Knowledge graph based System model configuration design

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Abstract. When solving the complexity problem between different fields, traditional document-based system engineering (TSE) is difficult to meet current research and development needs, and model-based system engineering (MBSE) is the best choice. With the implementation and application of MBSE in enterprises, the system model files are gradually accumulated. Therefore, this paper studies the reusability of the system model and builds the system model knowledge graph to achieve efficient reuse of the existing system model. A product configuration method based on subgraph matching is proposed and by configuring the product, the designer can obtain more feasible solutions, and then get the best design solution. Finally, an example of remote sensing satellite design is given to verify the effectiveness of the method.

1. Introduction

With the complexity, integration and multi-domain coupling degree of the system increasing, Complex Product System (CoPS) has evolved from System to System of Systems [1]. Due to the numerous texts are difficult to understand and inconvenient to exchange information, when modeling for CoPS development, the traditional Text-Based Systems Engineering has been difficult to meet the needs of systems engineering modeling. To solve this problem, the Model-based System Engineering (MBSE) method came into being [2]. Through its modeling language SysML, this method uses models, instead of documents, to model, which aimed at promoting standardization and formalization of CoPS development process modeling [3,4]. It supports requirements verification, design planning, analysis and validation, which during the CoPS development process, covers the whole life cycle of system development, and has the advantages of no ambiguity and visualization. However, because MBSE is still in the development stage, its modeling method and the modeling language SysML are not perfect. With the continuous accumulation of the number of system models, the reusable knowledge carried by them is also gradually increasing, and the designer's requirements for the modeling software platform are also increasing. The platform needs to support users to search, select and reuse models efficiently, so as to improve the efficiency and quality of system modeling.

In order to improve the reuse quality and efficiency of product design, Freeman et al. [5] put forward the product configuration theory. And Mittal et al. [6] gave the definition of product configuration design for the first time: one or more configurations that meet all requirements are obtained by predefined component attributes, ports and other structural constraints, configuration description and optimization rules. However, there are some defects in the existing product
configuration design methods, such as non-uniform and non-standard product configuration model, and the mismatch between configuration model and design information [7, 8]. Using system model to complete product configuration design can well solve the above problems and provide good theoretical support for system model reuse. Therefore a method of knowledge graph based System model configuration design is proposed. The designer can obtain more feasible solutions, and then get the best design solution. Finally, an example of remote sensing satellite design is given to verify the effectiveness of the method.

2. Methods

2.1 System model graph construction

In order to design reuse of the system model, first of all, we need to express the SysML model in a form that is easy for computer to understand and apply. Knowledge graph is a good choice [9, 10]. By establishing SysML meta model ontology based on MOF model, we can get the mapping rules for the transformation from SysML model to knowledge graph, that is, determine the data source and data pattern of SysML model sub graph. Each system model file contains many types of model elements. In order to achieve the purpose of SysML model reuse, each type of model needs to obtain different model information. As shown in Figure 1, SysML is a graphical modeling language. Its basic nodes are composed of a model, model attribute, model relationship, model location and other information. In order to make the knowledge graph suitable for model reuse and enrich model's relationships, the attributes in the system model are represented by entities to ensure that other types of models in the knowledge graph are standardized and unique.

![Figure 1. Correspondence between SysML meta model and knowledge graph elements](image)

In order to enhance the knowledge discovery ability of the system model graph and break the "information island" between entities transformed from different SysML model files, it is necessary to merge the obtained knowledge graphs, that is, graph fusion. Graph fusion is to merge the entity nodes
and entity relationships representing the same entity in different system model sub-graphs to form a unified integrated system model graph.

2.2 System model configuration design based on subgraph matching

In essence, system model matching is to match subgraphs in the knowledge graph, that is, graph isomorphism solution. Graph isomorphism problems can be classified into exact matching and approximate matching according to the accuracy of matching results. According to the applicable type of this study, the problem to be solved is exact matching. It is necessary to search the subgraph that completely matches the node and edge attributes of pattern graph $G_2$ in data graph $G_1$, as shown in Figure 2, and its mathematical definition is as follows:

![Figure 2. Schematic diagram of subgraph matching](image)

Known as data graph $G_1 = (V_1, E_1)$ and mode graph $G_2 = (V_2, E_2)$, we can establish a mapping function $f$ between mode graph $G_{sub} = (V_{sub}, E_{sub})$ and data graph $G_{sub} = (V_{sub}, E_{sub})$:

$$\text{for any } v_{mn}, v_{ln} \in V_{sub}, \text{ there are double mapping exists } f, \text{ that is } v_{mn} \leftrightarrow v_{2mn}, v_{ln} \leftrightarrow v_{2ln}, \text{ Among them, } v_{2mn}, v_{2ln} \in V_2, \text{ and } (v_{1mn}, v_{1ln}) \in E_{sub}, (v_{2mn}, v_{2ln}) \in E_{sub}, \text{ Then subgraphs } G_2 \text{ and } G_1 \text{ are isomorphic, where } V \text{ is the node set and } E \text{ is the edge set.}$$

In order to solve the problem of accurate of subgraph matching and reduce the time complexity in the matching process, vF2 algorithm is selected to complete model matching in this paper. And the subgraph structures studied in this paper have common parent nodes. Besides this paper uses the concept of state space representation to represent the mapping results. The definition of pruning rules is shown in Equations (1), (2) and (3).

1. $R_{in} = (\text{Card(Succ}(G_1, n) \cap T_{1}^{in}(s)) \geq (\text{Card(Succ}(G_2, m) \cap T_{2}^{in}(s)) \wedge (\text{Card(Pr ed}(G_1, n) \cap T_{1}^{in}(s)) \geq (\text{Card(Pr ed}(G_2, m) \cap T_{2}^{in}(s))$  \hspace{1cm} (1)

2. $R_{out} = (\text{Card(Succ}(G_1, n) \cap T_{1}^{out}(s)) \geq (\text{Card(Succ}(G_2, m) \cap T_{2}^{out}(s)) \wedge (\text{Card(Pr ed}(G_1, n) \cap T_{1}^{out}(s)) \geq (\text{Card(Pr ed}(G_2, m) \cap T_{2}^{out}(s))$  \hspace{1cm} (2)

3. $R_{new} = (\text{Card(N}(s) \cap \text{Pr ed}(G_1, m)) \geq (\text{Card(N}(s) \cap \text{Pr ed}(G_2, m)) \wedge (\text{Card(N}(s) \cap \text{Succ}(G_1, m)) \geq (\text{Card(N}(s) \cap \text{Succ}(G_2, m))$  \hspace{1cm} (3)

The above equations refers to the comparison of the number of out and in degrees of corresponding pre matching nodes and nodes in different sets, where it refers to the number of nodes in the corresponding set. During model configuration, you can enter a demand model or a demand model plus a function model. The basic principle is to match the model in the order of demand matching, function matching, function solution and structure solution.

Among them, requirement matching is to conduct requirement matching based on the requirement model after the Designer completes the demand analysis and constructs the demand model. If the matching is successful, it indicates that the existing design includes the satisfaction structure of the demand. Therefore, the designer can find the design scheme that meets the design requirements and complete the product configuration. When the requirements cannot be matched, the designer needs to
analyze and model the system functions based on the existing requirements model. The designer needs to analyze the satisfaction of the function to the requirements, obtain the input and output quantity and type of each stage, and complete the construction of the activity diagram. Then, based on the constructed function model, the function matching is carried out according to the method above. If the matching is successful, it means that the corresponding structure is found to meet the needs of the designer. When the current two matching methods cannot be met, it means that the previous design results cannot meet the new design requirements, which means that the previous function combination cannot be directly applicable to the new design. In this case, it is necessary to search and match in the map based on the input and output stream types contained in the functional model, find new connection methods and functional combinations, and finally find the structural combination that can realize the demand.

3. Examples
A vehicle environment control integrated system needs to integrate oxygen production function to meet the needs of operation in plateau environment. The system requires long support time and high oxygen production concentration. At the same time, the system also needs to filter toxic and harmful gases to adapt to combat tasks in complex battlefield environment. In order to complete the system design, the designer analyses, designs and constructs the requirement model, function model, structure and behaviour model, etc... On the basis of the proposed method, the system model graph is constructed so as to complete the design reuse.

Firstly, the designer analyzes the demand of the target system, obtains the functional requirements such as oxygen production function and harmful gas purification and specific index parameters, and constructs the requirement model of the system, as shown in Figure 3.

![Figure 3. System requirement model of vehicle environment control integrated system](image)

Based on the functional requirements, the corresponding functional model can be constructed, including functional elements, input and output flow and other elements. The function mainly includes two functional elements (action). The input is air containing harmful gas and the output is oxygen and other gases. According to the above model, the product combination mode shown in table 1 is obtained, mainly including molecular sieve oxygen generator + carbon fiber filter, membrane
separation oxygen purifier, oxygen etching oxygen generator + low-temperature plasma filter and other structural combinations.

Table 1. Configuration scheme composition

| Configuration scheme | Matching mode               | Structural composition                                      |
|----------------------|-----------------------------|-------------------------------------------------------------|
| 1                    | Demand matching             | Molecular sieve oxygen generator + carbon fiber filter       |
| 2                    | Demand matching             | Membrane separation oxygen purifier                          |
| 3                    | Demand matching + function  | Oxygen etching oxygen machine + low temperature plasma filter |
| 4                    | Structural solution         | High pressure oxygen cylinder + carbon fiber filter screen   |

4. Conclusion

In order to solve the problem of system model reuse, a system model configuration design method based on knowledge graph is proposed. This method constructs the schema layer of the system model graph based on the SysML meta model. A subgraph matching method is used to design the configuration of the system model. The requirements proposed by the designer are designed and solved by means of requirement matching, function matching and structure solution. Finally, an example shows that this method is an effective model reuse method. Of course, in the process of building system model graph, although the ontology layer of the graph is built based on SysML meta model specification, the interface function to obtain model information is based on specific software tools (CSM). Therefore, this method is difficult to truly realize the reuse process of heterogeneous system models. Building a cross tool system model graph is our next research focus.

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