Does Biomimetics Require a Unified Account of Function?

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Abstract
Biomimetics is considered as a field of research in which biological functions are transferred into the domain of technology. Much work has been done on functions both in biology and technology, with many foundational ontologies like BFO, DOLCE, SUMO, GFO, and YAMATO either containing classes for functions or providing other means to represent functions. These representational means are, in turn, referred to by many domain ontologies. It is, however, not clear whether all these classes really make up a coherent foundational category. In this paper, we collect and analyse definitions of function from various ontologies and the philosophical debate on functions in biology, engineering, and biomimetics. We discuss various strategies to deal with this wealth of ambiguity, in particular with respect to its relevance to the domain of biomimetics; we recommend avoiding the term as much as possible.

Keywords
biological functions, engineering functions, technical functions, computer-aided biomimetics

1. Introduction

Biomimetics is considered to be a field of research in which biological functions are transferred into the domain of technology in order to find innovative technical solutions (VDI 6220-1 2012). It bridges biology and technology, necessitating communication and collaboration between these distinct domains (McInerney et al. 2018). For Nachtigall, in the biomimetic research project, biological knowledge or inspiration is transferred to the technical realm, with functional abstraction serving as the foundation of this transfer (Nachtigall 2010). This seems to require a unified approach to function that accommodates both biological and technical functions, and such an approach has, in fact, been suggested (Drack et al. 2018). However, no one would probably suggest that all possible meanings that the word "function" can have should be integrated into such a unified approach, as the term "function" can refer to an ontologically quite diverse bunch of things, ranging from functions in the ontological sense via roles, actions and events to mathematical entities and algorithms (see Table 1).

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These counteracting observations give rise to the question of whether the term “function” refers to the same kind of things across all of the many classes and the various domains, and to which extent unifying approaches to function are justified. A well-known case is the Gene Ontology (GO) class *GO:Molecular function*, which is defined as “A molecular process that can be carried out by the action of a single macromolecular machine [...]” (Gene Ontology, n.d.) — i.e., in the terms of the Basic Formal Ontology (BFO), as something that goes under *BFO:Process* and not under BFO:Function. Another example is the Artificial Intelligence Ontology (AIO), where “function” represents a highest class that includes activation functions commonly used in neural networks. Similarly, in SNOMED CT, “function” is defined by way of exclusion as not being mainly morphologic or structural and is a subclass of *SNOMEDCT:Observable Entity*. In the REPRODUCE-ME ontology, “function” refers to a programming language code snippet in a script, classified as a subclass of *reproduceme:Plan*. In the Physical Medicine and Rehabilitation (PMR) ontology, it is a subclass of *PMR:Observation*. This shows the broad ambiguity of “function” in domain ontologies.

These ontologies, we claim, are not exceptions but rather prove the rule that functions are notoriously difficult to come by from the point of view of foundational ontologies. In particular, we argue that it is neither advisable nor necessary to have a unified account of functions in biomimetics. To do so, we first survey the treatment of function in several selected ontologies (section 2). We look then at the discussions on biological functions (section 3) and technical functions (section 4) that motivate many of the modelling decisions in applied ontology. The discussion on functions in biomimetics, situated at the crossroads of these disciplines, has, to our knowledge, not yet received any attention in applied ontology; we will present some of the definitions of function pertinent to this field (section 5). We conclude with a discussion of whether an ontology of biomimetics requires a unified account of function covering both biological and technical functions. Our answer will be negative.

Table 1
Possible meanings of “function” according to the *Oxford English Dictionary* (OED, n.d.).

(i)	an employment or an official duty
(ii)	a purpose or intended role of a person or thing
(iii)	a specific action performed by organs or other parts of living organisms
(iv)	what a linguistic unit performs within in a larger structure
(v)	religious or public-organised social gatherings
(vi)	the assignment of each element of a domain set to a single element of a range set,
(vii)	a mathematical dependency of some quantity on specified factors or variables
(viii)	an aspect of chemical behaviour of a molecule attributable to a specific functional group
(ix)	practical use or purpose in contrast to aesthetic considerations
(x)	in computing, an operation that enables computers to perform tasks
(xi)	a set of instructions within programs or software capable of performing specific tasks

2. Function Classes in Ontologies

Class and relation names and annotations containing “function” are widespread in applied ontology. A search on bioportal.bioontologies.org returns about 200 occurrences from 31 ontologies for the search term “function”. The EMBL-EBI Ontology Lookup Service lists 23,033 classes that carry the term "function" in their name, a synonym or within other annotations, plus 17,423 cases of imports of such classes into other ontologies (OLS, n.d.). Ontobee, on the other hand, lists 4138 unique classes or relations with 'function' included in their label (Ontobee, n.d.). This clearly shows the relevance of function for applied ontology, and foundational ontologies have responded to this demand by including respective classes for functions.

Table 2
Selected ontologies and their function definitions.

Source	Definition	Superclasses or Representation
Domain/Task Ontologies		
Molecular Interactions Controlled Vocabulary (MI, n.d.)	A function is a biological function of a participant or of an interaction.	Participant Attribute Name < Attribute Name < Molecular Interaction
Semanticscience Integrated Ontology (SIO, n.d.)	A function is a capability that satisfies some agentive objective, or (evolutionary) optimization.	Capability < Realizable Entity < Attribute
Function Reference Ontologies		
The Functional Ontology, Mizoguchi and Kitamura 2009	A function is a role played by a behaviour in a specified context.	This function ontology is compliant with YAMATO.
The Ontology of Functions, Burek et al. 2006	A function is the abstraction of biological process or another entity towards a goal.	Top-level ontology of biological functions intended as an addition to existing biomedical ontologies.
Top-Level Ontologies		
Basic Formal Ontology (BFO), Arp et al. 2015	A function is a disposition that exists in virtue of the bearer's physical make-up, and this physical make-up is something the bearer possesses because of how it came into being—either through natural selection (in the case of biological entities) or through intentional design (in the case of artifacts).	Disposition < Realizable entity < Specifically dependent continuant
Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), Borgo et al. 2006; Borgo et al. 2010	A function is [...] what relate certain input and output flows.	DOLCE does not contain a function class, but they can be represented as the behaviour of artefacts or operations on flows performed by artefacts.
Suggested Upper Merged Ontology, SUMO-GIT, n.d., Data Dictionary, n.d.	A function is a term-forming Relation that maps from a n-tuple of arguments to a range and that associates this n-tuple with at most one range element.	Single Valued Relation < Inheritable Relation < Relation Abstract
General Formal Ontology (GFO), Herre et al. 2006	A function is an intentional entity.	A function is ascribed by means of the *has-function* relation to entities and specified by a goal, requirements and a functional item.
Yet Another More Advanced Top-level Ontology (YAMATO), Mizoguchi and Toyoshima 2006; Mizoguchi, n.d.	A function is a role played by a behaviour in a specified context.	Occurrent Role < Role < Specifically Dependent [Entity]

Table 2 illustrates the abundance of references to functions in domain, task, function reference, and top-level ontologies, which proves that there is a noticeable lack of consensus regarding categorising or modelling functions in applied ontology. Classes labelled “function” are subsumed under different top-level classes in different ontologies, such as *MI:Attribute Name* or *SIO:Attribute*, resulting in categorical confusion. Such confusion continues in function reference ontologies as well. The Functional Ontology defines function as a role that can change from one context to another, whereas the Ontology of Functions emphasises the necessity of having a goal when defining a function, where the teleological dimension is of importance. Thus, the truthmakers of function ascriptions vary considerably depending on the function class chosen for the ascription.

The top-level ontologies in Table 2 deserve a special interest, as they are built with the intention of encapsulating all (relevant) entities in reality in a domain-independent fashion. However, not all top-level ontologies contain a category of function: DOLCE and GFO offer complex representations of function rather than categorising it. And even the ontologies containing a class *Function* define it differently. For example, BFO takes pain to distinguish (essential) functions from (accidental) roles, while YAMATO does not make this distinction. Lastly, the term “function” is defined from different perspectives. SUMO defines functions from a set-theoretical perspective, DOLCE from an engineering design perspective, GFO from a technical perspective, and BFO from a unitarian perspective to encompass both biological and technical functions.

3. Functions in Biology

“Function” is one of the most controversial terms in biology (Bock and von Wahlert 1965). There are several senses of function in biology, as a biological function can refer to an action, a role, an effect, a process-related property, a causal relation, or an adaptive service (Table 3). These notions can represent different philosophical approaches, such as etiological, life chances, and systemic or causal contribution accounts, along with the denial of functions in biology (cf. Table 4; Shrager 2003).

Several authors have tried to map the conceptual landscape in biology. Wouters (2003) distinguishes four ‘notions’ of biological functions. The first is *function as activity*, which describes what a part of an organism or an organism as a whole does or is capable of doing, like the rhythmic contraction of the heart. Second is *function as biological role*, which refers to the contribution of biological entities and the activity of an organism that contributes to a complex activity or a capacity, such as the heart’s role in pumping blood in the circulatory system. *Function as biological advantage* denotes traits beneficial to organisms, like the heart’s efficiency in the circulatory system; having a heart a specialised organ that pumps blood in the circulatory system, and increases the efficiency- is advantageous over any other possible transport system. Lastly, *function as the selected effect* refers to traits that have evolved for specific purposes and are maintained in the current population, such as the heart being evolved to increase the efficiency of the transport system. Similarly, Mahner and Bunge (2001) claim that there are at least five different and related ‘function senses’ in biology: (i) *Internal (biotic) activity* is the collection of all processes occurring in some system or subsystem, devoid of evolutionary, adaptive, or teleological implications; (ii) *External (biotic) activity* or *role* of a subsystem is the activity of the subsystem in the corresponding supersystem. (iii) In some cases, internal and external activities of some biological entities are interdependent, which forms a third sense called *internal cum external activity* or *total activity*. The three senses (i)–(iii) are often called *effects* as they do not inherently imply value or usefulness, although the third may be valuable to the organism. (iv) When the third sense is, in fact, useful or valuable, it is the fourth sense called *aptation*. Its usefulness or value need not have a teleological or evolutionary sense. Supporting spectacles is an aptation of our noses. Finally, (v) there is *adaptation*, which implies all the other function senses: it is an aptation that has been retained or improved on by evolutionary processes. For example, warming and moistening air in the respiratory system is an adaptation of the nose.

There is a lively debate in the philosophy of biology on what biological functions are. Depending on which theory one chooses, ascriptions of biological functions would have truthmakers from quite different ontological categories (see Table 4). While these theories disagree on the definition of function (and the truthmaker of function ascriptions), they may sometimes well converge on which feature of an organism is functional or not. For instance, causal contribution theories view the heart's function to pump blood in terms of its systematic contribution to the body, while etiological accounts interpret the heart's function to pump blood as a result of evolution processes favouring the development of such an organ that ensures survival and other vital bodily activities. Life chances accounts emphasise the critical role of the heart in maintaining life and the overall well-being of the heart's bearer by continuous blood pumping. The organisational account explains the function of the heart as its contribution to different ways of maintaining the overall system. Despite such material convergence, however, biology seems to be far away from a consensus on how to define function.

Table 3
Definitions of Function in Biology

Source	Definition
Bock and von Wahlert 1965	[...] the function of a feature is its action or how it works. [...] that class of predicates which include all physical and chemical properties arising from its form (i.e., its material composition and arrangement thereof) including all properties arising from increasing levels of organization, provided that these predicates do not mention any reference to the environment of the organism.
Hunter 2009	[A function is] the role that a structure plays in the processes of a living thing.
Jacobs et al. 2014	A biological function is [...] the adaptive "service" to the system or other systems in the biological levels of organization provided by a mechanism.
Toepfer 2011 (Transl. from Drack et al., to appear)	A function is a system-relevant effect of a component in an organized system, i.e., that effect in a system of interdependent parts (or process types) needed to maintain the other parts (process types) of the system and thus, because of the interdependence of the parts, to contribute also to their own preservation.
Mossio et al. 2009	biological functions [are] causal relations subject to closure in living systems
Thain and Hickman 2004	[...] the function of a component in an organism is the contribution it makes to that organisms' fitness.
Richter and Wirkner 2014	all [...] process-related properties which arise directly from the form of morphemes [...] without reference to the organism's environment

Table 4
Theories of Biological Functions (based on Röhl and Jansen 2014 with additions)

Source	Definition	Truthmaker
Causal Contribution Accounts (also known as Dispositional, Systemic, Forward-Looking)		
Cummins 1975	The function of a thing is linked to the present causal contribution of the function bearer in a certain context.	Processes
Etiological Accounts (also known as Backward-Looking)		
Wright 1973	[T]he functions of a trait are past effects of that trait that causally explain its current presence.	Past evolutionary benefits
Life Chances Theories		
Wouters 2003	[F]unctions [are] effects that enhance the life chances of their bearers.	Present contributions to system stability
Organizational Account (integration of Etiological and Causal Contribution Accounts)		
Mossio et al. 2009	Functions are […] causal relations subject to closure in living systems, [which are] organizationally closed and differentiated self-maintaining systems.	Dispositions

4. Functions in Engineering and Technology

In engineering and technology, "functions" can refer to (i) what designers aim at in creating the artefact and/or (ii) what users can benefit from using it. In other words, it explains the reason for the design and/or usage of the artefact: the designers' intention or all its possible effects or benefits beyond the designers' intention (Kitamura et al. 2006). In stark contrast to biological functions, technical functions are highly related to intentions/goals/purposes. Of course, users and designers can ascribe technical functions differently, yet functions are not necessarily defined solely in terms of intentions. A function can be defined in terms of the behaviour of the artefacts (Chandrasekaran and Josephson 2000), as an abstract formulation of a system's task (Pahl et al. 1996) or, as a combination of intention, capability and evolution as evidenced by the tradition of function ascriptions in user manuals and technical specifications (Houkes and Vermaas 2010). Table 5 lists a variety of function definitions in engineering and technology.

In their examination of function modelling approaches and applications, Erden et al. (2008) explore various definitions of function. They conclude that while the subjective character of function is prevalent among engineers, it is frequently defined as an input–output transformation or direct mapping to parts of an artefact.

Chandrasekaran and Josephson (2000) identify two main perspectives on technical functions. The first views function from the point of view of the environment as an *effect* of the technical artefact on that environment. The second perspective views function from the point of view of the device as that *what the device does.* According to the environment-centric viewpoint, a function is the intended or desired role of an artefact on its environment, while according to the device-centric viewpoint, function is a set of behavioural constraints that are actually satisfied by a device and intended by some agent. Additionally, functions can be described from a mixture of these viewpoints. Similarly, Deng (2002) classifies functions into two types. *Purpose function* is related to the designer's intention and thus subjective, whereas *action function* is related to an abstraction of the intended behaviour of the artefact (cf. Table 5).

Table 5
Definitions of Function in Engineering and Technology

Source	Definition
Umeda and Tomiyama 1995	A function is a description of behavior recognized by a human through abstraction in order to utilize it.
Sasajima et al. 1995	[F]unction [is] a teleological interpretation of behavior under a goal.
Gero and Kannengiesser 2014	Function is the teleology of the artefact.
Pahl et al. 1996	[Function is] the intended input/output relationship of a system whose purpose is to perform a task.
Mizoguchi and Kitamura 2009	A function is a role played by a behaviour in a specified context.
Erden et al. 2008	Function is [...] a *subjective category* that *links* the human intentions/purposes residing in the subjective realm to the behaviors and structures in the objective realm. [emphases in the original]
Deng 2002	[F]unction can be semantically classified into two types: purpose function and action function. Purpose function is *a description of the designer's intention or the purpose of a design.* [...] Action function is *an abstraction of intended and useful behavior that an artifact exhibits.* [emphases in the original]

Table 6
Theories of Technological Functions (Houkes and Vermaas 2010)

Name.	Definition of Function	Truthmaker
Intentional Function Theory	The intentions, beliefs and actions of agents determine the functional descriptions of artefacts.	Intentions, beliefs and actions of both users and designers
Causal-Role Function Theory	The functions of items are related to the causal roles these items have in larger composite systems.	Dispositions
Evolutionist Function Theory	A capacity to φ counts as an evolutionist function of an artefact x if and only if that capacity contributed positively to the reproduction of its predecessors and the current artefact x.	Reproducible capacities with past and current benefits
The ICE Theory	An agent a justifiably ascribes the physicochemical capacity to φ as a function to an artefact x, relative to a use plan up for x, and relative to an account A, if and only if: I: a believes that x has the capacity to φ; a believes that up leads to its goals due to, in part, x's capacity to φ; C: a can on the basis of A justify these beliefs; E: a communicated up and testified these beliefs to other agents, or a received up and testimony that the designer d has these beliefs. (Weber et al. 2012)	Information content entities like agents' beliefs and technical documentation

5. Functions in Biomimetics

Biomimetic research focuses on developing innovative technical artefacts whose design principles are taken from nature. Developing such an artefact includes abstraction, transfer, and application steps (VDI 6220-1, 2012). Drack et al. (2018) identify functions and working principles as the objects that are abstracted, transferred, and applied during biomimetic product generation. According to this view, the 'same (type of) function' is shared both in the biological system and the corresponding technical artefact. Given the huge difference between function theories in biology and technology, it is not at all trivial that such a transfer of function is possible.

As identifying functions is considered central to the biomimetic process, models of the biomimetic research process typically include a step dedicated to function identification or function abstraction (Fayemi et al. 2017). There are several semantic tools that aim at supporting the biomimetic research process, like the AskNature database or the Engineering-to-Biology Thesaurus. Typically, they incorporate functional terms derived from biology, or biology and technology, intended as primary keywords for searching biomimetic databases. However, every tool comes with its own (explicit or implicit) account of function. We summarise these accounts in Table 7. These definitions vary considerably. Some of them are (i) intention-oriented in the sense that they define functions as the 'purpose or task' of a system, thus aligning with what could be considered a very general dictionary definition of function (cf. entry ii in Table 1). In contrast, (ii) biology-oriented definitions focus on biological phenomena like adaptation or evolutionary advantages or mechanisms in organisms. In turn, (iii) design-oriented definitions focus on the design process and on what a design solution needs to achieve. Finally, (iv) process-oriented definitions characterise functions as (desired) input–output relations within the context of causal processes. As can be seen in Table 7, some of the semantic resources use combinations of these approaches.

There is no consensus on defining function in biomimetics: The intention-oriented definitions take functions as purposes, which is problematic since it claims that nature ascribes purposes to living entities. Functions can have subjective character in the design-oriented definitions, where functions are represented as a verb-plus-noun combination, whereas the process-oriented definitions define functions in terms of physical entities, where objectivity is preserved. The decision for a biology-driven or a technology-driven perspective influences how a function is defined.

In addition, there are competing formalisations of functions in biomimetics. Vincent (2016), for instance, does not explicitly define function in his ontology but utilises the Basic Formal Ontology as the foundation ontology, where functions are ontologically dependent on their bearers. On the other hand, ISO/TR 23845 (2020) suggests to define functions independently of a bearer and realisation.

One difficulty in defining functions in biomimetics lies in finding an overarching function theory that can encompass both biological and technical functions. However, it is unlikely to be overcome, not only because the term "function" is ambiguously used in biomimetics, but also because there is no overarching function theory for biology or technology individually. Therefore, biomimetics is destined to lack a unified account of functions.

Table 7
Definitions of function in biomimetics

Source	Definition	Intention Oriented	Biology Oriented	Design Oriented	Process Oriented
VDI 6220-1, 2012	purpose or task of a system	+			
ISO 18458:2015, 2015 VDI 6220-1, 2021	role played by the behaviour of a system in an environment			+	+
AskNature AskNature, n.d.	the purpose of something – the role played by an organism's, adaptations that enable it to survive – something innovators need their design solution to do	+	+	+	
The Ontology for Bio-inspired Design, Yim et al. 2008	the purpose of a specific system in the context of a larger system and strategy as the 'means by which this function is accomplished	+		+	+
E2BMO Stroble et al. 2009	an action being carried out on a flow to transform it from an input state to a desired output state			+	+
UNO-BID, DANE, IDEA-INSPIRE; SBF and FB models Rosa et al. 2015; Baldussu et al. 2012; Bhattacharya et al. 2022	a behavioural abstraction – represented as a schema that specifies its preconditions and its postconditions				+

6. Discussion

As we have seen, there is no unified treatment of functions, neither in top-level ontologies nor in low-level domain ontologies or application ontologies (section 1). Moreover, neither in biology nor in technology there is no consensus as to what exactly a function is. Both in the philosophical or theoretical literature, as well as in the semantic resources informed by them, there is a wide variety of incompatible definitions, that would often lead to different alignments to top-level categories.

The domain of biomimetics shows the very same pattern. There is no consensus on how to define functions. As biomimetics bridges biology and technology, and as it is often claimed that in the biomimetic research project, functions are transferred from biology to technology, one would expect an approach to function that integrates both biological and technical functions. In Table 7, various unsatisfying attempts can be noted: VDI 6220-1 (2012) very generally about 'purpose or task' and ignores that it is problematic to speak about purposes in biology. AskNature lumps together incompatible definitions from both domains. Drack et al. (2018) stay content (following Pahl et al. 1996) in saying that functions are described as a combination of a verb and a noun. This is probably oversimplified because many function descriptions would require not simple verb+noun constructions but more complex phrases. However, such descriptions are, in principle, available for both the biological and the technical domains. Given the more ambitious definitions of biological versus technical functions, it seems to be quite impossible to square them: biology knows nothing about designers' intentions, and technology accounts for function without reference to evolution.

Several strategies are conceivable to address the ambiguity of the term "function" and the ontological diversity that seems to go with it. First, one can search for a common core that can serve as a unifying framework across different domains. An attempt in this direction has been made by Röhl and Jansen (2014) regarding biological and technical functions. For some cases, the use of a common top-level ontology may suffice to integrate diverging representation schemes (as Garbacz et al. 2011 showed for two approaches to technical functions). Second, one can accept that there is nothing common to all the different notions of function but that they are nevertheless related to one another. This approach is explored by Carrara et al. (2011) regarding technical functions, who explore the possibility that the various meanings attached to terms like "technical function" constitute a family resemblance phenomenon, i.e., the multiple meanings of function share certain similarities and overlap without necessitating a single, universally applicable definition. However, given the enormous variety of definitions not only in different domains but also in the very same domains, the chances for successfully integrating all function classes in either of these ways seem quite small.

For the domain of biomimetics, we suggest a third strategy here: We recommend refraining from using the term "function" as much as possible or combining it with a modifier like "biological" or "technical" that indicates which variety of function is meant, and that makes it clear which truthmaker is intended in that case, be actual design specifications, user requirements, intended outcomes that define the purpose or task of the system, actual transformation process that changes the input state to the desired output state, or actual implementation or occurrence of the action described by the verb+noun combination.

Ideally, the term would be avoided altogether, and instead, terms indicating the intended truthmakers should be used. Talking about "purpose", "process", or "causal effect" would be much clearer and help to avoid intradisciplinary and interdisciplinary confusion. This strategy has two advantages. First, it avoids defining functions as a subjective category, as Erden et al. (2008) do, thereby maintaining the objectivity of function formalisations. Second, formalisations and ontological analyses of these notions can be conducted within a single foundational ontology without the need to reconcile different meanings and truthmakers. Thus, it eliminates the problematic practice of using function terms, explicitly reveals the true nature of the function in question, and simultaneously allows for different function descriptions across various domains, such as biology and technology.

For the domain of biomimetics, this would hinder neither the research process nor knowledge retrieval. Firstly, for the engineer involved (and for the success of the final product), it is not relevant whether, say, the feature studied is really a biological function of the organism, i.e., say, whether it actually provided an evolutionary advantage in the distant past. This is often unknown, and sometimes, a useful feature is even thought not to have been beneficial for the organism displaying it. Rather, it is important whether there are present causal dispositions that the engineer can learn. Speaking of biological functions here might be outrightly misleading. Additionally, for knowledge representation and retrieval, the focus would not so much be on the hierarchy of functions themselves but rather on the hierarchy of the processes that are the realisations of these functions. For this, it is irrelevant whether the realizables in question are analysed as functions or rather dispositions. A unified account of function covering both biological and technical functions is thus neither necessary nor sufficient for ontologically modelling biomimetic research processes.

7. Conclusion

In conclusion, we recommend not to assume a unified theory of function for an ontology of biomimetics. Rather, while the construction of technical artefacts with specific technical functions is the goal of a biomimetic research project, we do not think that biological functions, in any ambitious sense, are essential for the biomimetic research process. Instead, it seems to be rather the dispositions of certain organisms that are of interest to biomimetic researchers, be they functional or not.

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