Product Design Test using the Matrix of Functions and Functionality

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Summary:
After detecting the customer needs it is possible to define functional requirements and set the design goal. The latter is represented by a target defined specification list of requirements. Such defined functions can serve as a basis for the concept, created by means of the morphological matrix. The optimum solution is selected after a rough assessment of results from the technical and economic points of view. The current procedures do not allow tracking links between functions and technical systems during the subsequent phases of product development, which can be realized by the details of the as-built product. Such technical systems or sub-systems are usually called products or their sub-assemblies. The article presents the form of the matrix of functions and functionality (MFF) that in principle defines the elements, parts, assemblies and the product itself according to the level of the product's structure. On the other hand, it also defines the required functions. They can be ranked according to the levels of functional structures. The form of the matrix of functions and functionality is necessary in order to allow recognizing the quality of the final solution for a product. The article presents the main characteristics and the criterion for defining functions and functionalities. The model was tested on two industrial products.

1.0 Introduction

The use of the morphological matrix has had an important role in developing design methods [Pah Bei 1993]. It was later adopted in the recommendation VDI 2221. The morphological matrix is the basis for recognizing technical systems that can be used to fulfill certain functions. Due to the possibility that some developed technical systems are not in accordance with the natural physical and other laws, Koller [Kol Nor 1998] drew up a list of physical and other natural laws. His list included 156 laws. After revising and analysing the suitability of the laws, Žavbi [Žav Duh 2000] [Žav Duh 2001] presented a total of 136 physical laws, reduced in one part and complemented in the other one. Combining individual laws, he proved on several innovative solutions that solutions are not achieved randomly. Instead, they are a logical consequence of relations within the tree of laws, applied for a particular product. It should be stressed in particular that this applies to new products only and not to innovative and variant solutions or adaptations.

The innovative products are exclusively a matter of permuting different existing technical systems. Therefore, the use of the morphological matrix has a particular importance, regardless of the designer's working environment. Once the matrix has been made and the results have been analyzed, all important information from the matrix, i.e. the required function according to the existing procedures, are lost. Even the submitted technical systems have no proper value as the final solutions are eliminated from discussions when a product has been launched.[Eig Stel 2001]

It is clear that functions in a morphological matrix should be listed according to the functional structure. The latter is important for understanding the functioning of the product itself. At the same time, the functional structure is also reflected by the structural levels of the product. Even more – the pure functional structure can significantly contribute to the construction of the product and it is possible to determine its complexity in advance. However, defining the functions still includes a total abstraction of individual functions as well as parametric definition of the scope of functions for a particular product [Her at all 2000], [Har at all 2001]

When the morphological matrix is an important part of an innovative product's concept a question about the final evaluation of the product, built in all its details, comes up. Product's functions are also defined completely abstractevely and certain values or their intervals are parametrically defined. In this context, it should be stressed in particular that the initially required functions are completely the same for the morphological matrix and for the matrix of functions and functionality. They only change when they are complemented or expanded. The aforementioned matrix of functions and functionality is therefore a direct link between the functions (requirements) and the execution of the product (ID number of each product). The matrix itself as well as the criteria for defining functions and functionality will be presented in details.

By defining the MFF structure precisely, it is possible, in our opinion, to define the quality of development at the end of the product development process or even during the early phase. However, it should be pointed out that we will use the criteria of compatibility of different parts of the product and their functional individuality or complexity.

2.0 Matrix of functions and functionality

Generally speaking, the MFF is structured according to Figure 3. Functions are arranged by their levels. As a rule, there are three or four levels for each product that is being developed. A larger number of levels for a more complex machine, device or object only indicates the necessity that certain functions of an individual product's parts should be described as final functions. In doing so, decomposition by levels of a product's sub-assembly in question should not be considered.

Such structure by levels should be established for the morphological matrix already, during the concept phase. This is an important contribution to purifying the defined functions. It means a dynamic adjustment of functions, though. A deterministic approach or understanding of the morphological matrix revealed that the morphological matrix has its limitations. However, the use of dynamically composed functional requirements and definition of their levels showed that the morphological matrix can be an important contribution to the development of new functional requirements.

There are one or more solutions for each function or, inversely, each solution (the more complex one of the two) can fulfill one or several functions.

The other part of parameters can be described by the products themselves. When the development process is over, we have products. For the purpose of simplification, the products can be represented by their codes or, in our case, by their ID number.

It means that other parts of the matrix are represented by the product itself or its characteristic identification. At this point, it should be stressed that the situation was similar in the case of the morphological matrix. The only difference was the less precisely defined technical system and its compatibility while in this case, the function as well as the product's shape (termed functionality) are more precisely defined. It now means a more precise definition of a product's design characteristics.

2.1 Functional structure of a product

The product's functional structure is the first step towards making the matrix of functions and functionality. The functional structure enables presenting a product on the abstract level – it increases the creativity because we are not limited by a concrete solution. The functional structure is known from the methodology of design and it is used during the product's concept phase. [Pah Bei 1993]. Figure 1 shows different abstract levels. It is clear that the function is the linking part between the requirements and execution. The functional structure clearly indicates various functions of a product and their relations.

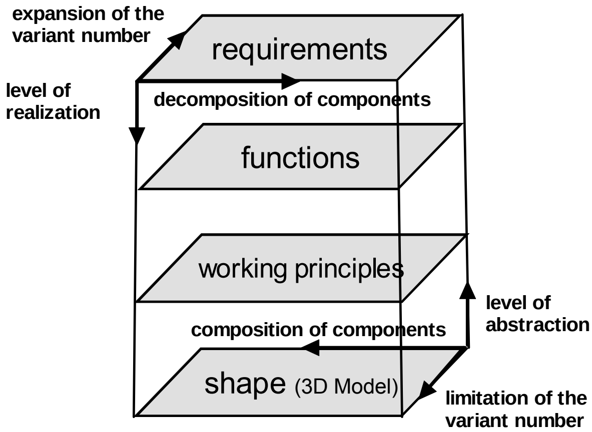

Figure 1: Levels of product abstraction and creative possibilities [Rude 1998].

Analysis of functions requires defining terms for the purpose of analysing a product. Several definitions and their relations were defined in [Duhovnik 1990], [Duh Zav 1992].

Function: The function is determined by the objective or the use of the designed technical system. The functions are described using physical expressions, and, if necessary, supplemented by geometrical and topological relations. Examples: transformation of mechanical energy, transmission of mechanical energy in 3D, prevention of relative rotation, output of forces, heat transfer, and electrical insulation. The functions fall into the following categories:
Required Function: This function is determined by the objective. It is fulfilled by the designed technical system.

Functional requirements are the listed requirements that the product as a technical system should meet in the sense of working, processing and physical characteristics. It basically means a detailed description of the project task, a design requirement, a development task or an order itself.

Sub /basic function: This function is executed by the shape model. More sub-functions can fulfil a required function. At the macro level, we use the term ‘sub-function’, and ‘basic function’ is used at the micro level.
Binding function: This function enables two shape models to be connected that contribute to the fulfillment of the required function.
Auxiliary function: This function is determined by the specificity of the working principle and the shape model.
Working principle: It presents a description, in the form of words or a scheme, of a physical law, relation or mechanism, that is the basis for the realization of the required function.
Examples: Pascal’s principle, friction, Doppler effect, Hooke’s law, Snell’s law, and the use of the chemical energy of oil derivatives.
Shape model (building block, component): This is the objectivization or the model of a working principle.
One of its characteristics is that it does not contain details (for example, the tooth flank curvature, or a correction of the helix angle) or special geometrical features, but is recognized by the names of physical components. The shape models are of various complexities, which depend on the complexity of the designed technical systems.
Examples: flat belt and pulley, roller chain, long pin, needle bearing, and splined shaft.
Technical model: In contrast to the shape model, this model contains all the details (for example the grinding of the upper part of the tooth flank, the surface quality, the hardness of the tooth flanks), and it also contains geometrical features (the shape of the hub and the gear body, for example).
Technical system (assembly, configuration): It represents the shape models and their interrelations, which fulfill the required function. Technical systems have varying complexities. Therefore, technical systems of higher complexity can be composed for technical systems of lower complexity. This hierarchy is useful for decomposition reasons. The meaning of this is explained further below. Examples: a bearing (element) that is a part of a reductor (simple technical system), which is a part of a stone crusher, which in turn is a part of a separation plant (complex technical system).

Functionality shall mean specific characteristics that a particular product should have, regarding the defined performance and loads. For example, a pre-tensioned two-part screw joint in the range between 1 and 10 kN is a function and the pre-tension force of 2,8 kN is a functionality.
Functionality always appears in a chosen or executed form, called technical shape or technical possibilities at production technologies. Usually, only the term functionality is used as a link between a function and a product or an execution because the technical shape or execution is subordinate to functionality.

Functional requirements are defined by detailed load and performance values etc for a particular product during the concept phase. The functional requirements depend on the environment where the prospective product is located. The technical possibilities at production technologies by functionality is required for a particular environment, which means that functional requirements are interrelated and comparable.
Below, breakdown of the function is presented, taken from [Žav Duh 1995].
The object to be designed is a mechanical drive unit. Transformation of mechanical energy is a required function. Form-fit is an example of available working principles, which fulfils the required function and ensures a constant transmission ratio. Among the appropriate models of shape there are parallel helical gears or planetary gear drive.
There is rolling as the upper binding function and appropriate working principle. Double-row spherical roller bearings is an appropriate model of shape, which can be loaded by specifying the largest radial and axial forces.
The next binding function is support. Hooke’s law and welded housing as the model of shape can be applied. One of auxiliary functions of parallel helical gear is prevention of relative rotation is assigned as the binding function.

Figure 2 shows the functional structure of an electricity meter. The main functions and their related functions are presented. It should be stressed in particular that we used the binding function of the assembly, based solely on the mechanical characteristics, i.e. functions. Other functions incorporate mechanical, electric and electronic functions. The main functional chain is defined by the connection, protection, measuring, connecting elements and the meter to its environment and electric power outlet. Within the functional structure, the breakdown of the meter should go as far as it is required for the purpose of assembling new variants.

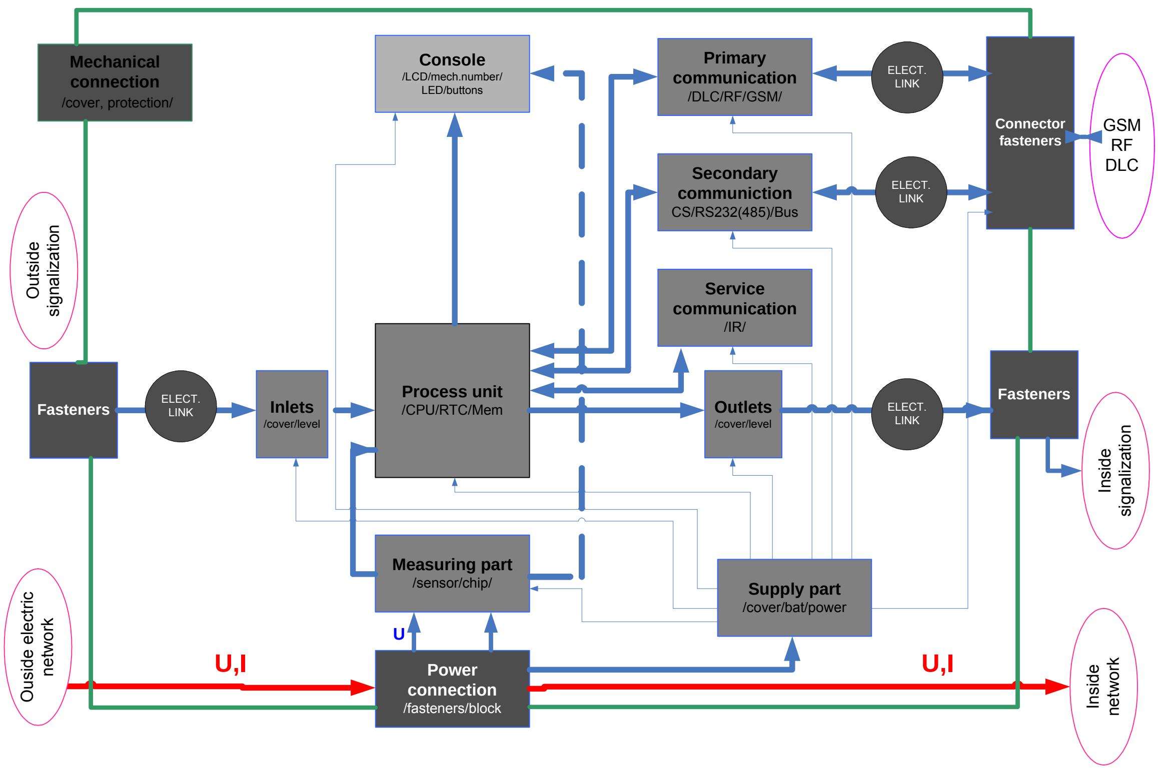

Figure 2: Functional structure of an electricity meter.

3.0 The function or functional requirements criteria

Before defining function or functional requirements it is necessary to define the procedure for defining the structure. In doing so, it is necessary to make sure that individual functions are independent. Suh also defined the functions in a similar way, however, he defined the functions for the purpose of product development [Suh 90]. In our case, the matrix of functions and functionality is to be used solely for the purpose of testing the results. In our opinion, the morphological matrix can encourage defining new technical systems. However, the products development cannot be mathematically pre-determined because it can interfere with the design process as well as a human's creative activities. If a certain mathematical law is applied for the executed solutions and we wish to carry out optimization of the parameters themselves, such as technological attributes in a specific area or environment, this approach is an important contribution to the products development. This is referred to as variant or adaptive development.

Function criteria are as follows:

1. As a rule, a product has the main, supplementary, auxiliary and binding function up to the n-th degree of relations. Each product usually has several functions that need to be precisely defined.
2. When several products within one assembly have the same or similar functions, it is necessary to check the saturation of the technical system.
3. The same function can be fulfilled by a product with at least one or more variants of shape models and at least one or more variants of technical shapes.
4. A function that is not fulfilled by the technical shape cannot be presented as a product.
5. Each function can be defined by a parameter (scope of application), known from the nature, that is measurable, definable and describable.

Example:
Display of electric power consumption is a function on the electricity meter. It can be executed by means of a mechanical or digital display. The product's functional structure should be broken down in order to allow a more detailed definition of the required function and then use it as a basis for a suitable technical system – element that fulfils or upgrades the requirements for a function. After defining the functional structure, the morphological matrix of technical systems is also usually made.

4.0 The functionality or functional requirements criteria

Some functions require appropriate conditions. The technical solution or the perfect solution for the product’s shape is an important condition. We termed it functionality. The term comes from a real situation where the shape is an integral part of all possible conditions, from manufacturing to design conditions and physical space. The product itself is the most representative attribute of functionality. If a product has been defined in the PLM system with all the information, required for the manufacturing, it means that its description has been defined by the product's ID number.

The criteria are as follows:

1. As a rule, a product has the main, supplementary, auxiliary and binding functionality. Each product can have more than one function.
2. Functionality is defined by one or several functions.
3. Functionality is defined by a narrower interval of use or by one and defined parameter value.
4. Functionality can be fulfilled by one or several technical shapes and not by the shape model.
5. When one functionality fulfills a larger number of functions this is an integral product and can be broken down by the process of decomposition if necessary.
6. If there are two products with a larger number of common functions and at least one or more different functionalities the possibility of combining them into one product should be examined.

5.0 Steps for making the matrix of functions and functionality

Making the matrix starts from the product's functional structure, which provides us with the list of product's functions and individual modules. The example of electricity meter's functional structure is presented in Figure 2. A simple example of the MFF for a car engine is shown in Table 1. The list of functions appears on the left and concrete functionalities are on top of the matrix. Air conditioning and power windows can be combined with all types of engines. However, in order to keep a better transparency and to generate a bill of materials automatically, only the main functions should be linked to the functionality. Therefore, the Y field are left blank. On the other hand, the automatic transmission is available with the stronger types of engines only.

Table 1: Matrix of functions and functionality – an example of a car engine.

	FUNCTIONALITY			
Function	**Diesel 90 kW**	**Diesel 120 kW**	**Gas 100 kW**	**Gas 125 kW**
Acceleration 100 km/h in < 11 sec		XX		XX
Acceleration 100 km/h in < 15 sec	XX	XX	XX	XX
Fuel consumption < 6 l / 100 km	XX	XX		
Use petrol	XX	XX		
Noise level (Lp) inside the cabin < 65 dB	XX		XX	XX
Automatic transmission		XX		XX
Accordance with environment standards	XX	XX	XX	XX
Can be used below -30 ^{o}C			XX	XX
Air conditioning	Y	Y	Y	Y
Power windows	Y	Y	Y	Y

The matrix arrangement is part of the product development process and it is a necessary condition for extracting valuable information from the matrix.

A function is directly linked to a functionality. Variants for different loads are a typical example. The basis of modularity is variation of the load or general changes of the parameter's interval that defines each function. The example is presented in Table 1.

Arranging the matrix is neither pre-arranged nor a matter of statistics but a dynamic establishing of functions' levels as well as their execution by the product itself, which is functionality. Recording the functions and variants is in principle a matter of coincidence because at the beginning, there are no rules for defining functions and variants. Therefore, each description of functions in connection with variants should be followed by the process of arranging. This process should be confirmed by an appropriate form of connections. The function that appears several times within a scope of variants should be given the priority or the highest status. In this way, the connections between functions and variants are being verified. Without connections, concrete variants are focused on fulfilling individual functions. It is possible to verify a pronounced requirement for such specific solutions. In this case, we look for modularity by functions. (Table 2)

Variants for individual functions should also be fulfilled at all times. In this case, the number of functions that a single variant fulfils is to be verified. This way, the grading from the highest possible fulfillment of function to the lowest one is confirmed and possible connections are verified. In this case, we can look for modularity by shape.

The MFF includes verification of connections between functions and functionality and vice versa. The arranged MFF shows how a functionality depends on different functions. It also indicates modularity and/or an increase in a product's complexity. Extra verification of modularity by functions only can be achieved by fulfilling the variant of another one. This way, modularity by functions is set up. It provides for a possible use of different technical systems for the same functions. The criterion of modifying the function's parameters is not taken into consideration.

Verifying the function's dependence on different functionalities. Differences in various variants with regard to fulfilling the functions should be arranged in such a way that the variant with the largest number of functions comes before the variant with the lowest number. Functions should also be re-arranged.

Table 2: The MFF after re-arrangement.

	FUNCTIONALITY			
Function	**Variant 2 Automatic air conditioning**	**Variant 1 Manual air conditioning**	**Variant 3 Dormer window**	**Variant 4 Power windows mechanism**
Cooling	XX	XX		
Temperature control	XX	XX		
Regulation of aiflow power	XX	XX		
Heating	XX	XX		
Separate tempearture adjustement for the driver and the passenger	XX			
Outside temperature measurement	XX			
Ventilation on the roof			XX	
Power windows				XX

Variant 2 (automatic air-conditioning) entirely covers variant 1 (manual air-conditioning). Therefore, variant 1 can be completely replaced by variant 4. The replacement should be carried out by an econometric study. Technical fulfillment only is not sufficient.

Recognizing partial functions from the functional structure in a descriptive matrix of functions and functionality. A characteristic form of individual partial matrixes appears. They completely fulfill functional requirements or recognized functions. As a rule, partial matrixes should completely match partial functions. The last lines parts of the matrix are characteristic of binding functions on the level of mechanical, electric, optical and other binding functions or variants.

Table 3: Partial matrixes appear in the arranged MFF of a complex product.

	Funcionality as a request or implemented variant																		
Function	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I8**	**I9**	**I10**	**I11**	**I12**	**I13**	**I14**	**I15**	**I16**	**I17**	**I18**
F1	X	X	X																
F2	X	X	X																
F3	X	X	X	X															
F4	X		X	X															
F5	X			X															X
F6					X	X	X	X	X										
F7					X	X	X	X	X										
F8					X	X	X	X	X	X									
F9					X	X		X		X									
F10					X		X			X									
F11						X	X		X	X									
F12						X	X	X	X										X
F13						X	X	X		X	X	X	X		X				X
F14											X	X	X		X				
F15											X		X	X	X				
F16											X			X	X				
F17											X	X	X	X	X				
F18											X	X	X	X					X
F18												X	X		X	X		X	X
F20																X	X	X	
F21																X	X	X	
F22																X	X		X
F23																	X	X	X
F24	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X

The MFF dynamically changes during the development phases because the product's structure as well as the entire product range is being set up. The MFF offers a concise overview of the entire product range, which is its main advantage. When the development is over, the MFF is stabilized and it becomes and important tool for development staff as well as a linking document for the sales purposes. Figure 3 shows the scheme for generating a bill of materials on the basis of a questionnaire about functions. The questionnaire is formed on the basis of selected functions from the MFF. By choosing a function, the sales person automatically includes the required building blocks into the part list.

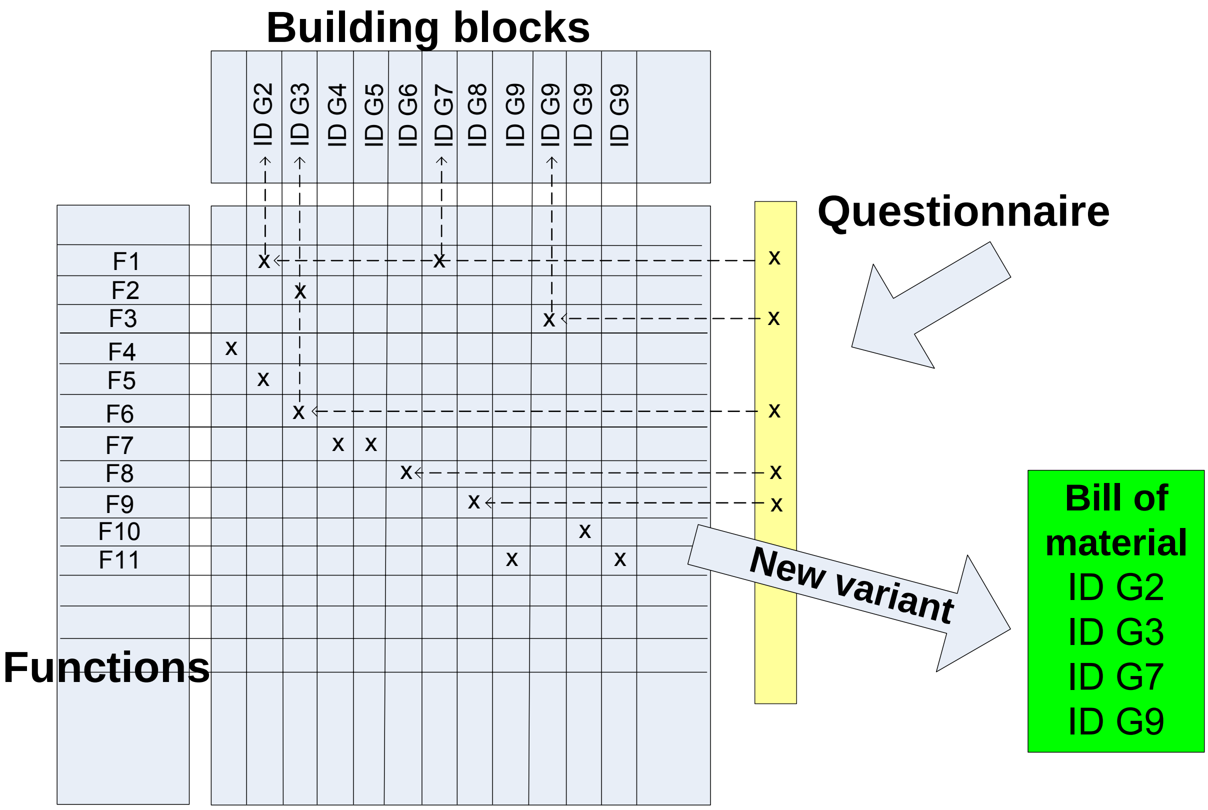

Figure 3: Generating a part list from the matrix of functions and functionality on the basis of a questionnaire.

6.0 Conclusion

The article has presented the concept of MFF, which brings multiple advantages to the management of product development. The MFF enables the analysis of the product's structure during the concept phase, which is the main advantage. From the arranged MFF it is possible to recognize which elements are a complete unity. It is also possible to recognize excessive interdependence between elements and the elements that stick out.

Records about the product's functions and its sub-assemblies during its entire life-cycle are also preserved by the MFF. This way, the MFF is the linking part between the development and other departments, the sales department in particular. The upgrade of the MFF model is planned by means of a suitable software support. Among other things, it will be possible to generate bill of materials on the basis of the required functions.

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