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DO FUNCTIONS EXIST?

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ABSTRACT
The paper proposes a model where functions are not considered as primitive objects in themselves but rather as a complex network of relationships between different, more fundamental entities.
Exploring the connections between goals, behaviors, operations, etc. at various levels has several advantages. It allows integrating in a unique framework different approaches to design, from the Function-Behaviour-Structure model to the Functional Basis one, and provides tools for a more powerful analysis. The new picture can also help modeling affordances, misuses, redundant functions, failures and so on.
The representation of the relationships between functions, user's goals and expectations, behaviours and physical features in the case study of a common glass shows how the model can help designing better products, and at the same time illustrates the various critical issues in the model itself and suggests possible directions of investigation.

Keywords: Engineering design, Functional analysis, Function-Behavior-Structure

1 TOWARDS THE MATURITY OF FUNCTIONAL ANALYSIS

> "If a tree falls in a forest and no one is around to hear it, does it make a sound?"
> *George Berkeley*

Many design theories include functions in their framework. This notion seems necessary to represent and articulate the abstract dimension of design. However, there is also considerable disagreement on the definition of functions, as well as on the appropriate representation strategy.
As Umeda and Tomiyama noted more than a decade ago [1], "there is no clear and uniform definition of a function, and moreover, it seems impossible to describe functions objectively". This debate has been revamped by a recent workshop on functions held at the University of Dortmund (see among others [2]) and by the careful reconstruction of philosopher of technology Peter Vermaas [3].
A recent survey [4] suggests that one of the origins of the definitional disagreement is the question whether functions are a subjective category, intermediate between intentions of designers and objects, as suggested, among others, in [5],[6],[7] or rather have an objective nature, as accepted in the systematic design research ([8]; see also [9]) and in the literature on functional bases [10].
Partially overlapped with the dichotomy subjective/objective there is disagreement over the representation strategy. Some authors consider functions as a primitive concept that is part of the designer knowledge, and therefore can be simply described by using a short sentence, formalizing the lexicon and common understanding of the designer [11],[12],[13]. Other authors construct functions with a bottom up process of generalization of "verb + noun" structures, building up functional bases [14],[15],[10] or databases [16]. Still others, moving from the field of computer science, aim at building up complete ontologies of functions, whose completeness could be demonstrated with the formal apparatus of theoretical computer science [17].
Finally, another area of disagreement lies in the distinction between function and behaviour, an issue made central by the various developments of John Gero's Function-Behaviour-Structure (FBS) model.
Another very interesting model, started in [18] and developed over many years (see for example [19] for recent versions) introduces the alternative notion of "transformation process" acting on an operand, along with five types of operators: human systems, technical systems, active and reactive environment, information system, and management system.
The existence of these disagreements between models hampers the progress of the field. At the theoretical level, the fact that within a discipline with sound scientific bases and very fast

developments such as engineering there have been controversies, over definitions and representations, lasting several decades is taken by external observers as evidence that the whole field of functional analysis has not yet reached the status of scientific maturity [3]. In epistemological terms, it seems that the whole field is in a pre-paradigmatic status. At the practical level, the lack of a unified language prevents the development and diffusion of large scale systems to be used in new product design and in other engineering fields such as maintenance, reliability, management of technical documentation and the like. This is preliminary to any effort to combine domain knowledge from engineering with advanced computational linguistics tools in order to push forward the level of automation. As we have noted elsewhere [20] the fact that the reconciliation of the functional bases has taken the perspective of the minimal spanning base (i.e. covering as many functions as possible with a small number of lemmas) has paradoxically increased the practical difficulties when performing large-scale analysis, because it has prevented the automation of operations over the base.

The present paper shows that the elimination of the concept of function as a primitive, objective entity can help in better understanding various design models and in settling down a long controversy among the design community about the nature of functions.

We start from the distinction between goals and physical effects, and from the related notion that functions can be described using atomic statements expressed in physical language, as introduced in [21],[22] following the initial suggestions of [8] and extending the physical base model of functions proposed in [23]. In such framework, functions are complex objects that can be represented as being composed by more elementary constituents. Yet, they still are fundamental entities that can be conceived and used on their own. Building on such approach, we now push the analysis even further and propose the interpretation of functions as operational constructions, as matrixes of relationships among the different entities that characterize a product and its use.

To better illustrate our proposal and its consequences, we start from the functional map of a simple object of everyday life, a common glass. Then we show the intimate relationship between functions and geometrical features of the product. Finally we introduce in the picture the physical behaviours and the user’s perspective.

We hope this is a first step towards the final goal of building a bridge between contrasting approaches, in the firm belief that each can benefit from the other and that a future framework combining them will prove the most useful. The present analysis is only a sketch of how such integrated framework may look like. It underlines the role of the framework in helping the design of better products, and at the same time it illustrates the various critical issues and suggests possible directions of investigation.

2 THE BUILDING BLOCKS OF FUNCTIONS.

2.1 Functions *vs* behaviours and goals

Our analysis starts with the well-known philosophical dilemma about the difference between the perception of reality and reality itself. Philosopher George Berkeley in *A Treatise Concerning the Principles of Human Knowledge* made the following observation: "[…] imagine trees, for instance, in a park […] and nobody by to perceive them. […] The objects of sense exist only when they are perceived; the trees therefore are in the garden […] no longer than while there is somebody by to perceive them." The concept was later popularized in the form quoted at the beginning of the paper.

Such sentence allows us to introduce the concept of function as a derived property.

We are not going into philosophical discussions; here we are interested in an operational definition.

The quoted riddle constitutes the cue to tackle a quite tangible issue: the relationship between behaviour (the falling of the tree) and function, which is not only detection of the behaviour but also interpretation of it (as the air vibrations that are also sound, *i.e.* meaning for the human observer).

Another formulation of the same question can be: “Can we assume the unobserved world functions the same as the observed world?” While in physical terms (we are not considering subatomic length scales, where the Heisenberg uncertainty principle becomes relevant) the answer is most probably yes, the same is not true when considering human artifacts. By definition they exist to satisfy a purpose.

Therefore the first two elementary objects in the picture we are developing are goals and behaviours.

Behaviours can be defined as the way the physical and chemical state of the product evolves in time and in its environment. They just happen, as a consequence only of physical laws and regardless of the user, of its perception or benefit.

On the other hand, every product is designed and manufactured with the precise purpose of satisfying certain needs (of any kind: material, spiritual, social) of the user. The product's aim at addressing a specific need is conventionally referred to as a goal.
One of the essential ideas of design theories (functional analysis, Axiomatic design, FBS) is that each goal can be translated in one or more functions that the product must carry out in order to fulfil that goal. In this sense functions are not separable from the human perception: they are nothing other than the result of the user's interpretative process about the product's physical behaviours. In other words, the user's interpretation of the product's behaviour is always conditioned by the goal that the user himself wants to achieve by using the product; functions implicitly embed all the above information.
Without goal, there is no function, but only behaviours. Conversely, a goal can imply one or more functions only when a particular physical realization exists for each of them.

2.2 Functions *vs* users and designers

Before going further, it is important to define what to be an observer means in the present context.
We also need to distinguish between observer and user, and treat them as separate entities.
We define the observer as the entity that records the physical realization of the action, that witnesses the evolution in time and space of the status of the system. He is the ideal observer in the sense of Newtonian physics: omniscient but neutral, he does not interfere with the system nor express judgments over it. The observer can be a human, an animal, but also a tool or a machine.
On the other hand, the user is the agent able to interpret the acquired data (those sensed by the observer). Precisely for being the one who utilizes, he attributes a goal to the physical behaviour of the system and to the temporal evolution from status A to status B. He actually wants to reach that certain goal by means of those behaviours. The user can also interact with the system according to his interpretation and expectations.
In practical terms of course, the role of the observer and that of the user are often interpreted by the same actor, *i.e.* the real user; on a conceptual level however they are two separate, independent entities.
The distinction is manifest for example in the perspective of the designer.
He behaves as an external observer of the whole product-user system. The goals of the real user enter in the design process just as other requirements and behaviours that will be realized at the end of the causal chain that takes place during the functioning of the product. The designer treats the user's voluntary interactions with the artifact just as any other physical phenomena, as if they were coming from another machine or product.
At the same time, in order to optimize the product, the designer has to understand how the user can interpret the evolving behaviors, thus figuring out goals that are not his own.
Moreover, he has his own goals, for example to avoid misuses and failures of the product, and these are invisible to the final user.
Finally, often the designer finds useful to consider the parts downstream of a machine as the beneficiaries, the "users" of the results of the behaviours coming from the parts upstream. That is, he attributes goals to the internal functioning steps of the artifact, the same steps that appear to the final user (acting as an observer) instead just as physical behaviours of pure action and reaction.
At this point it is clear that functions are strictly linked to the pair observer/user as well.
While it is obvious that the existence of reality is independent of human observers, functions, being the interpretation of an object's behaviour given by the user, cannot exist without interpreters.
The same equations dictate the motion of a stone that slips along a hill. In the case of a spontaneous fall of a stone due to ice formation between rocks we cannot say there is a function. This is because there is no agency, hence no action.
However the relationship between functions and human goals and perceptions is far from obvious and univocal, precisely because of the distinction between observer and interpreter.
In epistemological terms, such issue can be expressed in terms of the difference between the actual and normative dimensions of functions.
For example, in biology it is possible to ascribe to, say, the heart, not only the action but also the function of pumping blood. In contrast to the mere description, this way it is possible to talk about malfunction or dysfunction [24], but there is no formal need for introducing the "user" of the heart.
Now the problem in technology, differently from biology, is that it is logically impossible to describe the normative aspects of functions without considering the users of the artifact. A purely physical description of functions originating from the behaviours that the structure can exhibit is not enough.

A user can introduce a function that the designer did not intend to put into the artifact. These new functions may enlarge the set of functions of the artifact (and perhaps generate truly novel functions). Or the user may fail to use the artifact as intended by the designer, producing malfunctions or dysfunctions. Thus in technological functions the logical necessity of preserving the normativity of the concept brings us to explicitly include the user in the representation.

2.3 Functions *vs* features

The last ingredient we have to consider is the physical structure of the product.
In particular, features can be defined as the specific characteristics of a single part of such structure, in terms of the geometrical entities that define it and of the properties of the material it is made of.
It is important to decompose the object down to features that can be considered the elementary particles or bits of information for the physical representation of the product. Therefore, we state that two features are distinct if there is at least one geometrical or physical parameter (here parameters are intended simply as measurable quantities entering equations: length, weight and so on) that changes abruptly, with a discrete leap, when moving from one to the other.
Clearly, every function has to be implemented by a certain part of the product's structure, *i.e.* by a set of features. The converse is also true: to each and every feature has to be associated at least one function to which the feature contributes. Otherwise that feature is useless and therefore can be eliminated.
The link between functions and geometrical features is even deeper and deserves a wider discussion on its own. We postpone the issue to another paper, for the purposes of the present one it is enough to register the fact that the detailed structure of the product modifies the perception of functions and even the causal chain of relationships between them.
We finally note the interesting view about features as parts of a wider entity proposed in [18],[19]. There, the key elements are transformation processes acting on technical systems. The latter have internal and cross-boundary functions (what the relevant organ(s) can do), organs (connections or contacts between action locations on two or more constructional parts), and the constructional parts proper. Functions allow the organs and constructional structures to exhibit behaviors, *i.e.* changes of properties in response to external or internal stimuli. Properties include features (as elemental design properties of constructional parts, the only items under the direct control of the engineering designers), but also many performance aspects that are the end-result of these elemental design properties, once the technical system has been manufactured and assembled, and put into service.

3. A NEW PERSPECTIVE: FUNCTIONS AS CONNECTIONS

3.1 Functions as composite objects

All existing approaches to functional analysis, even those who recognize the complex nature of functions, at the practical level represent functions by using single, simple verbal expressions.
In our opinion, such representation cannot correctly capture all the implications embedded in each function. The use of natural language makes it too ambiguous, while the structure of the various set of functions that have been proposed so far is either poor or not rigorous.
As discussed in [21], in order to construct a rigorous representation and classification of functions, it is necessary to link the functional hierarchy to the physical constitution of the world, and to decompose function and sub-functions down to the most elementary physical effect or logical concept available.
In [22] we suggested a representation of functions as composite objects in a vectorial space.
Each function is obtained in a formal way as a linear combination of elementary constituents, which in turn are derived from physics (kinematics, dynamics, etc.) or from logics (union, intersection, addition, subtraction, etc.). The set of such elementary entities will constitute the functional basis, while physical and logical laws also supply the rules to combine them.
The proposed representation is unambiguous and takes into account all the nuances and conceptual differences that distinguish each function from the others. Actually, they are explicitly included in the definition of each function as components of the vector that represent it.
It is important to note that we are not claiming that functions can be derived only from physical principles (and chemical and logical ones). An artifact exists according to technical specifications and to the law of physics but it is there to fulfill human needs and values. Functions are exactly the connection between the two points of view, capturing the essence of how the product works and why.

The dichotomy between goal (from the user point of view) and physical implementation is typical of all Functional Analysis and is often reflected in the overall function *vs* sub-functions decomposition.
A good representation of functions should be unique, faithful, unambiguous, and capture both aspects.
The first idea is that physical inputs are a guide for rigorous and effective representations. Functions should always be expressed in such a way to make explicit the physical effect implied. The sense of the statement is that a parallel between the two alternative descriptions must always be possible.
Functions reconcile the bottom-up vision that behaviours derive from structure through physical laws, with the top-down perspective that translates the user's needs in requirements and then into functions.
Our second claim is that with the vector approach it is possible to represent both the physical part of the action and its goal (we note that the notion of action implies an intention by the agent). The two aspects are just different components, belonging to different subspaces, generated by different sets of basis elements. The function useful in engineering design is obtained by joining the two contributions.

3.2 The matrix

Gathering all the elements discussed in the previous paragraphs, the logical chain is clear: parameters defining the various properties (features) of the product enter as variables or constraints in the equations that rule the product's physical evolution (behaviours). If such behaviours are sensed or, better, if the results of the physical effects are perceived by the human being, they can be interpreted as means to achieve a goal or that can prevent from its achievement (functions).
Therefore the function of an artifact is defined as its teleology: it is ascribed to behavior by establishing a teleological connection between a human's goal and the measurable effects of the artifact [13].
In our opinion the action of connecting goals and physical effects means creating a functional representation. In the model we propose it has the form of a matrix.
We start from the notion, explained above, that functions can be represented as composite objects, and give now a different perspective of such property. We interpret that construction not just as useful way of describing functions but as their actual essence. Indeed, if something can be represented in the most efficient way by a structured set of more elementary objects rather than as an independent entity, the Occam razor principle dictates that it is a non fundamental object ontologically as well.
We can think at an analogy with molecules: they are not fundamental object in themselves, being made of atoms. Yet, a molecule as a whole has properties way more complex than what can be expected by the mere sum of atoms. The same brute formula can correspond to several molecules with completely different properties. Molecules are held together by associative links and forces following precise rules of combination, and the result are a precise spatial structure, a series of active sites and specific chemical properties.
In the same way, a function is not just the mere sum of goals and physical basic statements. Different relationships between different goals and the same behavior produce different functions. More than by the single components, a function is defined by the network of relationships between them. Actually, being an abstract construction, function IS the network of relationships itself. As for molecules, the complex intrinsic structure of functions generates specific properties, and can explain and deal with phenomena such as affordances, misuses, failures, user's need, designer intentions, and so on.
In a full developed model, where it would be possible to give a formal, even mathematical, description implementable in software operations, functions will probably be represented as matrixes acting on the status of the super-system given by the artifact and the user.
On the practical level, trying to figure out how such matrix may look like, we can imagine that the connection between a behaviour and a goal can be more complicated than a single link. In particular:

1. One single behaviour can simultaneously satisfy more goals at the same time.
2. More concurring behaviours can be interpreted as able to simultaneously satisfy some goals.
3. The link may have various degrees of intensity: strong links represent situation in which there is an almost unique interpretation of a behaviour in terms of goals, while weak to moderate links characterize situations in which a goal is only partially satisfied by using a certain behaviour or a behaviour can be exploited for multiple purposes.

Combining the statements 1, 2 and 3 we can say that a function is a weighted connection between some behaviours with some goals. Needless to say, the relationship is never biunivocal, or one-to-one.

3.2 Examples

We now analyze two approaches to functional design, the first systematic work on functions by Pahl and Beitz [8], and the rationalization of Stone et al. [14], finally synthesized in the Reconciled Functional Basis (RFB) by Hirtz et al. [10]. We have chosen them since they are amongst the most operational models, providing structured lists of functions and rules to combine them.

Pahl and Beitz's approach was very behaviour oriented, with functions described in a physical way (that is aiming at capturing what they do). Stone's research group on the other hand had the aim of reconciling previous efforts with different rationale, thus ending up with a mixed functional basis; as a result the RFB includes both physical based functions and goal based ones. That representation acquired a novel nuance (the goal), but lose the strict link (one to one) to the physical description.

We appreciate both the deterministic approach of the former and the synthesis of latter, but we believe the route to a complete framework lies in the construction of functions from elementary blocks and in a matrix-like representation.

For example, in the RFB, some verbs appear listed under different primary classes. There are two possible reasons: (i) the verb has multiple meanings (e.g. *locate* can mean both position and localize); (ii) the same verb can be seen from different perspectives: goal based *vs* physics based.

The first case is just a consequence of having used natural language. The two entries are two totally different functions. As for the second case, consider for example *emit*, where the how dimension is listed under *export* and the goal under *display (signal)*. Similarily, *constraint* something we have to *reduce its degrees of freedom* (physical behaviour) with the aim of *securing* it (goal). Finally, *allow* is a correspondent for both the secondary functions *import* and *regulate*, where the main difference is in the how dimension. The double affiliation is an attempt to fit the complex nature of functions in the hierarchical small set of RFB, but the tree-like structure of the existing Functional Basis is not suitable to correctly represent all the various aspects that characterize functions.

Actually in the RFB very few verbs display a dual nature. However the risk is to loose for many functions either the physical implications or the goal related ones.

Of course there are functions where just one aspect is enough. For example *abrade* is a candidate for a representation purely behaviour-based since it means, by definition, to remove solid at boundary by cutting (using multiple, fine crystalline grains). In this case the goal coincide with the behavior.

But that is not always the case. Consider the verb *polish*: it is listed under *remove*, thus correctly capturing what happens physically when polishing and object, but the true goal of the action, that is increasing the optic quality of the object itself, is lost. The two functions *extract* and *remove* share the same "how", that is the physical separation, but again there is no way to explicitly track the different goals: for *extract* the user's interest is in the part extracted while in *remove* is in the part remaining.

As last example of function with mixed implications is *dope*; from a chemical point of view, it means adding impurity in bulk in a proper way, but the aim of such action is to increase conductivity.

4. CASE STUDIES

The new paradigm can be implemented with a top-down approach, namely starting from the direct interaction between the user and the product, or in a bottom-up direction starting from features and structure and deriving the description of goals and behaviours.

The first case study presents a set of interactions from a user-centered viewpoint. Through the example of a glass we explore the concept of guess, the affordance of a product, its misuses and its failures.

The second case study shows a more designer-centric point of view: the same product is decomposed into parts and features, its use is split into logical phases, goals and behaviours are analyzed in detail and step-by-step. In both cases the behaviour-goal approach help substitutes the functional explanation and enriches the picture with a more precise description clearly based on how and why.

4.1 Case study 1: top-down

The first case concerns situations in which the goal dimension and the role of interpretation dominates over the behavioural component of the function. In this context, additional concepts related to the user role emerge, such as affordances, alternative uses and so on. Let us review them.

Affordances

"Affordances are possible actions" and in particular "the affordances A of a device are the set of all potential human behaviours, (Operations, Plans, or Intentions) that the device might allow" [25]. Thus, affordances can be recognized from experience, can be learned from direct or indirect use and also inferred by analogy. Perceived affordances [26] are context-dependent actions or manipulation possibilities from the point of view of a particular actor [25]. The actor is considered to be the entity, human or otherwise, capable of taking actions.

Let us to present a simple example already described by Mayer and Fadel [12]: the chair. A user sees some chairs around a table, he needs for an empty room (**goal**), so he focuses the attention on a set of **geometrical features** of the chairs' structure which could allow the chairs to mate each other (**behaviour**). He will say that he stakes (**function)** the chairs one over the other or that the chairs have the ability to be staked (**affordance**). Without a goal in mind he did not turn his/her attention to such "manipulation possibility". When he recognizes the affordance it means that he figures out a possible action or remembers a past action oriented to the goal of reducing the room the chairs take up.

Alternative uses

Keuneke and Allemang [27] stated that an alternative use is a possible use connected to the context and to the material decomposition of the device. Accordingly to the presented perspective, to use a product for achieving a goal means that the product can function in a certain way. Therefore the reformulation of the Keuneke's sentence can be: the "material" decomposition of a device allows the user to exploit all the product functionalities accordingly to his/her goals.

Let us continue with the previous example. The user wants to sit, but there are no chairs in the room.

In such simple case the user's **goal** can be captured by describing the status of the user after he had performed the action on the product. For example, the sitting position can be described as a human configuration in which the feet are in contact with the floor, the height of the knees is the same as the hips, the back stands straight. Therefore, without chairs around, he will start to look at objects where he can sit (for example an object with a flat surface-**behaviour 1**), that can support his/her weight (**behaviour2**) etc., and allow him/her to get the sitting position (within a certain tolerance).

A 30 litres paint can, a travelling suitcase, the stairs (and in particular the third step) can all be *interpreted* as products that can be used to sit, because they share the same combination of specific features (flat, horizontal platform with reasonable size above the ground) which enables you to sit. Each product delivering such feature combination, allowing certain behaviors may allow you to sit..

In summary, the alternative uses are the possible **behaviours** of a system *interpreted* by the user as possibilities of achieving **goals**. It means that, from the user's point of view, the system presents new **functions** besides those designed by the designer.

Misuses

Misuses are defined as those conditions in which the user manipulates the product in ways that were not intended by the designer. Cascini *et al* [2] propose to distinguish between two kinds of misuse:

1. user's manipulation is based on his/her belief that the product affords, but such affordance was not intended by the designer.
2. user and designer agree on the affordances, but the user has erroneous expectations about the behaviour of the product.

However, misuses can be described as follows: the possible user's behaviours over a system that reacts producing **behaviours** interpreted by the user as not enough for achieving his/her **goals**.

From the user perspective the product does not **function** properly, so he *interprets* the product fails; conversely, from the designer perspective the product is not designed to function (or better to behave in a way able to satisfy a certain goal) as the user *believes*.

How can be these notions included into a functional representation?

The example in Figure 1 shows possible affordances, false affordances and misuses for a simple category of objects, drinking glasses.

Let us consider the case of a common plastic glass (see Figure 1 (a) and (b)).

As in the case of chairs, the ability to be staked (b) is an affordance of the product (a).

Having in mind the disposable, plastic glasses, users usually throw damaged, broken and deformed ones away. In a sense, we can consider the crumpled look as a marker of the fact that the main function of the glass cannot be fulfilled properly, pushing the user to get rid of it.

The container portrayed in Figure 1 (a1) is a ceramic mug, a design object by Revol intended to look like a crumpled plastic glass, with the purpose of appearing "cool".

This is an example of false affordance [26]: a user may mistake it for a true damaged plastic glass and may want to throw it away. When he grasps the object, he finds it heavier than expected and the false

Figure 1. Affordances, misuses and alternative uses in case of a glass

affordance is removed suddenly. Such mismatch between interpreted and actual behaviour, since it does not cause any consequence, results funny for the user. However, even when the first false affordance is resolved, the user may try to stack it (as it happens in Figure 1 b) with similar mugs. Actually, he fails because they are bulky, un-deformable ceramic objects (Figure 1 (a1-b1)).

In the case of a chocolate glass (a2), by making an analogy with a standard one, the user can erroneously pour some hot coffee, but the result is a disaster: the chocolate melts and the coffee exits from the glass (misuse). However the chocolate glass can be used as a container for cold beverage, can be piled in winter without sticking, etc. and in such cases hypothesized and actual behaviours coincide.

Finally Figure 1 (a3) is a case of a well-known alternative use for a glass: a pen holder (different goal). Using the Revol mug all the pens can stay located on one side, and the user can believe the glass is going to fall down (hypothesized behaviour=false affordance), but, since it is not made in plastic, it shows a higher stability and will not collapse (actual behaviour).

4.2 Case study 2: bottom-up

The idea is that is possible to represent the functions of a device without ambiguities by using its behaviour and the goal, thus including explicitly the how and why dimensions.

In this context we define the goal as the final status of the environment+user at time T_{n+1} that has to be achieved moving from an initial status T_n. Such definition can be applied at every status transition. The user senses both the statuses and gives an interpretation of the difference between them.

Furthermore, the goal can be expressed more precisely in two ways:

1. an affirmative sentence describing the status of the environment after the action;
2. a negative sentence showing the drawbacks to be avoided during the action.

Table 1. Equivalence between functions and goal-behaviour couples

Phase	Function (verb+flows)	Goal	Behaviour
Transport Glass			
	Transport glass+water	Water is close to the mouth	Move
	Stabilize glass+water (vertical sliding)	Glass and hand are steadily coupled (otherwise transport cannot be achieved)	Apply pressure
	Align	Glass and hand are steadily coupled (axes are aligned)	Rotate-translate
	Control position	The 6 DOF of the glass and the water are known	Sense visual signal

	Position glass near the mouth	Water is close to the mouth	Move, control trajectory
Mate			
	Mate (glass on lip)	The user and the environment remain dry	Deform lip, compress-repulse
	Stabilize shape	-	Compress-repulse
	Decrease pressure	The lips have to remain the same as in the previous state (the glass does not cut the lips)	Distribute Pressure
Export water			
	Rotate	The water level has to be higher than the exit level	Rotate
	Distribute water	-	Water moves
	Guide	The user and the environment remain dry	Deviate
	Export	Water is inside the user's mouth	Water moves

Let us continue with the plastic glass as example. During the use of the product the user interacts with the glass in several phases. Hypothesizing that at T_0 the glass is on the table, the phases are: the user fills the glass with water, he grasps it, brings it near the mouth, leans the glass' rim against the lips, rotates the glass and pours the liquid into the mouth, and finally removes the glass and puts it down on the table. Given the space available, we focus on three of them: the first transport from the table to the mouth, the mating of the lips and the export of the water into the mouth.

Table 1 presents on the same row the function and the equivalent goal-behaviour couple. Even if the case is simple and the number of phases is reduced, there is no ambiguity: the function can be read either in the function form or in the goal-behaviour one without misunderstanding.

A remark about the two rows where there is no goal associated to the function. Actually in these cases the macro-function of the phase (mate and export water) are split in more sub-functions. Even if all sub-functions have a goal from the designer point of view, some of the related behaviours are not perceived as separated by the user and therefore he cannot associate a goal to them.

5. CONCLUDING REMARKS

Our analysis starts discussing the notion that functions do not exist outside the relation between behaviours and goals and continues constructing a more complex representation.

We are fully conscious that, even if the approach proposed in this paper describes a product in a more accurate way, (i) the designers are more familiar with functions and can find too complicated to describe separately the physics (behaviour) and the user's intention (goal), (ii) functions, because of their ambiguities, allow the designer to simultaneously captures both the how (behaviour) and why (goal), (iii) functions constitute a common and intelligible language for the communication between designers and marketing, purchase, after-sale divisions.

Moreover functions, though not precise, are versatile, synthetic, abstract and practical at the same time, and therefore are most useful in the heuristic analysis of products.

On the other hand, our model can be more effective when a more detailed or sophisticated analysis is needed. Indeed, the focus on the goal dimension helps to recover the centrality of the user. It allows to deal with aspects as affordances, needs, perceptions, that are difficult to include and manage systematically if using functions taken from limited sets.

At the same time including behaviours allows to connect the ontology of functions to physical and logical laws, thus assuring more rigorous statements.

From the theoretical point of view, our approach can constitute a bridge between the FBS-like models and those based on taxonomies, basis, databases.

On the practical side, the relational matrix enriches the vectorial paradigm that is particularly useful for example in the search for functional variants, in the comparison between products, when performing QFDs and so on.

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