Utilization of graph constellations for the development of customizable product spectra

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Abstract

Difficulties of assigning mass customization approaches to mechatronical products can be found in the high complexity concerning the structural assembly of product elements. Here we present an approach for a tool, which assists the product designer in identifying specific ranges in product model networks. These networks are highly cross-linked due to the representation of increasing variability. In consequence we introduce an appropriate interface between product designer and product model, which permits the handling of extensive interdependency chains resulting from the mapping of variability. The implementation of the tool comprises eight modules, whereas the most important ones are the parallel graph and matrix visualization. In a user-defined number of frames these possibilities of network description allow simultaneous execution of control, creation, and adaptation of interdependencies. The handling of complexity is supported by filter and analysis modules. The presented proceeding consists of two steps to reach manageable partial graphs of specific characteristics. Starting from an arbitrary product definition the general characteristics (colourability, function of distance, etc.) are determined. After this specific partial graphs, such as minimal frames or path sets are extracted from the graph in question. The approach will be extended in the future by integrating a methodical support for the interpretation of specific substructures.

1. Introduction

Mass Customization as a promising strategy in manufacturing is persecuted in many industries [9]. Examples for a comprehensive realization of customizable product creation (production of clothing, shoes, cosmetics, or furniture) already exist. In contrast to this development efforts are still required for the application on mechatronical products. The difficulties of assigning the mass customization approach to these products can be found in their exceeding complexity concerning the structural assembly and the mutual interdependencies of the product elements. Here we present an approach for a computer based tool, which assists the product developer in identifying and interpreting specific interdependencies in complex product models. Furthermore we introduce an appropriate interface between product designer and the product model, which permits the handling of extensive interdependencies.

2. Development of conventional product structure models

The importance of a reasonable product structuring is described in various procedures of product development. This structuring serves mainly for a better handling of the product complexity [8]. In current product development methodical procedures and descriptions for function or building structures exist [10]. However no guideline to an application-referred kind of structuring is available. Figure 1 illustrates a conventional proceeding of product development starting from the product idea and leading to a comprehensive product structure. At first a structured list of important requirements has to be acquired and a fundamental functional structure will be developed. Based on these functions the product can be partitioned in (usually) component-oriented modules, which are subdivided in component groups and single parts in a hierarchical structure. In the end, the completely detailed modules are combined in a comprehensive product model and represent together with the functional and the requirement structure the definition of the product.

By means of the product structuring the predetermined design task is divided in smaller and less complex sub-tasks, which are easier to manage. As it can be seen in Figure 1, this is a recursive procedure, where the number of necessary loops depends on the complexity of the product range in question.

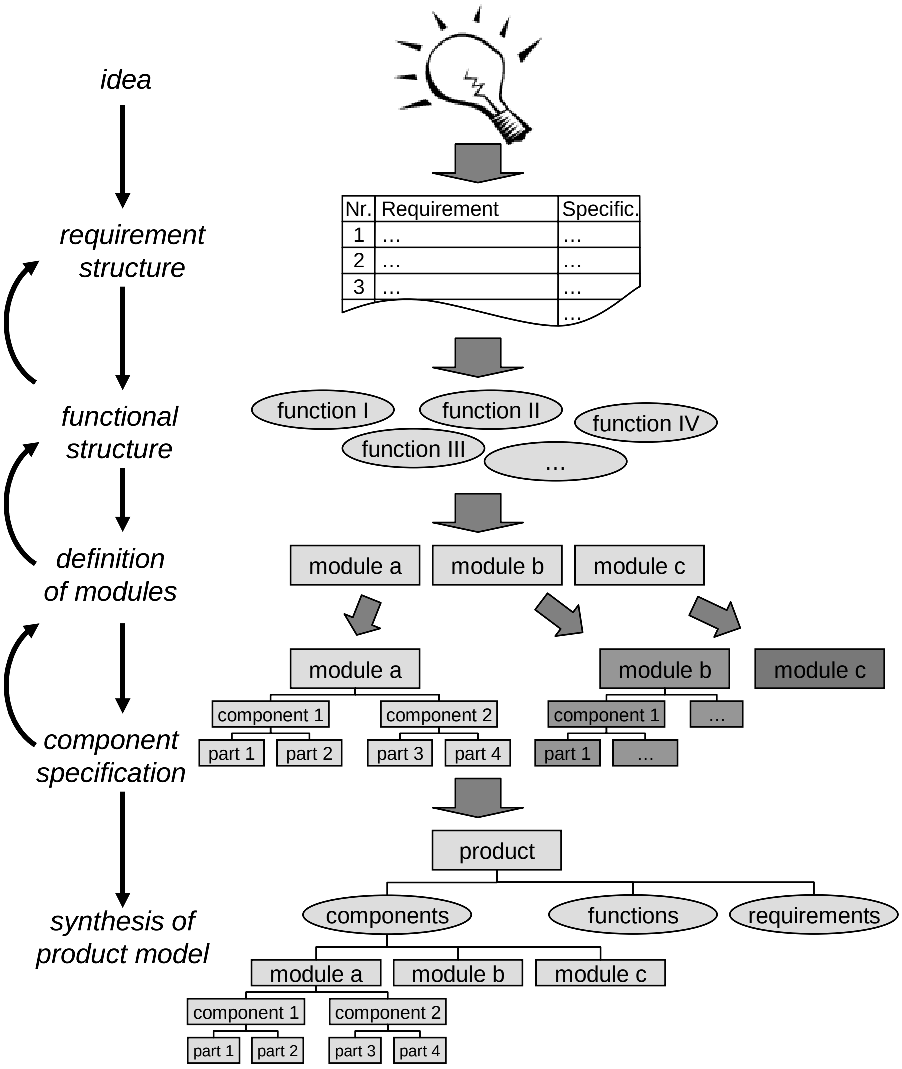

Figure 1: A conventional proceeding for product structuring

3. Integration of variability in conventional product models

A product structure, which results from a conventional process for designing mass-produced products, doesnot possess possibilities of variability. If adaptations have to be made, the complete product spectrum has to be reviewed in consideration of compatibility with the new and/or changed product elements. Especially aspects of the entire product, which cannot be directly associated to individual components, but result from the product as a whole, must be examined for possible changes. A typical example is the product quality, which has to be guaranteed even when extensive product adaptations will be done. Thus, in conventional product design most steps of the development process have to be newly gone through. In order to minimize the partly enormous developing costs due to a additional building of product variants, strategies of integrating product variability have been created [8]. These strategies realize a variant or modular design, which allows the customer to choose between options in the specification of products. However the variation in product specification is limited to a selection and Boolean combination of forecasted alternatives of product parts and component groups.

Figure 2 depicts the extension of a simple hierarchical product structure by logically cross connected component and part variants. By using this sort of interdependencies it is possible to describe the compatibility of variants. Such combinations of hierarchical structuring and logical interconnections are widely applied to actual product data management (PDM) systems [2]. These possibilities of product model description are very capacious, but the critical disadvantages are a difficult handling and a very complex representation.

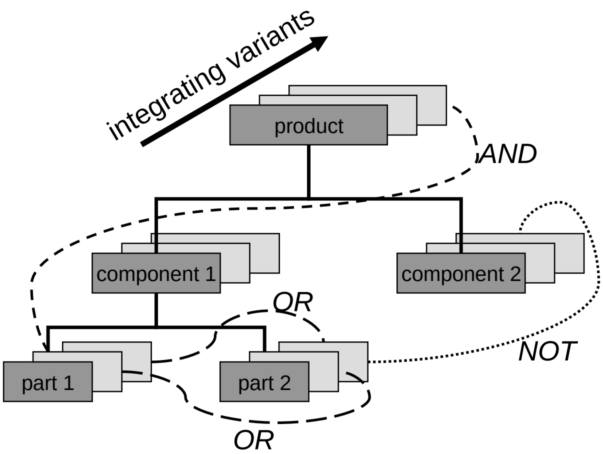

Figure 2: Integration of variants to a conventional product model

4. The use of customizable product spectra

Compared to variants emerging from already predefined specifications, the integration of degrees of freedom represents an improved flexibility to the product model. Degrees of freedom are defined as the options of choice of the customer, whereby the kind of description is not specified in detail. A special case of a degree of freedom is the option to choose between variant specifications (e. g. customer can select between three colours), which is identical to the variant product structure mentioned before. Other degrees of freedom can describe limited or even unlimited ranges of real numbers, which theoretically results in a possibly infinite number of product variants. Further on implicit restrictions represent an additional extension of degrees of freedom contrary to explicit product variant definitions. As an example we can take the degree of freedom “Power unit between 5kW and 10 kW”. On one hand this degree of freedom contains a both-side limited range of values of real numbers, on the other hand only the existence of a power unit is pretended. Thus, the decision between an electrical, a combustion, or any other kind of power unit is freely selectable. If degrees of freedom do not lead to a determined number of product specifications (variants), also the possibilities of variability can no longer be explicitly represented in the product model.

The comprehensive, abstract description of the product including its degrees of freedom is named product spectrum. Out of this realizable products can be derived by specification of the existing variability, where specific possibilities of choice may affect large areas of the product and even its structural order. For example both functional structure and component structure of a machine with electrical engine compared to another one with a combustion engine will fundamentally differentiate. Thus, the use of an identical product structure does not seem to be practicable. The designer of customizable products has to assign, how degrees of freedom as a representation of forecasted customer requirements can effectively be integrated into a non-rigid product model. Here the handling of the complex cross-linking of the product components is of crucial importance. Analysis must be feasible, permitting the determination of the influence of degrees of freedom and newly integrated components on other product components. If e. g. the basic functional model of a pressure washer is available, the expenses (and with it often the costs and the delivery time) for enabling the possibility to choose different values of water pressure can be derived from the value of connectivity of this degree of freedom in the existing structure. Furthermore complex interdependencies must be mediated at the interface to the product designer, so that an effective adaptation of structural components can be realized. For example a dependency between the functions “mobility” and “pressure generation” exists in the product “pressure washer”, even when it seems neither to be a direct one nor of a high intensity. But the designer needs the information that product adaptations concerning a higher water pressure will probably lower the mobility because of e. g. increasing pump and enginge dimensions (or weight).

5. Computer-supported development of product spectra

As mentioned before product spectra of customizable products possess a high degree of complexity concerning their mutual interdependencies. Thus, the product designer must be effectively supported in the composition and additional adaptation. When composing a product spectrum the designer frequently gets the impression that “everything is linked to everything” or that some components are related “a little bit”. The fact that interdependencies cannot easily be described by discrete values complicates the composition of a product spectrum model. A possible support for the product designer is the methodology of the “Design Structure Matrix” (DSM), which contributes in a matrix representation to set up interdependencies between product components [1]. Furthermore this methodology offers an implementation of fundamental algorithms, which allows the organization or the scanning of a product structure for certain criteria [4, 5]. Since the DSM methodology possesses only fundamental possibilities of navigation, its application seems to be confined to relatively small product spectra. Additionally the DSM is limited to the linking between elements of the same type of element, so that interdependecies between e. g. product requirements and product functions cannot be satisfactorily described. Better possibilities of navigation can be offered by graphs, which are frequently used in Data Mining techniques [3]. These graphs also permit the effective tracking of large dependency chains and facilitate the interactions with specific product spectrum ranges for the product designer [6, 7]. The here presented approach of a computer assisted tool for product spectrum composition as well as product spectrum handling connects consequently the possibilities of matrix and graph based interaction techniques. Both representational forms are parallel used and adaptations made in one representation are dynamically transmitted in the other one. Figure 3 shows the fundamental modules of the tool as well as the information stream taking place between them.

The central component of the tool is the "controlling"-module, which is not externally visible to the user and handles the tasks of controlling and coordinating the other modules. This "controlling" module communicates directly with the "runtime memory" module, administering temporarily resulting data, parameter and meta data. The "control panel", the "graph visualization", and the "matrix visualization" serve as modules of the customer interaction. Using the "control panel" the user can select fundamental functionalities, e. g. calling standard filters or arranging individual filters additively from basic algorithms. All possibilities of structure visualization are started and controled by use of the "control panel". The "matrix visualization" represents an extension of the possibilities of the DSM methodology. It concerns a highly flexible matrix form presented in a discrete window, where existing interdependencies between elements can be depicted by means of symbolism, numbers, and letters.

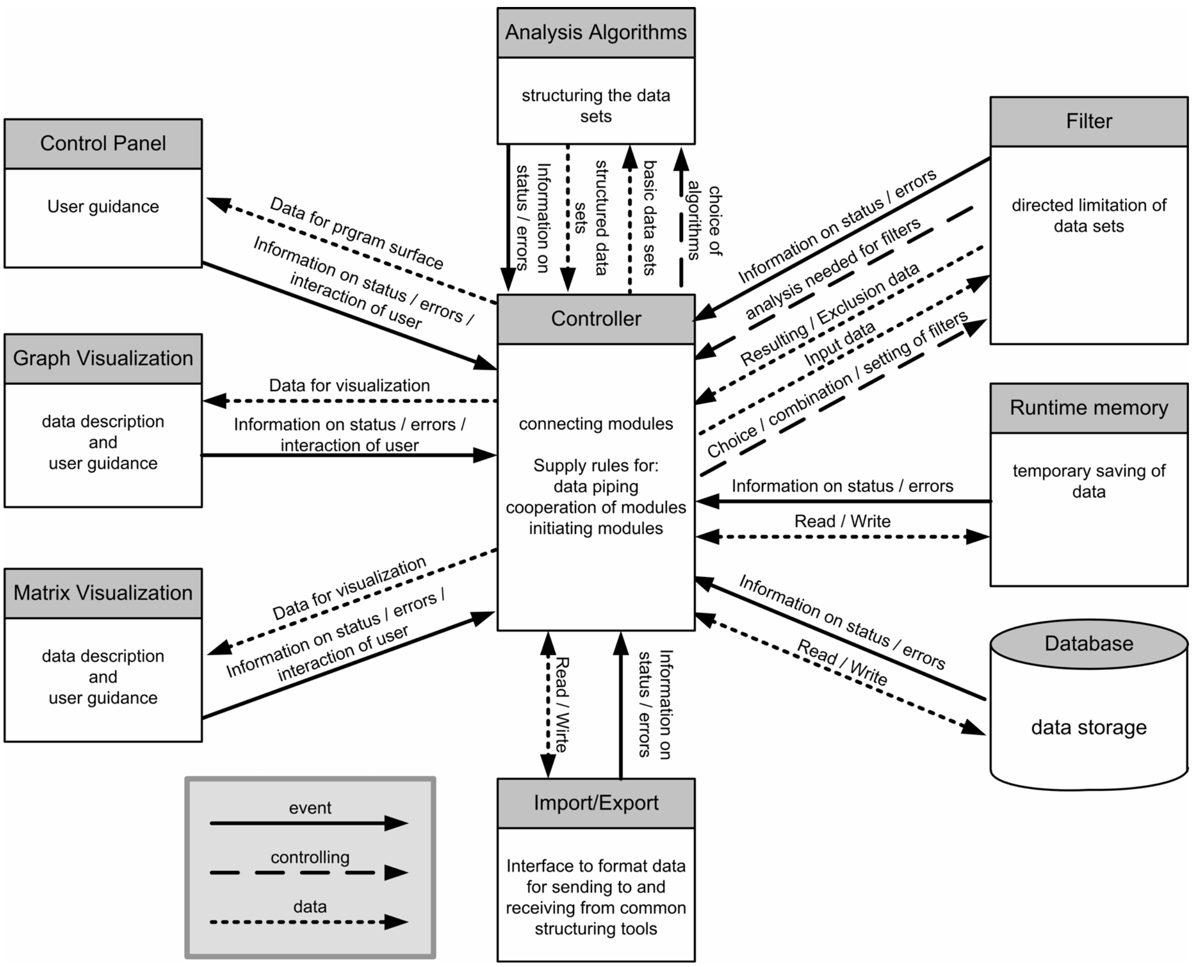

Figure 3: Modules and configuration of a tool for the handling of product spectra

The linked elements are fixed in the line and column heads and specified in the "control panel" module. A related "graph visualization" window can be displayed simultaneously to every "matrix visualization" window. This dynamic representation of certain interdependencies of the product spectrum can be used as an addition of the description given by the matrix form. Furthermore the user can directly execute adaptations of the structure in the "graph visualization" module. Additional "graph visualization" windows can be used for an effective navigation in the product structure. Thus, the user passes (in the graph structure) through the product spectrum up to a desired product range and is able to display this chosen area now for viewing in a more detailed matrix form. A further important component of the tool is the standardized "import/export", which enables the user to communicate with related structuring tools in common description languages [11]. The "database" module provides the fundamental structure for saving all relevant information. Based on mathematical models deposited in the "analysis algorithms" module, the "filter" module provides a functionality to easily reduce complex data sets to specific data set areas.

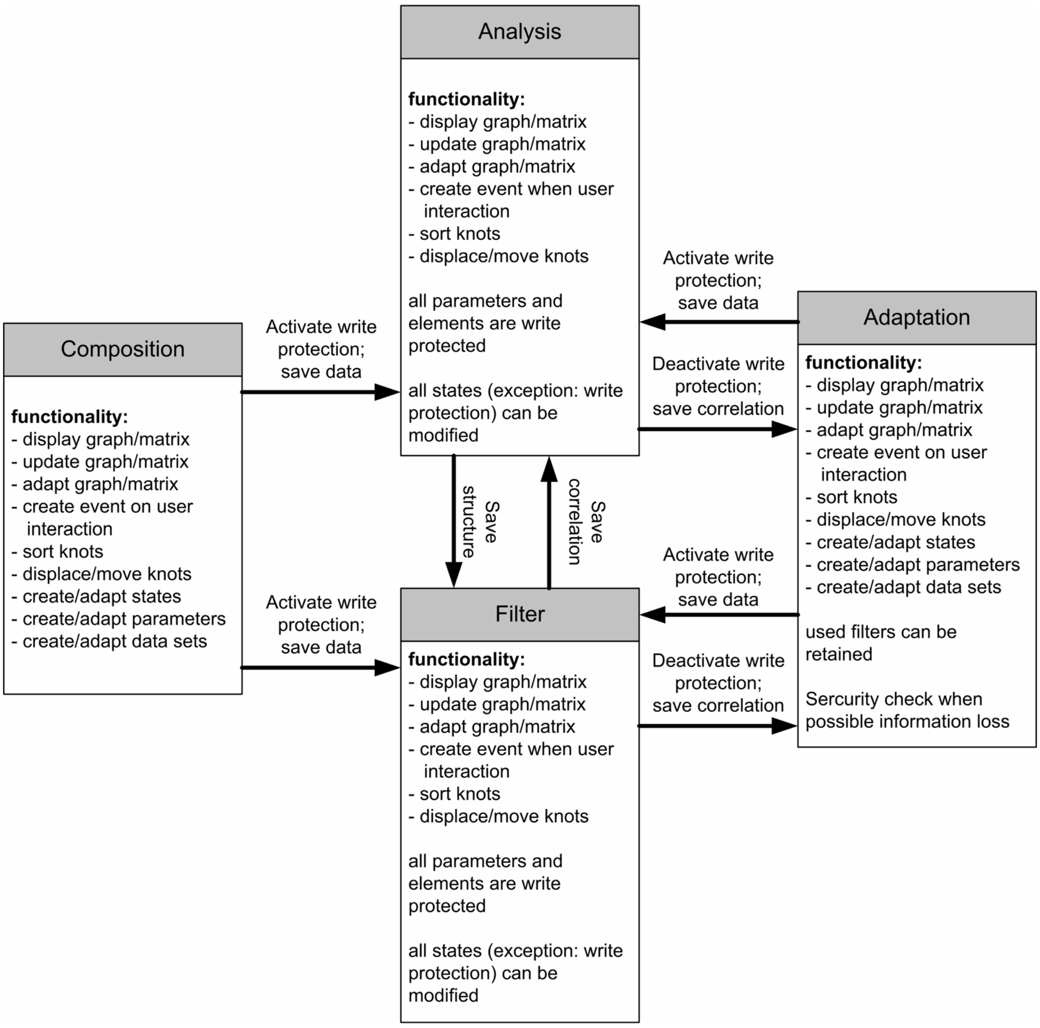

Figure 4: Four phases in the design of product spectra and associated functionality

When using the tool four phases are differentiated, whose interaction and functionality is described in Figure 4. During the phase of "composition" a product spectrum is progressively created by the user, whereas in the phase of "adaptation" the specific changing of parts of the spectrum is focused. In the phase of filtering data sets there are no permanent data modifications allowed, thus this phase is useful for handling complex product spectra by temporarily hiding unimportant information. The phase of adaptation provides the application of comprehensive mathematical algorithms to the product structure in order to detect specific (e. g. hierarchically structured) parts inbetween the whole spectrum. Thus, Figure 5 shows the proceeding and the actual available algorithms for analysing an arbitrary product spectrum. The proceeding consists of two main process steps, which can be iteratively executed, depending on the complexity of the structure in question. The first step implies algorithms for a general analysis of the structure, in the second step specific partial structures are derived from it.

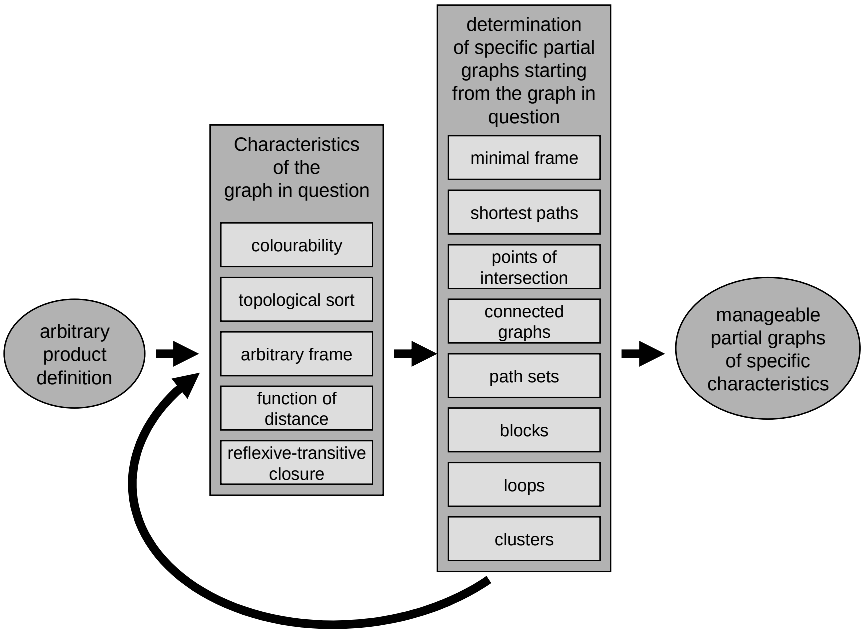

Figure 5: Proceeding of algorithmic product spectrum analysis

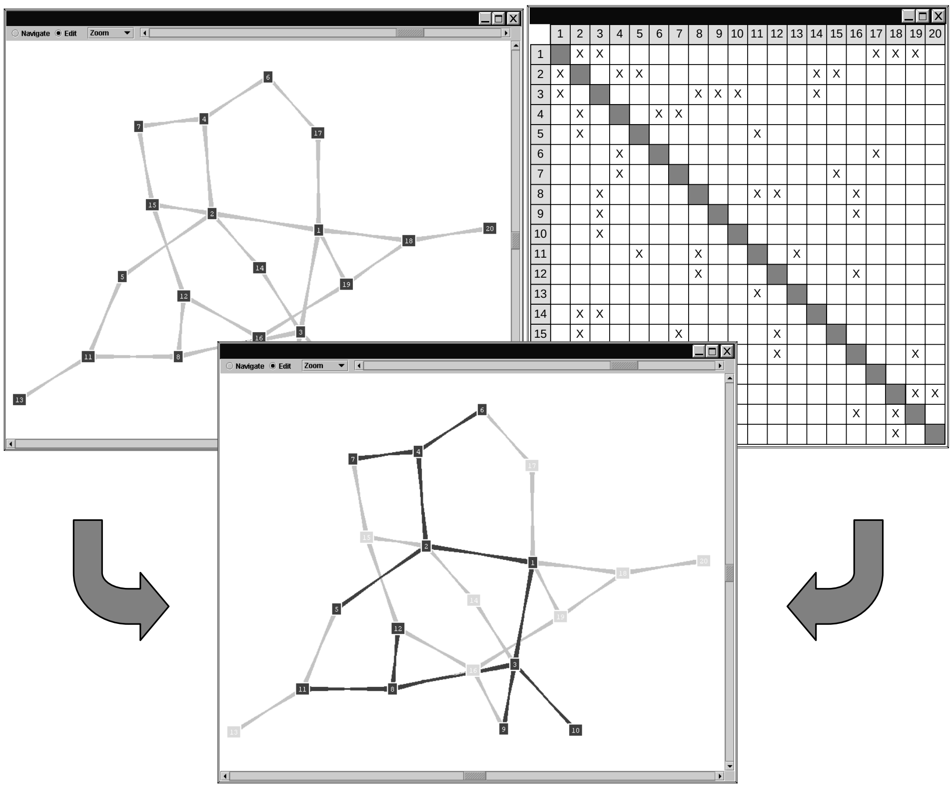

Figure 6: Parallel graph and matrix visualization and hierarchical search results

When regarding a functional product spectrum of a pressure washer, the first step of analysis can e. g. lead to the perception, that the spectrum (the totality of all product elements and their variability) is too complex to be treated as a whole. This fact can be deduced from a high value of the colorability of the corresponding graph, which represents a very high interconnectivity. A high value of the function of distance would point out the appearance of many indirect interdependencies. In the second step now specific parts or building sets could be selected for closer consideration by e. g. filtering a block from the comprehensive graph. So, if the entire graph depicts a product spectrum of a pressure washer, a component based block could be the building set of a pump or the engine. Figure 6 shows a screenshot of the graph and matrix visualization in the phase of analysis. Starting from a simultaneous graph and matrix description of a (in this example simple) structure the application of a hierarchical search algorithm (chosen in the control panel) identifies a hierarchical ordered substructure, displayed in a new graph window.

6. Conclusion and further work

In the here presented approach we pointed out the need for an effective support of the product designer in developing customizable products. The existing procedures for the methodical development of product structures provide fundamental possibilities for the configuration and the basic analysis of mutual interdependencies. Since customizable product spectrum models are very complex, available methods have to be extended to powerful navigation and analysis capabilities. Thus, in the here explained software implementation, perceptions of the graph theory are consequently combined with the application of matrix oriented methods.

The presented tool will continuously be extended in the future. We will improve the methodology of analysis concerning far reaching and complex product structures. Additionally the support for the interpretation of specific substructures will be integrated to help product designers in the adaptation process.

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