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B-Cube, behavioural modelling of technical artefacts

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ABSTRACT

A new model, B-Cube, is described for managing knowledge at the behaviour level of the function–behaviour–structure framework. The model proposes a three-dimensional approach to the behavioural modelling of technical artefacts using definitions based mainly on the meta-ontology DOLCE as concepts of behaviour.

The present work aims to show how these terms and those from the NIST functional basis can complement each other in functional design. It is assumed that this model achieves similar objectives with behaviours to those obtained by the NIST functional basis with functions, i.e. the representation of behaviours in CAD and KBS, a scheme for the modelling of behaviours and a universal set of behaviours. The modelling language IDEF was adapted to be able to produce a graphic example of the modelling of technical artefacts in the FBS framework using B-Cube terminology at the behaviour level.

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1. Introduction

The aim of this article is to present a new model of functional design based on the function–behaviour–structure (FBS) framework that can be implemented in a solution-synthesis system and act as a link between different libraries of software applications. This model proposes a three-dimensional approach that uses definitions as behaviour concepts. It is assumed that this model achieves similar objectives with behaviours to those obtained by the NIST (National Institute of Standards and Terminologies) functional basis with functions, i.e. the representation of behaviours in Computer Aided Design (CAD) and Knowledge Based Systems (KBS), a scheme for the modelling of behaviours and a universal set of behaviours. It is able to solve, a priori, the shortcomings encountered in previous research when trying to link functional design with TRIZ-based Computer Aided Inventing (CAI) tools [1], e.g. loss of information within the use of taxonomies at the functional level (such as ambiguities, synonyms and functions without correlations). The present work aims to show how these terms and those from the NIST, the Reconciled Functional Basis (RFB) [2], can complement each other in functional design. The B-Cube (Behaviour Cube) model is based mainly on the meta-ontology of DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [3,4] and on Garbacz's functional development of it [5,6].

The concepts of function and behaviour, as part of the FBS framework [7,8], are at the core of our research. The FBS framework is widely used among designers for design process analyses, as it is capable of representing the evolution of the design state from the study of protocols [9]. More recently, Gero and many other researchers have extended the study of FBS representation [10–15]. Within this framework, function is the abstract purpose the design is oriented towards. When the function is carried to a lower level of abstraction and defines how the device or its components will be related to the uses for which they are employed and designed, we are defining the term *behaviour*. Devices and their parts have physical structures and these structures and their relation with the environment determine the behaviours, which are in turn related to the functions of the device [5,16–18].

The FBS framework allows computational modelling to be carried out, that is, software applications can be produced that are able to use search and explore procedures in order to find and combine design-solving procedures for a problem represented by functions. Thus, several authors have tried to develop approaches and software applications to implement FBS-based procedures [19], while others have attempted to model function and/or structure libraries to be implemented in functional reasoning processes [20–24]. The possibilities of these systems have been increased by function classifications achieved by means of hierarchies [16] and the use of taxonomies.

A taxonomy consists of a group of concepts and relationships that are organised hierarchically and whose concepts can be arranged as classes with sub-classes [25]. Taxonomies were introduced into the industrial world by Gershenson and Stauffer [26], but Szykman et al. [27] were the first to differentiate

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functions with their extensive review of function terminologies within the engineering context from 1976 until 1998. Since then, several function taxonomies [28,29], as well as behaviour [5,30–32] and structure taxonomies [33] have been developed. In the case of function taxonomies, the most significant are those provided by the NIST [2] and those based on DOLCE [6,34].

The RFB allows overall product functions (especially from the electromechanical and mechanical domain) to be modelled as sets of connected elementary sub-functions. Function is described in a verb–object form and represented by a black-box operation on flows of materials, energies and signals. A sub-function is also described in verb–object form but it is represented by a well-defined basic operation on well-defined basic flows of materials, energies and signals. The black-box operations on general flows representing product functions are derived from costumer needs and the basic operations and basic flows representing sub-functions are arranged in libraries. Some authors have remarked that the descriptions of operations-on-flows may be better understood as representing the behaviour of products and their components rather than functions [16,35,36].

The RFB supports a number of engineering tasks, including the archiving, comparison and communication of functional descriptions of existing products and the engineering design of new products. For example, the RFB has been used to develop and refine a web-based repository of design knowledge. This repository (which includes descriptive product information such as functionality, physical parameters of components, manufacturing processes, failure modes and component connectivity) contains detailed design knowledge about consumer products and the components they are made up of. Design generation tools, like function–component matrices and design–structure matrices, can be readily created from single or multiple products and used in a variety of ways to enhance the design process [37]. The functional basis is applied even outside the engineering field, for modelling functional processes, manual operations and human-centric procedures [38].

Hence, a formal function representation is needed to support functional modelling, which helps to clarify the meanings of terms and also to support representation of device knowledge for automated reasoning [39]. In this regard, research efforts are being made to move functional basis towards a functional modelling language [40]. Another line of research is the work of Garbacz [6], who reviewed the RFB and refined it formally, with the help of the conceptual framework of the DOLCE ontology [3]. This line of research served as the inspiration for our model, B-Cube, which is introduced in the present article.

Furthermore, in Section 7 a graphical modelling approach is proposed to model technical artefacts in the FBS framework by adapting the modelling language IDEF4 [41] and using the B-Cube's terminology for the representation of behaviours. The aim is to achieve an intuitive, easy-to-understand model that can be used by any designer and also to represent the examples that are included at the end of this article to provide a clearer illustration of how behaviours are modelled with B-Cube. A more complex example of a functional design expressed using the B-Cube model's terminology can be seen in [42], where the authors defended the usability of this kind of model to establish a link between functional design and CAI tools.

2. Functions and behaviours

Despite the importance of function and behaviour in engineering design, there are still some fundamental ambiguities and confusion regarding their definition. The disadvantage of lacking conceptual consensus becomes an important issue when functional and behavioural descriptions have to be shared. This occurs when, for instance, designing is modelled as a procedure in which existing knowledge about the relations between the functions, behaviour and physical structure of artefacts is partially retrieved from knowledge bases. In such cases, having a common set of definitions is essential [43].

Chandrasekaran distinguishes between two general approaches to defining the functions of technical artefacts, called the functional representation approach and the functional modelling approach [35]. The two approaches involve performing research that is mutually complementary. First, functional representation research provides the basic layer for the device ontology in a formal framework that helps to clarify the meanings of terms such as function and structure, as well as supporting representation of the device knowledge for automated reasoning. Second, functional modelling research provides another layer in the device ontology by attempting to identify behaviour primitives that are applicable to subsets of devices, with the hope that functions can be described in those domains with an economy of terms. This can lead to useful catalogues of functions and devices in specific areas of engineering. With increased attention to formalisation, work on function modelling can provide domain-specific terms for function representation research in knowledge representation and automated reasoning.

Functional modelling and functional representation might merge over time. Ontologies of the sort being developed by function modellers are certainly going to be useful for device knowledge representation because the current body of representational primitives in artificial intelligence does not have terms for the properties, behaviours and functions of devices in specific domains [35].

In relation to the functional representation approach, Chandrasekaran and Josephson [44] isolated five meanings of behaviour and two of function. The meanings of behaviour are characterised using the primitive notion of state variable:

- Behaviour as the value of some state variable of the artefact or a relation between such values at a particular instant.
- Behaviour as the value of a property of the artefact or a relation between such values.
- Behaviour as the value of some state variable of the artefact over an interval of time.
- Behaviour as the value of some output state variable of the artefact at a particular instant or over an interval.
- Behaviour as the values of all the described state variables of the artefact at a particular instant or over an interval.

The two meanings of function distinguished by Chandrasekaran and Josephson are called the device-centric and environment-centric meanings. Without going into detail, a device-centric function of an artefact is a behaviour of the artefact that is selected and intended by some agent (in device terms). It is a function that is described in terms of the properties and behaviours of the artefact only. An example of a device-centric function is 'making sound' in the case of an electrical buzzer. An environment-centric function is, in contrast, an effect or an impact of this behaviour of the artefact on its environment, provided that this effect or impact is selected and intended by some agent (the 'why' of the device). This kind of function is conceptually separate from the artefact that performs or is expected to perform the function. Thus, 'enabling a visitor to a house to inform the person inside the house that someone is at the door' is an environment-centric function of the buzzer.

Functional modelling includes the functional basis model by Stone and Wood [45] and the RFB [2]. Stone and Wood modelled the overall product functions of technical artefacts, especially from the electromechanical and mechanical domain, as sets of

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