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FUNCTION-BASED SOLUTION RETRIEVAL AND SEMANTIC SEARCH IN MECHANICAL ENGINEERING

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ABSTRACT
Providing relevant information at the right time to the right person is a key-factor for successful products and for efficient processes in mechanical engineering. To support the information chain in the area of product development – and especially in retrieving existing solutions – different approaches exist (e.g. keyword search, classifications). Nevertheless, various barriers still hinder a fast and easy access to information about existing solutions.
The presented research approach improves knowledge reuse in the intra- or inter-enterprise information exchange by using semantic technologies. The access to relevant information about possible solutions is based on describing solutions by functions. These functions are abstracted and structured according to their goals. The function-based description is realized in an ontology model, based on classifications and standards used in German industries. Undertaking the first step, the ontology is built by extracting relevant concepts from different documents. The presented research approach will be used to structure solutions in a web-based electronic-market-platform and provides the access to various solutions from different sectors and enterprises.

Keywords: information retrieval, solution search, function models, ontology development

1 INTRODUCTION
Due to the rapidly increasing amount of information (e.g. in the internet), technologies and methods have to be developed to make this information retrievable. In the last years, semantic technologies are gaining importance. Several research projects focus on developing tools and knowledge models in the context of semantic technologies. Even in industrial practice, hidden data become more and more a problem (e.g. information appearing in e-mails, memos, notes support operations). This kind of data is stored in an unstructured way and therefore not – or only with enormous efforts – accessible. Hidden data can make up to 85% of data in an enterprise (according to an estimation by Merrill Lynch, [1]). Therefore, the optimization of information logistics in supply chains by semantically enriched content promises a possibility to overcome or to minimize this problem. With a new semantic infrastructure, enterprises can communicate more efficiently with others, and, more to the point, with their customers as well as consumers. In the process of product development a quick access to relevant and up to date solutions – for instance from similar applications – is a key factor for an efficient development process. Especially in the field of solution retrieval, a high potential becomes apparent. However, because of the lack of cost- and time-efficient technologies to retrieve existing solutions (either within one enterprise as well as on the market), “new” solutions have to be developed instead of reusing existing ones ([2]). This results in a waste of time and high expenditures, and mistakes tend to be repeated.
Therefore, research is needed to develop methods and technologies for solution retrieval in the field of mechanical engineering. In the Use-Case PROCESSUS, which is one part of the German research project THESEUS, this research is just in progress ([3], [4]). Within PROCESSUS, an ontology based solution search will be developed and evaluated that shall enable the quick and precise access to the required solution and application knowledge – so that the development processes are fundamentally accelerated and optimized.
PROCESSUS is specified and demonstrated in a state-of-the-art scenario, taken from the domain of automation technology (see Figure 1); this scenario is following the result in [2]: a product

development engineer (Mr. Design) from a company offering system solutions for the layout of plants is looking for solutions to a sub-system of a new packaging station. One important subsystem of the packaging station is the transfer of bottles. Since the solution has to be cost efficient but of high quality, the engineer wants to investigate alternative solutions from various manufacturers. He can use different information sources to find relevant alternatives (e.g. databases, product builder). If he wants to find solutions from various manufacturers he mainly has to use the well-known marketing channels (e.g. general distribution, expositions) or search on the internet or in some e-Marketplaces. At present however, information providers as well as clients face a huge complexity due to extremely heterogeneous contents and inadequate access mechanisms. The main barriers are different or varying taxonomies and classifications or different wordings (e.g. different viewpoints in sales, marketing, and engineering). Even the consideration of competing technologies for a given application is currently rarely supported in existing systems. So these barriers between an information seeker with a technical problem and companies offering possible solutions have to be overcome if the potentials of existing solutions are to be used more efficiently.

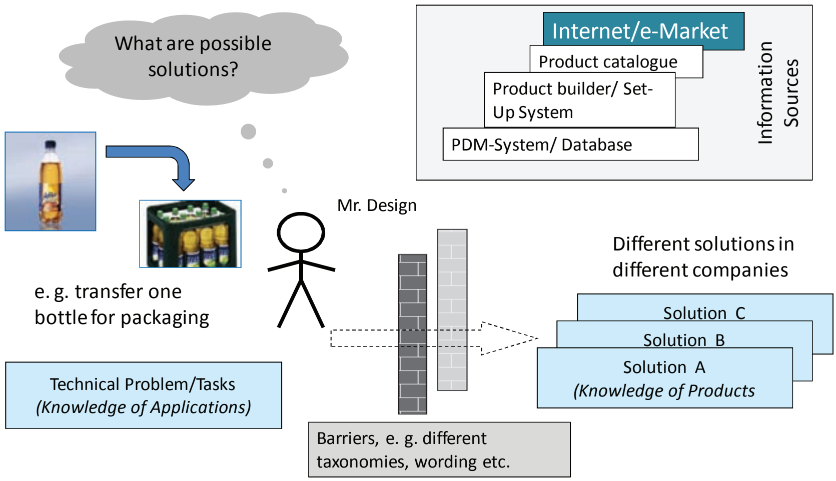

Figure 1. Solution search and information sources in Mechanical Engineering

2 SOLUTION RETRIEVAL IN MECHANICAL ENGINEERING

Products and solutions in mechanical engineering often are the result of more or less complex development processes and engineering tasks. Solutions – as understood in the presented context – are the result of a development process, which ends up in a user-specific solution for a problem. Therefore, a solution for one use case is not exactly a solution for the next use case – but it could have some relevance for the next customer project. The reuse of existing solutions promises a shorter process and an already approved solution.

2.1 Searching Solutions

General Aspects in Product Development

Many models exist to describe a product on different levels ([5-7]). The basis for generating a solution are always the requirements. Built upon the requirements, the product is formed on the functional level. Based on the functional level, the concept is defined in its principles. Subsequently, the principles are detailed and product is embodied. Therefore, solutions appear on different abstraction levels: functional level, conceptual level and the detail design or embodiment level.

Understanding Solutions in the Scenario

In the presented approach, finding solutions is focused on the design level. In this level, products are completely detailed and are in use in the same or similar applications. These solutions are the result of

the engineering process; they are built up from different parts and assemblies and combined to a system with the ability to fulfill the customers' requirement.
The following criteria define the necessary description of a solution in this context:

- A solution fulfills one or more specific functions in an application field and fits to one or more customers' requirements and needs. The description of a solution is complete when the solution and its corresponding application are described.
- To generate a solution, some designing work has to be done explicitly; it is a combination of different components and assemblies. A solution is not just extracted of a product catalogue; it has to be adapted to the specific usage.

In the scenario, possible solutions are different systems for transferring bottles (Fig. 2): such system can be a transfer system with pneumatic drive or a bottling system with electric motor drive. The solutions can also differ in their mechanical construction, e.g. a one-hand robot vs. a portal system. They have in common, that they can fulfill the function of transferring objects. Each solution is adapted for the special needs of the later plant user.

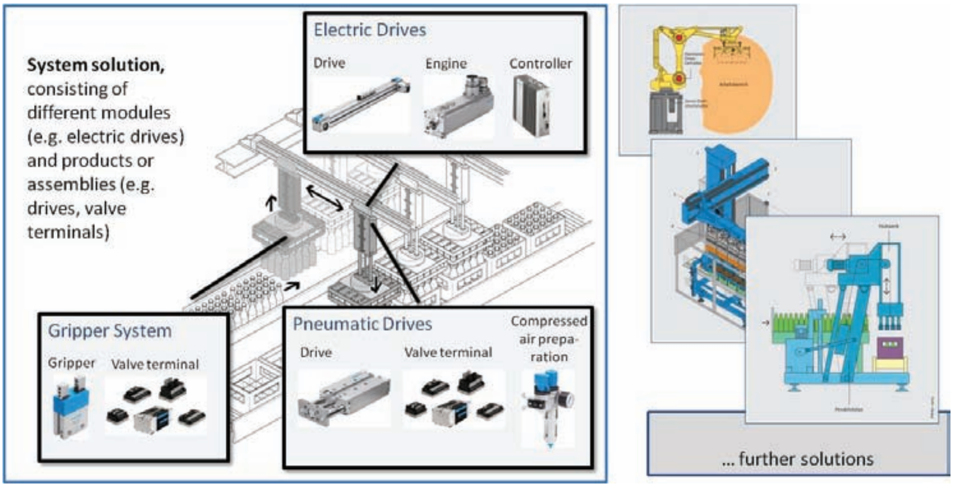

Figure 2. Possible solutions for transferring objects e.g. for packaging bottles

2.2 Methods and Technologies for Information Retrieval

In computer science different methods and technologies enable the information retrieval (IR) in databases or unstructured data storages. In the context of search mechanisms, keyword-based methods represent the backbone of many systems. The user describes his problem or search request with one or more words – possibly linked with different Boolean operators – and receives the information, which is connected with this keyword. These search mechanisms can be optimized by more or less intelligent indexes. These indexes can use statistics or other kinds of intelligence (manually designed index). The problem of these indexes is, that the context the keyword is used – either on the user-side or on the information side – is not captured; if the user types in "handle crate" the computer does not understand, whether he searches for handling "fruit crates", "dog crates" or even "a crate of beer". To overcome this lack, methods for understanding the meaning have to be used. Besides the keyword search, users have the possibility to navigate in different structures (e.g. classifications, taxonomies) to find the information required – if information is stored or presented in a structure the user can understand ([8]).
New web technologies (semantic web, ontologies) try to close the semantic gap between the user and the representation of information. In the semantic web, ontologies form the backbone and are a key part of semantic-based search mechanisms. Ontologies are a formal conceptualization of reality, which a machine (e.g. computer) can understand. In the field of mechanical engineering, different ontologies have readily been developed ([9], [10]). The intentions for these ontologies were information retrieval as well as structuring the existing knowledge in the product development process. However, they do not take into focus solution search and retrieval.

2.3 Information Sources for Retrieving General Solutions on different Levels

To give a brief overview of the present situation in the area of mechanical engineering, some existing sources to support a developer with the required information about solutions or parts of a solution are presented. In addition, some deficits of these sources are shown.

Many different approaches exist to supply required information to a developer (Fig. 3). For the search for basic principles, collections of physical effects exist ([11], [12]). In addition, databases with effects from various areas of natural science can be used (amongst others CREAX, GINA and GoldfireInnovator - formerly Techoptimizer from Invention Machine). Furthermore, a variety of product catalogues, construction catalogues and internet-based databases deliver requested information. The internet increasingly gains an important role in the delivery of this information. Several market platforms (e.g. VDMA-e-Market und Xpertgate) exist which offer the possibility to search for products of more than one company.

These existing sources have some deficits regarding the retrieval of existing solutions. Either they are very abstract (collections of physical effects), or quite a huge amount of knowledge is needed finding and using them (construction catalogues). If the user does not know the particular defined terminology for the source, it costs a lot of time to find the needed information. Furthermore the search for and the comparison of products from different companies is very time-consuming. In addition to that, the maintenance of market platforms is very challenging as the heterogeneous viewpoints and terminologies of the included companies have to be provided. All the presented approaches have the deficit of a real function-oriented search, which links functions to the complete system solution.

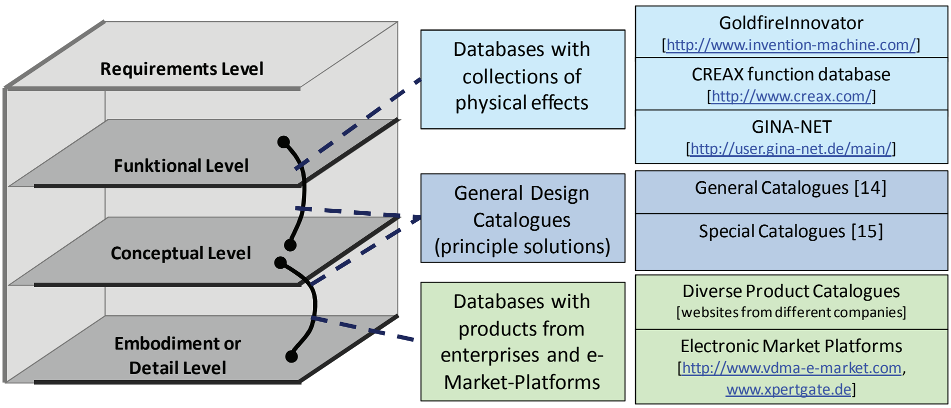

Figure 3. Information sources for solutions on different abstraction levels

3 SOLUTION APPROACH BASED ON FUNCTIONS AND FUNCTION GOALS

To overcome the semantic gap between the problem and the solution side both have to be abstracted to a level, that the designer searching for a solution can understand and in which the solution can be described. According to the general model of products, functions are the level of technical products that describe them in an abstract understandable way. Problems still exist in the different wordings, the different views and the different meanings of some functions. Therefore, comparing different functions and to decide their relevance to each other, requires mapping them to a similar level of abstraction.

3.1 Defining the Functions of Systems

Every technical system can be described by the functions it fulfills. According to [7] and [13], functions of systems are described with a verb and a noun. The verb describes the operation that the system applies on the object which is represented by the noun in the functional description.

In design methodology and in systems engineering, a function describes the system from an external point of view: what is the input and what is the output (also called black box principle). The functionality itself is not in focus, it does not matter, in which way the function is realized. Functions can be described on different decomposition levels of systems ([14, 15], Fig. 4):

- Functions on the first level (basic functions, overall function; in the scenario the "first level" e.g. to package the bottle).
- Functions on more detailed levels (subfunctions; in the scenario the "second level" e.g. to grip the bottle, to move the bottle as subfunctions of "to package the bottle").

In the presented approach, the function of a system on the first level is in focus to describe the necessary understanding of a system as a solution for a certain customer application.

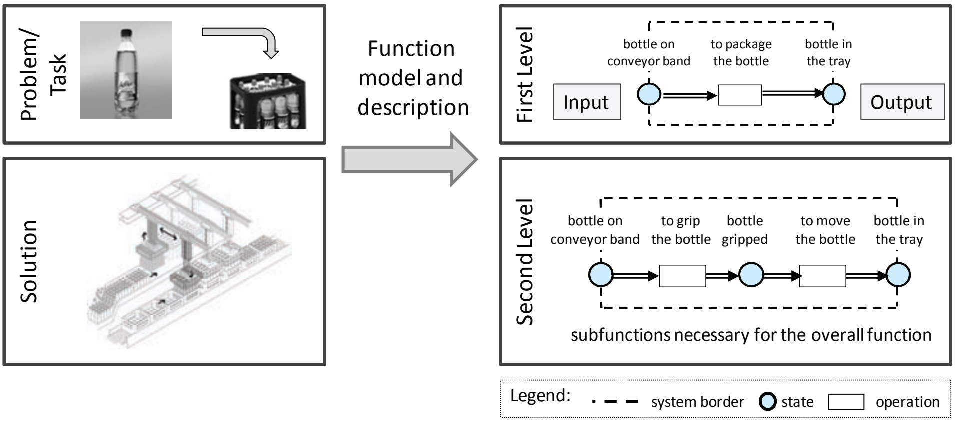

Figure 4. Definition of a system function on different abstraction levels

3.2 Structuring Functions by a Functional Basis

Different approaches to structure functions can be found in literature ([16], [17], [18]). There are already functional bases, which structure functions or separate objects and operations. Objects are classified with their physical properties (e.g. material, signal, energy [19]); operations can be classified depending on their action (e.g. branch, channel, connect, control magnitude, convert, provision, signal, support [19]). The problem with these structurings is that they are very general and that they have a clear vision of the technical aspects the system works on. To describe functions from an application side, the intended goal or intention why the user uses this system has to be described. For that reason the goal of the function or at least the goal of the operation, effecting the object, has to be extracted.

Abstracting Operations by defining their Goals

According to [20] technical verbs can be sorted and structured in relation to their goal; every verb – and therefore every operation in a function – has the goal to do something with one or more attributes of an object. Four logical actions exist: to generate, to eliminate, to conserve or to change an attribute (see Fig. 5). These actions can be applied to all attributes of objects and then describe the goal of a technical system or solution from the users side. The mapping of functions to their goals enables possibilities to cluster them in different groups, as needed for a search for special interest.

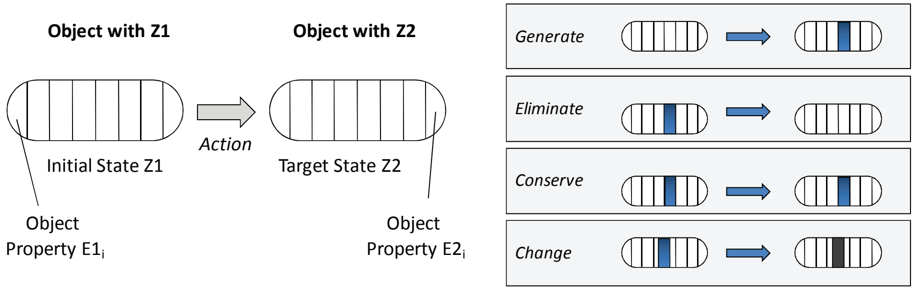

Figure 5. Goals of functions as transforming an object from initial state to target state

Defining the Attributes and Properties of the handled Objects

Besides the operations described and abstracted as described above, objects have to be represented by a model. According to [21], objects or systems have different attributes:

- **Conditional Attributes** – These attributes describe the origin attributes of an object (how is the object conditioned?). Examples are shape, material and surface.
- **Functional Attributes** – What effect or impact has the system? These attributes describe the ability of a system to transfer an input to an output.
- **Relational Attributes** – These attributes describe the behavior of the system in relationship to the system environment (e.g. the costs …). The relational attributes are based on the functional and the conditional attributes.

These attributes can also be divided into direct and indirect attributes from the viewpoint of influencing the attributes of a system in the design process. The designer defines the direct attributes (e.g., he defines geometries, materials). The result of these definitions is found in the functional and relational attributes (e.g. the attribute "corrosion resistance" cannot be designed directly; the designer has chosen a certain material in order to influence the corrosion resistance). [5] orders the attributes of objects in elementary design properties and intrinsic and extrinsic attributes, also according to their possibilities to be influenced. Regarding the functional view, objects are passive – they are handled by an operation. Therefore, the functional attributes or the relational attributes are from minor interest when describing functions of a system.

The "Operation-Goal-Matrix" used as a adequate Abstraction Level

To combine the object and the operation description, each technical verb can be mapped into a so-called "Operation-Goal-Matrix" (OGM). In this matrix, every verb is assigned to one or several abstract operations on the attributes of an object. The attributes are structured into geometric (e.g. length, area, volume), kinematic (e.g. position, orientation), material-energetic (e.g. color, temperature) and structural (number, composition) attributes (according to [21]). Besides these typical object attributes information as a general class can be acted on. The matrix consists of the attributes in the columns and the different operations in the rows (Fig. 6). The connections between the operations and attributes are the four abstract operations mentioned above, augmented by two actions resulting of a possible uncertainty when filling the matrix. As there is always an uncertainty due to the high abstraction level, the OGM offers not an exact mapping, but should rather represent a further possible option to overcome the barrier of different wording.
In this way, for example, the two operations "package" and "settle" can be linked as both "generates coherance". Thus, a solution for "settle a bottle" can be found even if a solution for "package a bottle" is searched.

Attributes

Operations

	Geometric			Kinematic				Material-Energetic						Structural			
Operation	Length	Area	Volume	Position	Orientation	Direction of motion	Speed	Color	Temperature	Concentration	Aggregate State	Penetrability	Material	Coherence	Number	Composition	Information
Detect																	+
Extract																	
Fix					o	-	-										
Fold	a	a	a														
Go				x	?	?											
Handle				a	x	a									?	?	
Grip				o	o									+			
Move				a	a	a	a										
Package				x	?	?	?							+			
Power				x	x	x	x +										
Push	x	x	x	x								x		x +			
Recognize																	+
Settle				x										+			
Transfer				a	x	a	a										
Unpack														-			

Actions	
+	Generate
-	Eliminate
o	Conserve
x	Change
?	Feasible
a	All actions possible

Figure 6.Section of the Operation-Goal-Matrix (with operations from the packaging area)

4 ENGINEERING AN ONTOLOGY FOR SOLUTION RETRIEVAL

Based on the solution approach focusing functions and abstraction as the connecting level between the problem or application side and the solution, a knowledge model has to be developed which can be used in state-of-the-art search engines. Ontologies perform an adequate tool to model the problem and to use it in semantic technologies ([22]). The developed ontology has to support the user (e.g. the developer within a beverage packaging systems manufacturer) in finding solutions and products for different subsystems of the system he wants to develop. The search is not limited to known and applied solutions within the own company (intranet), but also contains the capability to research for possibly fitting products from other areas of interest, which can be found in the internet. Thus, the description of components and products is extended with the knowledge of the related application. As there are many different heterogeneous viewpoints in the various areas of mechanical engineering, their respective specialized terminology has to be linked systematically and consistently. To achieve this, further classifications and taxonomies are integrated in the ontology.
The ontology is developed in the context of the use-case described above. Based on several product descriptions in the area of packaging technology, the ontology is built step by step and increased continuously. In future steps, the ontology can be enhanced by integrating products of other areas of machine or plant engineering. The ontology can be divided into two parts: the first part yields from the description of the functions of the system. It creates the base structure of the ontology. The second part results from the approach of describing different viewpoints of the solutions. Within a further classification and taxonomy, it is possible to embed different views of different industrial sectors.

4.1 Methodology and Ontology Development Process

The different steps to build the ontology are shown in Fig. 7. They correlate with the typical steps for building ontologies ([10]). After analyzing the existing taxonomies and classifications and integrating them into the ontology, the focus was put on the instances and especially on the functions. They were extracted by literature review and document analysis.

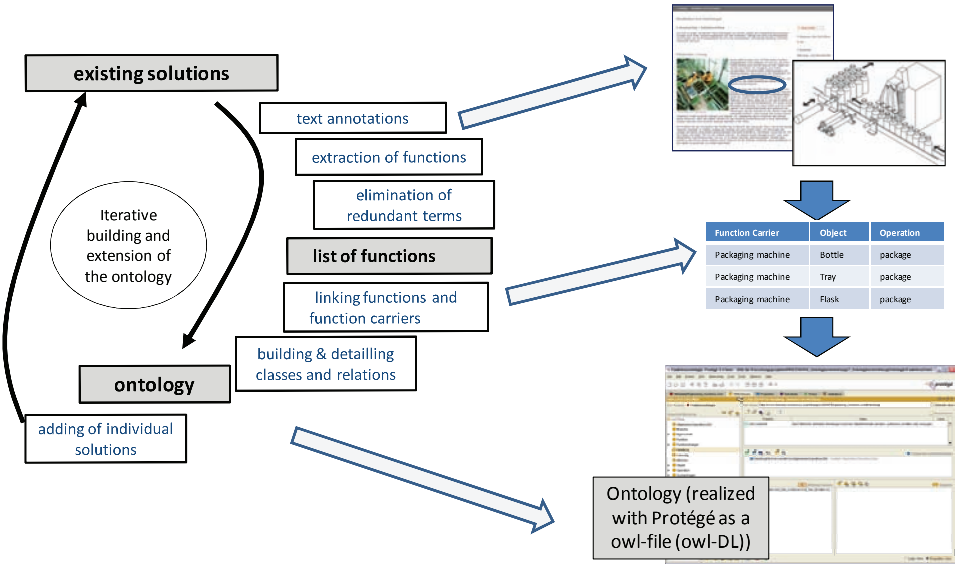

Figure 7. Steps and results building the function-based ontology

Based on existing product descriptions (in this case: packing machines), functions are extracted by annotating text. Redundant terms of semantically equal meaning (e.g. bottle, flask, PET-bottle) are then eliminated. The outcome is a function list in which the functions are linked to the related systems (function owners), objects and operations. The links between the function owners and functions form the basis for the ontology. The structure of the classes and relations results from the requirement that the functional modeling of the product can be described completely. In the next step, this ontology is filled iteratively with information about other solutions from the packaging technology and is complemented with additional classes and relations when required. So far the demonstrated steps are performed manually so far. In a next step, existing solutions will be scanned automatically for relevant functions and objects and embedded in the existing ontology.

4.2 Structure and Organizing Principles in the Ontology

Structure and Instances

The structure of the ontology is strictly focused on retrieving relevant solutions for a specific problem. Therefore, existing classifications and taxonomies have to be integrated in the ontology. Fig. 8 shows the structure of the ontology at the root level with the information sources the concepts stem from. The base structure includes the classes and relations of the highest hierarchical level. The functions of a product, the relevant industrial sector, in which the products are used, properties and operations are described. The function has the central position. It is used in a special industrial sector, executed by a function owner and performs a certain operation on a decent object. The operation has the operation goal, which is defined in the OGM. In addition, objects can have defined properties.
Within the several classes of this base structure, further classification contains subclasses, which assure detailed distinctions of all contained data. The instances (function individuals, object individuals) are filtered out of the text annotations and related with the appropriate subclass. The information sources are in textual form (e.g. the norms and textbooks, [23-25]). To transfer this information in a computer-understandable format (here the ontology) is a task, which request knowledge of the application domain as well as the well-known standards.

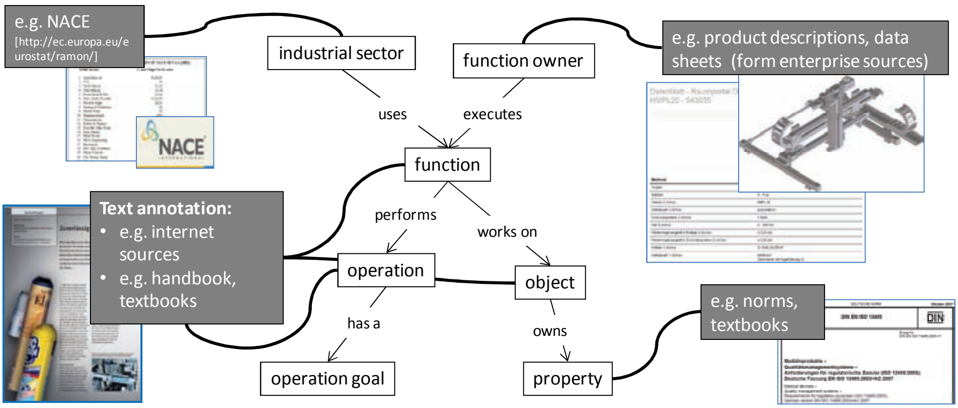

Figure 8. Structure and relationship in the ontology with the according sources

As the result, the ontology – at the present state – consists of about 80 concepts with ca. 30 different relationships between them. The relations are implemented as properties in the ontology. For example, the property “function performs operation” connects the two concepts “function” and “operation” (see Fig. 8). About 250 instanced were extracted out of 20 descriptions of solutions in the field of packaging industry. Depending on the focus packaging industry, no complete classifications, thesauri or classifications are integrated yet. The ontology just contains the relevant concepts and instances and can be enlarged by including complete classifications in a further step.
It is important to mention that the analyzed document (e.g. norms) do not include all information necessary for detailing and describing the individual concepts and instances sufficiently. Therefore, the knowledge model implies more than just the information – it´s a high-sophisticated step to collect different information and to transfer them to the ontology.

Organizing Principles for different Viewpoints

By defining the properties of the concepts, the individual concepts are linked by the concepts relationships. This forms the basis for reasoning tools, which can use the modeled knowledge and interfere new relationships. These reasoning tools allocate the single terms (represented as individual

instances in the ontology) into different structures depending on the viewpoint. Therefore, baesd on the representation of the semantic connections in the ontology structure, different views on the deposited terms and concepts can be used. These views can be seen as organizing principles and are integrated into the ontology.
Using the example of the functions, the concept of the organizing principles will be described. Taking different views on an existing solution out of different perspectives, several functions exist to describe one possible solution. For example, different companies describe - according to the particular industrial sector (assembly technique, packaging technique) - their solutions and products in a different way:

- Company A, a manufacturer of robots for different assembly tasks, describes its solution for the packaging of bottles into boxes with the function "handle bottles".
- Company B, a manufacturer of pneumatic components and related system solutions describes its solution as transfer system for bottles with the function "transfer or transport flasks".

Both views are considered in the ontology in the form of organizing principles. Hence, functions which describe similar or equal tasks or jobs can be integrated in separate taxonomies – according to their industrial sector.
However, both classes possess properties and specifications of significant attributes which enable building a relationship between them: Both of the functions can – on a more abstract level – change the position of an object. With this commonality it is possible to automatically sort them by reasoning of the ontology and combine them in the more general class "change position" (Fig. 9).

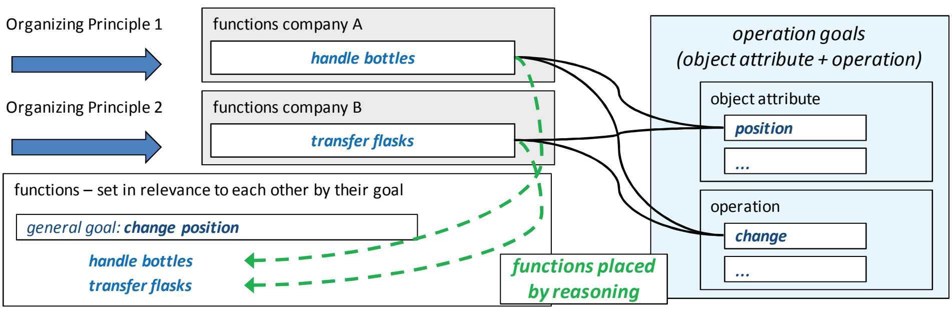

Figure 9. Organizing principles and reasoning different viewpoints

5 EVALUATING THE SOLUTION APPROACH IN THE SCENARIO

To evaluate the solution approach, it is applied to the user-scenario on a virtual eMarket-platform. Supported by the function-based knowledge model, a prototype is developed and implemented to support designers searching for possible solutions for packaging bottles in crates. This prototype bases on a semantic search engine looking for specified web sites of different companies. The information relevant to the use is identified by links and relationships in the ontology.
In the above-described scenario, a designer can find existing alternative solutions while searching for a system to "transfer a bottle" (representing function and application with an operation and object). To find relevant information for possible solutions he uses the virtual platform, which is supported by the German Engineering Federation (VDMA) and offers at the actual state different products from different sectors. With the Operation-Goal-Matrix (OGM) an efficient linking between the problem´s side and solutions is achieved.
In the scenario, the designer is supported to describe his problem ("I want to package a bottle") in an abstract and more general view, e.g. "change position". The relationships between the concrete problem descriptions and the general concepts are implemented in the domain specific ontology for the packaging industry. After describing his problem, the engineer is led to a number of promising solution principles (e.g. mechanical, hydraulic, and pneumatic). The solution itself is linked into the ontology in the same way the designer described his problem. Whereas the product is described with "package bottles", the ontology supports abstracting the operation of the product and describing it in a more general way with "change position" (Fig. 10). By setting further requirements (e.g. batch quantity, merchandise, packaging material), the solution space can be narrowed down and different

solutions and products as well as a number of companies offering these products are returned as the result.
The quality of presented solutions depends on the quality of the ontology. The user´s world has to be modeled as well as the possible concepts of the presented solutions. Here, automatic mechanisms (e.g. ranking algorithms) support the ranking of the relevant items and terms and enable the extraction of the important ones. Besides representing the relevant concepts in the ontology the quality of the relationships is of high influence on the quality of the search results. The evaluation and evolution of the ontology is a very crucial aspect directly influencing the acceptance of a semantic based search engine.

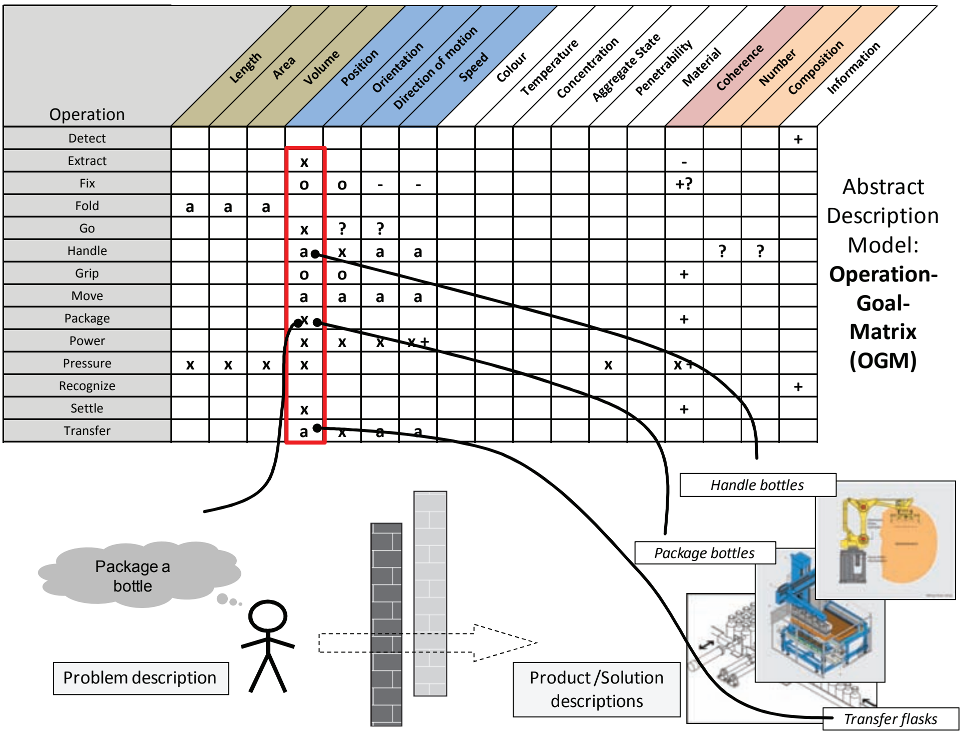

Figure 10. Overcoming the semantic gap by the Operation-Goal-Matrix (OGM)

6 CONCLUSION AND OUTLOOK

Conclusion and Summary

The presented approach bases on a function-oriented description of solutions and search request. At presence, different barriers hinder employees in mechanical engineering companies– either in development or in sales and marketing processes – to reuse existing solutions or to find relevant information. The core of this approach is the connection between operations in functions and their corresponding goals (Operation-Goal-Matrix). This allows an abstraction level independent of concrete solutions, offering the right information about relevant solutions "solution seekers" rapidly and cost-effective.
The research approach is applied to solutions in packaging industry. The Operation-Goal-Matrix is realized as an ontology and complemented with further essential concepts for solution retrieval (industrial sector, function carrier). These concepts were extracted from different sources and integrated manually in the ontology.

The developed ontology will be integrated in a search engine in the near future and enable information seekers to get the requested information about relevant solutions. The ontology will work in analogy to an optimized index, supporting a broader solution space.

Outlook

As the overall research project is still in progress, some open items and questions have to be addressed. The most important one is to evaluate the quality of the improved semantic search in detail (precise and recall).

Further questions concern the evolution of the existing core ontology. The intention of the e-marketplace is to include solutions from various companies. Therefore, it is intended to include further partners in order to expand and detail the ontology. Due to the high effort necessary to develop the ontology manually, a semi-automatic support is planned (e.g. statistic methods to decide the most important terms and wordings).

REFERENCES

[1] Blumberg, R. and Atre, S. The Problem with Unstructured Data. DM Review (Data Management Review and SourceMedia, Inc, 2003).

[2] Gaag, A. and Ponn, J. „Suchen und Finden“ im Maschinen- und Anlagenbau - Eine Studie in Zusammenarbeit mit dem VDMA. CiDaD Working Paper Series, 2008(4).

[3] Franz, J., Gaag, A. and Abuosba, M. The Semantic Enterprise - bringing Meaning to Business Processes. In Thoben, K.-D., Pawar, K.S. and Gonçalves, R., eds. Proccedings of the 14th International Conference on Concurrent Enterprising (ICE2008) (Centre for Concurrent Enterprising, Univ. of Nottingham, Lissabon / Portugal, 2008).

[4] Gaag, A., Kohn, A. and Franz, J. Semantic Enterprise - Unlock Solution Know-How in the Domain of Mechanical Engineering. In STI2, S.T.I.I.-. ed. 2nd European Semantic Technology Conference (ESTC 2008)Vienna, Austria, 2008).

[5] Hubka, V. and Eder, W.E. Theory of technical systems – a total concept theory for engineering design. (Springer, Berlin 1988).

[6] Hubka, V. and Eder, W.E. Engineering Design - General Procedural Model of Engineering Design. (Heurista, Zürich, 1992).

[7] Ponn, J. and Lindemann, U. Konzeptentwicklung und Gestaltung technischer Produkte. (Springer, Berlin 2008).

[8] Pearlson, K. and Saunders, C. Managing and Using Information Systems: A Strategic Approach. (John Wiley & Sons, 2004).

[9] Ponn, J. and Lindemann, U. Intelligent Search for Product Development Information - an Ontology-based Approach. In Marjanovic, D., ed. Proceedings of the DESIGN 2006, 9th International Design Conference pp. 1203-1210 (Faculty of Mechanical Engineering and Naval Architecture, Univ. of Zagreb, Dubrovnik, Kroatien, 2006).

[10] Ahmed, S., S., K. and K., W. A methodology for creating ontologies for engineering data. ASME 2005 International Design Engineering Technical Conferences & Computers and Information in Engineering ConferenceLong Beach / USA, 2005).

[11] Koller, K. and Kastrup, N. Prinziplösungen zur Konstruktion technischer Produkte. (Springer, Berlin 1994).

[12] Roth, K. Konstruieren mit Konstruktionskatalogen, Band 2: Konstruktionskataloge. (Springer, Berlin 1994).

[13] Pahl, G., Beitz, W., Grote, K.-H. and Feldhusen, J. Konstruktionslehre. (Springer, Berlin, 2006).

[14] Hubka, V. and Eder, W.E. Functions revisited. In Culley, S., Duffy, A., McMahon, C. and Wallace, K., eds. Design Research - Theories, Methodologies, and Product Modelling: 13th International Conference on Engineering Design ICED 01, pp. 69-76 (Professional Engineering Publ., Glasgow / UK, 2001).

[15] Ulrich, K.T. and Eppinger, S.D. Product Design and Development. (Mcgraw-Hill, New York, 2004).

[16] Kitamura, Y. and Mizoguchi, R. Ontology-based systematization of functional knowledge. Journal of Engineering Design, 2004, 15(4), 327-351.

[17] Kitamura, Y., Washio, N., Koji, Y., Sasajima, M., Takafuji, S. and Mizoguchi, R. An Ontology-Based Annotation Framework for Representing the Functionality of Engineering Devices. Proceedings of the ASME 2006 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2006 (American Society of Mechanical Engineers, Pennsylvania / USA, 2006).
[18] Ookubo, M., Koji, Y., Sasajima, M., Kitamura, Y. and Mizoguchi, R. Towards Interoperability between Functional Taxonomies using an Ontology-based Mapping. In Bocquet, J.-C., ed. Proceedings of the 16th International Conference on Engineering Design ICED'07, pp. 419-420 (Design Society, Paris / Frankreich, 2007).
[19] Hirtz, J., Stone, R.B., McAdams, D.A., Szykman, S. and Wood, K.L. A functional basis for engineering design: Reconciling and evolving previous efforts. Research in Engineering Design, 2002, 13(2), 65-82.
[20] Birkhofer, H. Analyse und Synthese der Funktionen technischer Produkte. Diss. Technische Universität Carolo-Wilhelmina, Braunschweig (1980). (VDI-Verlag, Düsseldorf, 1980).
[21] Ropohl, G. Systemtechnik - Grundlagen und Anwendung. (Hanser, München, 1975).
[22] Cardoso, J. and Sheth, A. Semantic Web Services, Processes and Applications. (Springer, New York, 2006).
[23] DIN. Deutsche Norm DIN 55405: Begriffe für Verpackungswesen, Teil 1 bis 7. 1987).
[24] Drechsel, D. and Vetter, F. Wäge-, Abfüll- und Verpackungsprozesse. (Oldenbourg Industrieverlag, München, 2001).
[25] Haas, K. and Elze, J. Thesaurus Verpackung. (Fraunhofer-Institut für Lebensmitteltechnologie und Verpackung, München, 1992).

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