, 2006).

[7]In this example, the contexts share their support systems, e.g., the support of both $C_1$ and $C_2$ is the circulatory system $S$. In general, however, the contexts for a specific object can have different support systems.

[8]Biologists usually reject to select this sound producing behavior of the human body and do not consider the "persistence of sound" as a goal, as discussed in the philosophical literature (Wright, 1973; Wouters, 2005). We show that the sound producing behavior of the heart *is appropriate if* one selects that behavior of the human body. Such a selection, however, depends on the knowledge of the domain and the scope of the analysis, see also Section 8.

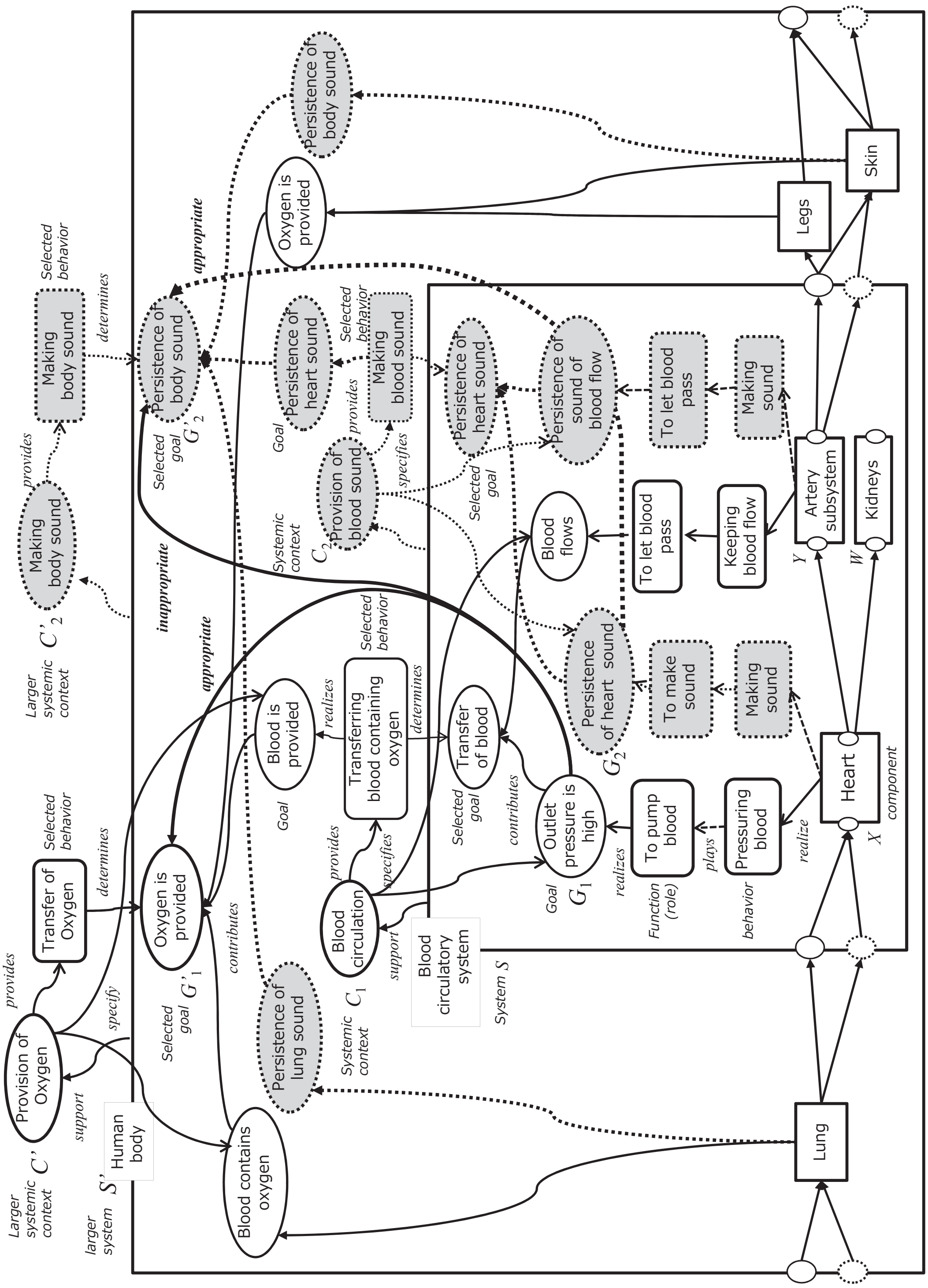


Fig. 2. Functions and Systemic Contexts for the Heart.

not restricted to physical laws in general. For a different example involving social laws, consider the behavior of a person in the context of a school with respect to the educational goal. When the person has some connection to the school, say, s/he plays the role of teacher, the systemic context with respect to the educational goal considers only the behaviors relevant to this role and this goal, e.g., complying with the schedule, giving lectures and assigning homework, and leaves aside things like feeding pets and skiing. The latter behaviors are behaviors of the person, of course, but are not contributing to the achievement of the system's goal.

## 6. Systems and the Systemic Contexts

In general a system does not provide enough information to identify a unique systemic context; some elements, typically goal and focused component, need to be identified counting on further information (recall that the system contains no explicit intentional agent that provides the context's goal). As we have seen in the introduction of systemic contexts, the relationship between a system and a systemic context requires: a selected behavior of the system, selected behaviors of the given components and subsystems, and also the identification of the component whose function is to be determined. Let us call the latter the *functional component*. The selected behavior of the system identifies the goal of the functional component, say $X$, within the systemic context as seen in the previous heart/human body example.

Let us look at this point more precisely. Once a functional component $X$ is given, what we need is a direct functional context $C$ and its support system $S$. Since $S$ does not have to be minimal, it might contain multiple components, among which $X$. The component $X$ has a function in $S$ if one (or more) of its behaviors contributes to the realization of the selected behavior(s) of $S$, and it is in this sense that the selected behavior(s) of S provides a goal $G_1$ for $X$.

The reader should have noticed our use of the term goal which generalizes the standard notion as discussed already in the introduction: the goal in the systemic context is not the goal of an agent and, more precisely, it is *not* an intentional goal.[9] In particular, in systemic contexts the term 'goal' points to a state of the system, identified by the selected behavior, that must be achieved (via the contribution of the focussed component's behavior).

The previous information and knowledge of physical and social laws enable us to make sense of the function of $X$ identified using a direct systemic context $C$. That is, we try to find a general systemic context whose $S_1$ is equal to $S$, $C_1$ to $C$ and $S_n$ to a system $S'$ together with a selection of its behavior. If it is successful, that is, if goal $G$ is appropriate for $G'$, specified by the selected behavior of $S'$, then the function of $X$ makes sense in the sense that it contributes to the realization of the selected behavior of $S'$. If we cannot find any general systemic context for $X$ with a fixed $S'$ for any of its behaviors, then we can conclude that $X$ plays no function with respect to $S'$. This shows that the relationship between the system and the systemic context is partially determined by the structure of the system itself.

## 7. A Unified Definition of Function

The ultimate goal of this paper is to propose a unified definition of artifact functions and biological functions. Usually, this means to find a generalization of these two kinds of function and argue that it forms the *common core* for the notions so that each one is obtained as a direct specialization of it. The identification of such a core-notion is the aim of this section. In doing this, we start from the three kinds of functions isolated earlier, namely systemic, use and design functions.

We said that functions are roles, here called *functional roles*, played by behaviors in a function context. In the previous sections we defined three types of function contexts; their distinction is the crucial element here. These function contexts differ, among other things, in the way they identify the functional role. In systemic contexts, the functional role is given by the systemic context where the appropriateness of its goal is determined with respect to the (goal provided by the) selected behavior of the overall system, which has the functional object as component. In the case of design contexts, the functional role is determined by the designer's intention. Finally, in the case of the use context, the determination is given by the

[9]It is clear that the system's behavior, which is part of the systemic context, has been selected somehow, and this selection can be the result of an intentional choice. For instance, the standard heart/human body example is selected by researchers aiming to understand the heart function in the human body system. The point we are making is that the systemic context, differing from the design and use contexts, does not (need to) contain nor refer to an agent in charge of this choice.

user's intention. It is now time to formalize the corresponding function types based on the definition of appropriate goal (Definition 2) and that of generic systemic context (Definition 7).

**Definition 9** (Systemic Function)**.** Given the following

- an object $O$ and a systemic context $C$ for $O$ with its support system $S$ and goal $G$,
- a systemic context $C'$ with its support system $S'$ and goal $G'$,
- a general systemic context $C_1, \ldots, C_n$, where for $1 \leq i \leq n$, $S_i$ is a support system of $C_i, C_1 = C, S_1 = S$ and $C_n = C', S_n = S'$,

then we say that a behavior $B$ of $O$ *plays a functional role* in $S$ with respect to $C$ and, thus, $O$ *performs a systemic function* in $S$ with respect to $C$ when:
(1) according to the general systemic context, $O$ is a component of the system $S'$, and
(2) the goal $G$ is appropriate for the goal $G'$ via the sequence $C_1, \ldots, C_n$.

Let us see two examples of systemic functions that can be performed by a heat exchanger $O$ in a boiler $S$, subsystem of an electric power plant $S'$. One systemic function of $O$ is "to heat": the heat-transferring behavior $B$ of the heat exchanger $O$ plays the functional role "to heat fluid" in $S$ with respect to a systemic context "increase heat-energy of the fluid", which specifies the goal $G$ "to have fluid's temperature at the outlet higher than that at the inlet". This goal is appropriate for the goal $G'$ "generate electricity" for the support system $S'$.

If now we take $S$ to be the cooling subsystem of the engine system $S'$ of a car, the systemic function of $O$ is "to cool". In this case, the same heat exchanging behavior $B$ of $O$ plays the functional role "to cool fluid" in the cooling subsystem $S$ with goal $G$ "to have temperature of the fluid at the outlet lower than that at the inlet", which is appropriate for the goal $G'$ "generate kinetic energy" specified by the systemic context with support system $S'$.

Regarding the definition of the systemic function, the goal $G'$ specified by $C'$ is determined, as discussed in Sections 5 and 6, by the selected behavior of $S'$, i.e., the support system of $C'$. Also, the behavior $B$ of $O$, by playing the role determined by $C$, contributes to the realization of the goal $G'$ specified in $C'$, by the definition of appropriateness (Definition 2). Recall that the term 'goal' points to a state to be achieved (by the corresponding component under consideration), which is here captured as the realization of a behavior since, from Section 4, the systemic context does not refer to intentional agents nor to intentional goals.

Secondly, we define use functions, based on the use contexts, as follows:

**Definition 10** (Use Function)**.** Given an object $O$, an agent $U$ and a use context $C$, we say that a behavior $B$ of $O$ *plays a functional role* in $C$ and, thus, $O$ *performs a use function* in $C$ for $U$ when:
(1) $O$ and $U$ participate in the event $E$ (the performance) associated with $C$,
(2) $U$ plays the user role from $C$'s perspective,
(3) $U$ believes that the goal $G$ specified by $C$ is achievable by the behavior $B$ of $O$ in $E$, and
(4) the goal $G$ of $C$ is appropriate for $U$'s goal $G'$ in $E$.

The examples of the use functions of a (claw) hammer are explained in Section 4, which are "to open a door" and "to hammer nails".

As noted in the last paragraph of Section 4, a use context is a systemic context where the system $S$ includes the object $O$ and the agent $U$. In other words, the use function is a systemic function where the systemic context's goal is provided by an intentional agent which is part of the system, namely the user. Thus, the use function is a specialization of the systemic function.

Use functions are not intrinsic to the entity but are, so to speak, created by the users. The notion of use function is important for a unified notion of function. It is justified by the notion of accidental function, which will be discussed in the next section, and by the fact that even natural things may have this kind of function in some contexts.

Next, we define the notion of design function, based on the design context, by combining the previous definitions. Here we use the term situation to denote the event of a use context or the support of a systemic context.

**Definition 11** (Design Function)**.** Given an object $O$, a designer $D$ and a design context $C$ for $O$, we say that a behavior $B$ of $O$ *plays a functional role* in a situation that satisfies $C$'s requirements and, thus, $O$ *performs a design function* in that situation when $O$ is designed by $D$ and

a) if the situation is an event, then $O$ performs a use function in this event for the user determined by $C$;
b) if the situation is a complex entity $S$, then $O$ performs a systemic function for the system $S$ whose behavior is selected by $D$.

The main difference between the use function and the design function is the intentionality source. A design context comprises an envisioned use (thus, an event intended by the designer) or a systemic context, plus the designer's intention. For instance, the design function of a (claw) hammer is not "to open a door" but "to hammer nails". The design function is a systemic function where the systemic context's goal is provided by the designer. We conclude that the design function is a specialization of the systemic function.

Having seen that use and design functions are specializations of systemic functions, we will now introduce the unified notion of function that includes both artifact and biological functions. Recall that the systemic context category is neutral with respect to intentionality, it subsumes both systemic contexts where the goal is provided by an intentional agent, and systemic contexts where the goal is not provided by an intentional agent. A biological function is identified by a systemic context of the latter type. It follows that biological functions are also a specialization of systemic functions. We will discuss high level goals like "to maintain its life" and essential biological functions in Section 9.4.

We have thus the following result:

**Proposition** (*Artifact and Biological Functions*) Both artifact and biological functions are systemic functions.

From which:

**Corollary** (*Function's Unified Definition*) The definition of systemic function provides a unified definition of function.

The conclusion about biological and artifact functions does not mention use functions. Indeed, use functions are orthogonal to the biological-artifact divide. However, it is an important notion to consider. Natural entities can have use functions, e.g. using a tree to get shade. On the other hand, a use function of an artifact may coincide with a design function for that artifact. Use functions may also comprise accidental functions (see below).

Let us sum up this view using the heart/human body example. One can claim that the function 'to pump blood' is common to a natural heart and to an artificial heart in the blood circulatory system. This function is a systemic function since the behavior of both these objects contributes to the circulation of the blood in the circulatory system of the human body. This function is not a design function for the natural heart since there is no design context for this heart. It is instead a design function for the artificial heart since the goal of the designer is that the behavior of this artifact contributes to the circulation of blood in the circulatory system of a human body.

In conclusion, by accepting the role-based view on functions, the notion of systemic function *does* furnish the core for at least the types of function discussed in this paper: biological, artifact, design and use functions. All these functions can be obtained by specialization of that core notion.

## 8. Essential and Accidental Functions

Most proposals in the literature take the distinction between essential and accidental functions seriously, and explicitly separate function ascription from performance. For these authors some objects seem to have a special dependence relationship with some functions: these are deemed essential to them because the existence of those objects is ontologically connected to the performance of these functions. This view is often motivated by the study of biological organisms, like human and animal bodies, and (social) artifacts, like hammers and airplanes.

Considering our function contexts, it should be clear that a use context does not deal with the distinction between essential and accidental functions. In some use contexts, a hammer is used to open a door (accidental function); in others to hammer nails (essential function). From the use context viewpoint, these are just functions and nothing suggests a special relationship between the hammer and the opening or the hammering. In the case of artifacts, the design context provides information on the reason an object, the artifact, has been designed. Thus, the design context binds an object to some use situations which determine a function (or functions) for the object itself. Indeed, the object is intended to perform the function that the designer envisioned in the design context. This historical and, so to speak, generative dependence of the object on the function intended by the designer distinguishes the latter as having a causal role for the object's existence, and thus is taken to be essential for its existence. Note here that this observation is based on the assumption that the envisioned use situation matches the actual use context and, more generally, the actual systemic context. Therefore we can conclude that the essential function(s) of a designed object is consistently explained within the systemic view.

In the case of natural entities, only the systemic context determines the function of a component. We have seen that the pumping blood function of the heart is meaningful only in the context of a system and only if the heart is a component that contributes to the system's behavior. Thus, the pumping blood function is performed with respect to the blood circulatory system and might not be a function in other systemic contexts, e.g. the reproduction system. Not all the systemic contexts are on a par, of course. Essentiality of the systemic functions should be judged according to the existence of a contribution to the goal determined by the selected behavior. Therefore, all the systemic functions are essential *with respect to some systemic context*.

Ontologically, the essentiality of a biological function depends on the systemic function [10]; use functions are accidental to organisms. So, the pumping-blood function of the heart is essential in the context of the circulatory system, the sound-making function of the heart is essential in the context of the sound-making behavior of the human body. Note that the sound-making function of a heart is essential only when the sound-making behavior of the human body is selected by the systemic context. This function may seem somewhat odd but it just depends on the selection of the sound-making behavior of the human body. However, being odd or not escapes ontological considerations as discussed in (Cummins, 1975, p.762).[11]

These observations lead to a classification of functions with respect to an object $X$:

- A function $F$ is *irrelevant* to $X$ when $X$ cannot perform $F$ in any function context.
- A function $F$ is *relevant* to $X$ when $X$ performs $F$ in some function context.
- A function $F$ is *essential* to $X$ when $X$ performs $F$ in some design context or in a systemic context which is not a use context.
- A function $F$ is *accidental* to $X$ when it is relevant but not essential to $X$.

[10] See 9.4 for discussion about essential biological function.

[11] Sometimes the observation "Most spermatozoids fail to fertilize ova" is taken as a counterexample to the contribution theory of functions (Artiga, 2011). However, success/failure can be established only in the correct context which, in this scenario, is the spermatozoid meeting an unfertilized ovum. Therefore, the case of a spermatozoid that reaches an ovum already fertilized and fails to fertilize it, is not a counterexample.

## 9. Evaluation of the Unified Definition

We evaluate our definition from three perspectives based on (1) general requirements, (2) possible claims against our behavior-oriented definition of function, and (3) problematic examples. Finally, we will look at the essentiality of biological functions and at the continuant vs occurrent ontological distinction for functions.

### *9.1. The Unified Definition and known desiderata*

In this section we evaluate our proposal against some general requirements discussed in the literature. To keep the evaluation smooth and clear, we discuss a list of desiderata collected in Artiga (2011) since it is concise, aligned with respect to the literature, and collects the main issues at stake.

Our discussion of these points is twofold: it shows how our approach does justice of important intuitions about functions, and provides an indirect comparison with other theories in the literature, for references see Artiga (2011).

Artiga's desiderata are the result of a discussion mainly about biological functions, but they apply to artifact functions as well. To properly evaluate artifact functions we need to include two further elements: intentionality and the notion of use function. Needless to say, intentionality is the key to distinguish between biological and artifact functions, and is unavoidable in discussing artifacts' identity. In the philosophical discussion on biological functions, use functions seem to have no place. Even accidental functions are undesired elements, so that stating the difference between essential and accidental functions is of primary importance in this sector. In the discussion on artifact functions, however, one cannot avoid dealing with use functions: simply there are too many relevant functions which exist in virtue of being induced by an object's user.

Leaving aside intentionality and use functions, which have been discussed earlier, we now concentrate on Artiga's desiderata rephrased, for the sake of the discussion, as follows:

1. *(Naturalized) Teleological property: The attribution of a function to an object points at some activity that explains why the object exists.*
   From the point of view of the Unified Definition, all functions are fundamentally systemic function. The object which realizes the systemic function exists to contribute to the systemic goal specified by the systemic context. Each systemic function is thus teleological relatively to a systemic context. The reliability of the choice of the systemic context depends on our domain knowledge and is thus expected to increase as science advance. Of course, in the case of design functions, there is a further teleological aspect related to the object's "expected activity" (namely, behavior) in the envisioned use context.
2. *(Naturalized) Normativity: An object's function is something an object is supposed to do, in the sense that livers are supposed to filter wastes from blood.*
   From the point of view of the Unified Definition, this desideratum refers to an expected performance specified by the functional role and determined by the systemic context. In our approach, functions do not inhere in the object and are related to it via the notion of functional role, that is, via a temporary and non-essential property of the entity playing it. The functional role, played by a behavior of the object, indicates what the object is expected to do. By calling an object "liver" or "hammer", one fixes (normalizes) the systemic context for the object and thus what it is supposed to do.
3. *Performance: The object's function is determined by the object's current performances.*
   From the point of view of the Unified Definition, this is a direct outcome of the proposed definition since any systemic function, including design functions, depends on the behavior of the object in a specific context. The context is either an actual event or what is envisioned that includes the actual behavior of the component of a system. To talk about design functions, you always need to mention its intended function, and hence its envisioned use context.

4. *Essential and accidental functions: An object's function is appropriately distinguished from an object's accidental effects.*
   This issue has been addressed in Section 8. Here we add some further explanation. In the case of biological functions, all systemic functions which contribute to keeping the overall system exhibiting its behavior (typically, those determining its liveness status) are essential. At the same time, use functions are accidental: there is no intrinsic reason for a biological organism to be used by some intentional agent. Thus the idea of use function helps to make order in debated examples like the glasses-holding function of a nose, see Artiga (2011). The glasses-holding function of the nose is a use function, hence it is accidental. Our definition clearly distinguishes accidental functions like this from the essential (systemic) function of the nose, namely letting air enter into the body. Lastly, in the case of artifact functions one can easily determine which, among all functions, is essential by looking at the designer's goal.

## 9.2. Behavior-based definition of function

Our definition of function is behavior-based. We here investigate whether or not such behavior-based definition is adequate for capturing all types of functions. We can envision the following two kinds of claims:

### 9.2.1. Qualities have functions

One may claim something like "a green color has a function to heal persons, and hence any talk about functions only in terms of behavior-oriented model lacks generality". There are two ways to understand the claim: (1) The quality itself has a function (2) An object with such a quality has a certain function because of the quality.

Although at first glance this seems to be a reasonable criticism, both readings are faulty. Reading (1) does not make sense because we are discussing functions attributed to an object, that is, an ontologically independent entity. If we accept for the sake of the argument that function could be attributed to a dependent entity, it remains that reading (1) can be reduced to reading (2), so only the latter needs to be discussed.

Since there is no physical quality without physical effects, we can identify the physical behavior due to the green color, that is, to reflect only green light (or absorb all light spectra other than green). So, if having such a quality has some function, it is possible to talk about that function of green color in an appropriate function context based on a behavior-based model. Since this result does not depend on the function bearer, the criticism does not apply.

### 9.2.2. Structures have functions

One may claim something like "a structure has a function". For example, a fence has the function to prevent animals to enter the enclosed area. Functions of the type "to prevent" need special care. Typical examples, besides fences, include rails, paperweight, etc. These objects manifest concrete behaviors which prevent possible effects of other objects' expected behavior only under specific conditions. For instance, when there is wind the paperweight prevents the paper from moving; when there is no wind, it seemingly does nothing. In the case of fences, we distinguish two cases: (1) an animal physically tries to enter the enclosed area, and (2) an animal gives up to do so when seeing the fence. Case (1) is similar to the paperweight case when it prevents a sheet of paper from moving, thus it is behavior-based. Case (2) has a different explanation. Some animals do not attempt to enter the enclosed area when they see the fence because the "being standing on the way" of the fence makes them realize (perhaps due to previous experiences) that it is not possible to enter. So, the proper way to look at the fence's function in case (2) is in terms of the process 'constantly standing in a position' (thus, behavior-based) rather than in terms of the object's structure. Indeed, these animals would not try to pass even though the fence where made of paper, that is, deprived of a suitable structure.

In both cases, the behavior-based unified definition of function maintains its generality.

### 9.3. The Unified Definition and problematic examples

#### 9.3.1. Self-reproduction and apoptosis

First of all, self-reproduction and apoptosis in an isolated situation, that is, without mentioning the goal to be achieved, are not functions but only behaviors. If we want to relate it to function, we can still talk of "capacity" to perform a behavior as a so-called "capacity function" (Kitamura and Mizoguchi, 2010, 2013). Imagine, John got an accident and cannot walk anymore. One would say that John lost his walking function which, in our setting, is just a capacity function: he lost the capacity to walk. Capacity is a context-independent notion. Function, instead, is intrinsically context-dependent.

Regarding self-reproduction and apoptosis, we have to say (1) how to deal with these notions; and (2) what they are when an appropriate context is given.

1. Self-reproduction and apoptosis are behaviors of a system acting on itself, e.g., a cell produces cells by dividing itself into two cells or kills itself under some circumstances. In this case, the cell is both the performer of the action (it plays an agent role) and the operand to which the action is directed (it plays an operand role). Our definition of function does not put constraints on these aspects: the same object can play different roles at the same time.
2. The context of self-reproduction or apoptosis would be an organ (a complex system) which needs new cells or to throw out old and worn-out cells. Given these contexts, one finds their appropriate functions. If we assume the goal "to have at least/an average of N cells in the organ", the function of the self-reproduction behavior would be to increase the number of cells when the status is not satisfied. If we assume the goal "to have fresh cells in the organ", the function of the apoptosis behavior would be to get rid of old cells.

#### 9.3.2. The mother and factory examples

Some biological systems have the capacity to generate their offspring. To produce offspring is a behavior (or a capacity function) when we see it in an isolated setting. However within the context of the biological species, this behavior of a single entity satisfies the species' goal of survival. Similarly, one could think that a car factory has a car-making function. As before, car-making is just a behavior of a car factory. A function needs a context. In the context of modern economy, there is a demand for cars and thus the behavior of the car factory, from the perspective of the market, has the function of providing cars to the market. In conclusion, whether the agent and operand roles are played by a single or multiple objects does not cause a problem in the application of the unified definition of function.

### 9.4. On essential biological functions

Since the notion of essential function is quite important and our theory uses a broad notion of systemic context, we now complete the discussion on how such a theory of function does justice of essential functions. We already showed how the theory identifies essential functions in the cases of design and use functions, so only the case of biological functions needs to be addressed.

Recall that in Section 7 we claimed that all the systemic functions of organisms are essential functions *for the given context*. Our theory can set an appropriate systemic context for any organism and hence the function specified by the systemic context is the essential function of parts/components of the organism under consideration. This claim is made purely from the ontological point of view. For those working in the biological domain, this would be too weak. To address their concerns, we need to consider domain knowledge as well. In order to see the issue in more detail, let us separate two types of biological knowledge:

*(a)* Knowledge regarding what the organism (as a whole) is expected to do in the real world
*(b)* Knowledge regarding the behavioral level and the anatomic structure of the organism (including how its components behave across the organism's structural hierarchy of components).

Replacing the knowledge of *(a)* by "to maintain its life" enables us to determine a biologically appropriate systemic context of every part/component of the organism under consideration. By including the knowledge of type *(b)*, we have all the elements to talk about essential functions of the components. Note, however, that the essential function of an organism as a whole cannot be ontologically determined because knowledge of type *(a)* is ontologically arbitrary. That said, essential functions of all the components of the overall organism can be identified. We call those biological functions identified in this way "liveness functions" which make sense under an assumption that biological system is a subclass of general system specialized by adding "to maintain its life" as its meta-goal.

Note that "to maintain its life" cannot be classified as a goal introduced in the systemic context we have discussed thus far. It requires a larger system including the overall organism under consideration which is expected to contribute to realizing the selected behavior of the larger system. Indeed, the expression "to maintain its life" refers to the organism itself, not to a larger system. Furthermore, we take it to be a meta-level entity, relatively to the domain knowledge, in the sense that it is the most abstract activity in biology.

Systemic function whose behavior can be selected arbitrarily, on the other hand, is independent of the knowledge of what a proper behavior of an organ is. It only needs knowledge about what makes sense as a system. Needless to say, one cannot identify the essential function of an organ which is not known.

Of course, knowledge of type *(b)* evolves in time and new essential functions may be identified in the future for the very same organism. On the other hand, some of today knowledge might turn out to be incorrect. Considering these observations, the identification of essential functions of particular organisms is not ontologically possible. We point out that there is an important, and too often missed, distinction between the ontological definition of function and the identification of the function of an object. Our approach is purely ontological and thus addresses the former issue. The latter is not an ontological issue *per se* since it requires to consider domain knowledge even to identify the target object as a system.

### *9.5. On category of function: continuant vs. occurrent*

Most philosophers consider functions as dependent continuants. Others, including most engineers (Stone and Wood, 2000), take them as occurrents. The former push forward the distinction between function, a continuant, and functioning, an occurrent. Here we discuss this issue from the viewpoint of our theory and show how one can justify the claim that both functions and functioning are occurrents.

"To pump" is a function, this is accepted by both perspectives. In the philosophical literature functions inhere in objects, thus "to pump" must inhere in an object, namely, in the object that (does or should) pump. However, this is hard to justify because "to pump" is also an occurrent, and occurrents do not infere in their participants. This dilemma affects all theories of function based on function inherence in objects. To make it tenable, one should understand an expression like "to pump blood is a function of a heart" as a way to talk about capacities or dispositions of the heart: whenever "to pump" is considered a type of function, there must exist an object with the "capacity/disposition to pump". Similarly, instead of saying "to pump is an essential function of a pump", one should say that the capacity/disposition to pump is essential for a pump. However, considering the amount of papers on function published to discuss this issue, one should conclude that such post-hoc terminological countermeasures do not work in practice. Even those who claim that a generic function is an entity that inheres in an object must admit that a concrete function cannot inhere in the object. In the case of artifact functions, functional requirements come first, and then an artifact is engineered and produced to realize the functions by designing their structures and behaviors. Considering this and the fact that a function can be realized in different ways, a concrete function such as "to pump" is not something which inheres in an object. In fact, our definition of function makes a clear distinction between "to pump" and "pumping", i.e., its manifestations.

In (Kitamura and Mizoguchi, 2010, 2013) it was shown that both these notions of function (the "capacity to pump" and the "to pump") can be accepted. In our theory this is done by taking a functional role as an occurrent, a role played by a behavior, thus not just a realization of a capacity/disposition function. In this way, we overcome the above "to pump" dilemma. Both function and functioning turn out to be "occurrent roles", a notion that is explained next.

Generally speaking, a role is understood as an entity that depends on a context and that is played by a continuant, typically an object. Such roles are called *dependent continuants*. A *continuant role* is a role whose player is necessarily a continuant. For example the school teacher role (a dependent continuant) is played by a person (an object) and, according to today's legislation, it is also a continuant role since only persons can be teachers. What about a role played by an occurrent? Let us consider a preparation step in a laboratory test procedure. A preparation step is a phase that is done before the test itself. Thus, it is apparently an occurrent. However, what happens in that phase is not a preparation *per se* but only with respect to the test occurrent that is going to happen next. There must be a concrete occurrent it refers to in order for the first to be considered as a preparation. Thus, a preparation satisfies the following conditions necessary to roles:

**(1) Anti-rigidity:** No occurrent is essentially a preparation
**(2) Externally founded:** when an occurrent is a preparation then a latter occurrent is also identified and the latter happens only if the first does.
**(3) Dynamism:** Another occurrent could be called a preparation because there can be different ways for a preparation to happen.

These properties show that "preparation" is to all effects a type of role and that it is played by an occurrent: hence we call it an *occurrent role*. Since a behavior is a process, an occurrent role played by a behavior inherits the properties of processes: it exists wholly at any instant during its existence (see Section 3). Since the requirement of being a continuant is mainly aimed to satisfy this manner of existence, shared by processes, we have shown that our definition does justice of this view.

## 10. Related Work

In the previous sections we argued that our definition of unified function satisfies the Artiga's desiderata. That discussion made clear our position with respect to important issues discussed in the literature. In this section, we add a few observations by comparing our work to other theories. Many definitions of function have been proposed in engineering design, philosophy and ontology research as discussed in these surveys (Erden *et al.*, 2008; Perlman, 2004; Wouters, 2005; Röhl and Jansen, 2014). Our theory, built upon the notion of systemic function, falls within the so-called *contribution (or dispositional) theory* (e.g., Boorse (2002); Cummins (1975)) which is contrasted by other approaches such as the etiological view. The most important difference between our theory and other contribution approaches is that we clarify how the goal is determined in terms of kinds of context, a step that is missing in both Boorse (2002) and Cummins (1975). Also, we reconstruct the different functions in terms of sub-types of a single notion of systemic function. We also do not identify functions with properties (capacities) of an entity like in Cummins's theory (Cummins, 1975), or with dispositions to contribute to the system like in Johansson et al.'s definition of biological functions (Johansson *et al.*, 2005).

Houkes and Vermaas (2010) proposed a different set of desiderata for technical functions: (1) proper and accidental, (2) malfunctioning, (3) measure of support, and (4) innovative functions. The first item was already discussed since included in Artiga's list. Our systemic function satisfies (2) because of the normativity desideratum, and (3) because of its nature based on contribution. Finally, (4) is satisfied since our proposal puts no restriction on innovativeness of functions.

In addition, much research has been carried out on comparing biological functions and artificial functions (Krohs and Kroes, 2009), and some attempts to unify them have been proposed. Krohs (2011) exploits a different intuition: the unification is based on the concept of function in terms of systemic roles of type-fixed components, where the type-fixation is a source of normativity. Our approach differs from these since our notion builds on the notion of context and does not rely on the entity's type.

In (Arp and Smith, 2008), the BFO notion of function is defined as “a disposition that exists in virtue of the bearer’s physical make-up and this physical make-up is something the bearer possesses because it came into being”. In this view, functions are dependent continuants and form a subclass of dispositions. In contrast, the notion of function we have presented defines functions as dependent occurrent. A BFO function inheres in an object (the bearer), while in our theory an object has the capacity to perform a related behavior, and the functional role to be played by the behavior exists in the function context rather than in the object. BFO is originally designed for the biological world and this might explain the lack of consideration for the goal and context factors in function talk. Another shortcoming is the difficulty in explaining malfunctioning (Röhl and Jansen, 2014).

Recently, an organizational account of function has been proposed as a unificatory theory of etiological and dispositional theories (McLaughlin, 2001; Mossio *et al.*, 2009; Artiga, 2011). This view is based on three conditions according to which an object *O* has a function (excerpt from Artiga (2011)):

1. *O* contributes to the maintenance of the organization *Org* of a system *S*,
2. *O* is produced and maintained under some constraints exerted by *Org*, and
3. *S* is organizationally differentiated.

Artiga claims that the organizational account does not satisfy his desiderata. Thus, it is instructive to compare this with our definition. The main difference between the two is that the organizational theory is essentially based on the assumption that function is something possessed by an object (a trait in their terminology), which is not needed in our definition based on the notion of role where what is possessed by the object is the capacity to perform the role, via its behavior, rather than the function itself. As Artiga suggests, it is very hard to fulfil all the desiderata by a theory that starts from the organizational theory’s assumption since a function is intrinsically dependent on something external to the object.

In (Röhl and Jansen, 2014), the authors survey existing definitions of function mainly from the BFO point of view with emphasis on the distinction among disposition, function and role. The final aim is to overcome the shortcomings of the BFO definition of function but the attempt is not general enough to provide a unified notion. The survey mentions also our initial work on a unified definition of function (Mizoguchi *et al.*, 2012) failing to properly understand it. The discussion in this paper of the essential and accidental functions (Sections 8 and 9.4) as well as of the seven desiderata considered in (Röhl and Jansen, 2014) should suffice to clarify our position.

## 11. Discussion and concluding remarks

As discussed above, our definition belongs to the contribution (or dispositional) approach to functions and satisfies Artiga’s teleological, normativity and essentiality desiderata, usually considered problematic within such approach. This result is due to several aspects of our theory that we discuss below.

In order to cover both biological and artifact functions, we explicitly introduced the notion of context within which to apply functional talk. In the literature on biological function, it seems to be implicitly assumed that each organism has its own inherent context to perform its function, so one can claim: *This is “the” function of organism O*. The consequence is that the function definition of an organism tends to be confused with the function identification of that organism. The explicit introduction of the notion of context enables to separate the two by making the notion of function relative to its context and to include biological functions as a special case of systemic functions. This has the consequence that the biological context is now explicitly recognized, and is clearly separated from the ontological background of functional talk. The choice of the biological context can now be justified only by biological arguments. This move allows to talk about function conditionally to the assumed context, and thus to satisfy the teleological desideratum.

The previous observations explain the difficulties of the other theories in attempting to find a function of an overall system like the human body. To identify such a function one needs an appropriate context of which the system itself is a component or subsystem, similarly to the case of the heart (a component of the circulatory system) or of the circulatory system (a subsystem of the human body).

Note also that our teleological explanation is naturalized in spite of the fact that the goal is set by the systemic context. The focus on the selection of the behavior of the overall system, which includes the component whose function is under consideration, explains why function identification and function definition are different. After all, the former depends on our knowledge but not the latter. For example, when apoptosis is required in an organism, a specific function context needs to be assumed as "the" systemic context. Thus, the actual identification of apoptosis forces the choice of a specific context. Instead, it suffices to hypothetically consider such a situation to explain the definition of the apoptosis function.

All this is achieved while maintaining the definition 'open'. If one makes the assumption that there is "the" context (without further specifications) for an entity, then we can refer to "the" function (without further specifications) for that entity. In other words, we can say that we loosened the desideratum which originally requires to identify "the" function of any organism. In fact, our approach implies that any particular function has to rely on some domain knowledge (needed to make the choice of the context) and that no domain knowledge can be taken to give "the right context" for a given object.

Regarding normativity recall that a function, as we define it, is not something that exists in the object under consideration: what inheres in the object is not the function itself but some capacity to perform the behavior which can play the specified functional role. Thus, the pivoting idea is that of functional role or what the object is supposed to do when it is put in the function context. This aspect contributes to satisfy the normativity desideratum. The separation between functional role and behavior is made possible by the dependence of function on context.

On essentiality, our definition satisfies the desideratum thanks to the introduction of the notion of use function. The notion of use function enables us to claim that all the systemic functions are essential to the components under their systemic contexts, and that all use functions are accidental to all natural objects. These three notions (context, functional role and use function) where identified in the engineering domain where one cannot avoid to talk about designers' and users' intention. The latter is crucial since users can use anything in any way they want, which provides various, sometimes unexpected contexts for the objects.

Finally, let us look at the notion of malfunction. First of all, recall that the malfunction problem is relative to a well constrained issue: whether or not the definition of function is satisfactory in the way it distinguishes objects that have the function attribution but for some reason cannot perform (and thus malfunction) from those that lack the function attribution itself. The main difficulty of other approaches within the contribution theory is the assumption that a function inheres in an object, from which one cannot distinguish when the function is not present or is present but not performed. In our theory, the distinction follows from the separation between functional role and behavior. We have seen that the notion of function is essentially that of functional role, thus this notion is at the type level. Malfunction instead is attributed to an individual (actual) behavior, thus to an occurrent token. Within the selected systemic context, the object's actual behavior either contributes to the realization of the goal or does not. That is, while the function is fixed by the context, the success (or unsuccess) depends on the behavior. When it is said that an object malfunctions, this means that the object's behavior does not satisfy the given functional role, i.e., does not contributes to (or even prevents) the realization of the goal. Of course, in this view malfunction turns out to be context-dependent, as function is.

**Definition 12.** A component $O$ of a system is said to malfunction, with respect to a given systemic function with systemic context $C$, when none of its actual behaviors $B$ achieves the goal $G$ specified by $C$.

Degrees of malfunctions can be distinguished by qualifying the mismatch.
We do not discuss this further.

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