A REUSE METHOD OF MECHANICAL PRODUCT DEVELOPMENT KNOWLEDGE BASED ON CAD MODEL SEMANTIC MARKUP AND RETRIEVAL

Qinyi MA*, Lu MENG, Lihua SONG, Peng XUE, Maojun ZHOU, Yajun WANG
Department of Mechanical Engineering, Dalian Polytechnic University, Dalian116034, China
E-mail: onlypony@163.com (Qinyi MA)

***ABSTRACT**: Most of the product design is variant design or adaptive design, which needs to reuse product development knowledge implied in existing CAD model. This paper aims to reduce the semantic gap between the geometry features of Mechanical CAD models and the high-level design intent of human, thereby enhancing the reuse of the models. A reuse method is presented for mechanical product development knowledge based on CAD model semantic markup and retrieval (MPDK-CADSM&R). A design intent ontology is built on the basis of mechanical product modelling knowledge, engineering analysis knowledge and manufacturing knowledge. The CAD models are annotated according to the design intent scenarios using ontology semantic. The product development knowledge can be reuse by retrieval the semantic similarity of the model according to the current scenario. A prototype system is developed based on UG redevelopment by filtration, retrieval, grouping and other functions.*
***KEYWORDS**: Semantic Markup, Retrieval, Knowledge Reuse.*

1 INTRODUCTION

Product design mostly evolves from the existing products. To shorten the development cycle, product designers have frequently turned to proven products for inspiration (Wang and Lu, 2013). The various types of design, namely initial design, variable design and adaptive design, are differentiated by the degree of utilization of the original product. Therefore, a key factor in new product design lies in the reuse of previous knowledge and process (Ullman, 2010). Taking computer-aided design (CAD) for example, the user must understand the purpose and method of modelling before making effective reuse of existing materials. In other terms, it is necessary to learn about the design intent reflected throughout the product lifecycle (Wang, 2010).

The reusability of a CAD model relies more on the modelling, definition and communication of the design intent than the technology (Bodein, 2014).

The advent of 3D annotation has enabled the user to integrate the manufacturing information into the product model, push forward various links of design with CAD model, and make better reuse of existing products. For instance, the model-based enterprise (MBE) was created on annotated 3D models, known as Model-based definitions (MBD). The MBE is an integrated, collaborative environment shared across the enterprise with the intent to achieve rapid, seamless and affordable deployment of products from conception to disposal (Whittenburg, 2012). The centrepiece to the MBE is product definition, that is, the 3D model-based annotations that facilitate the comprehension of design information and product reutilization.

In 2003, the American Society of Mechanical Engineers (ASME) published the Digital Product Definition Data Practices (ASME Y14.41) to establish requirements for model-based definition upon CAD software and those who use CAD software to create product definition within the 3D mode. On this basis, the International Standardization Organization (ISO) rolled out rules on 3D model annotations in the Technical Product Documentation: Digital Product Definition Data Practices (ISO16792: 2015), marking a milestone in the application of digital technology.

To pinpoint useful 3D models and reuse the model data, more and more attention has been paid to 3D model retrieval technology. The extensive research gives birth to so many retrieval methods, ranging from keywords-based retrieval, content-based retrieval, to the latest semantic-based retrieval (Zhang, 2009). The most popular method is content-based retrieval. However, this method only considers the underlying features, failing to address the gap between these features and the high-level semantics of human (Tang et al., 2012). Due to the lack of semantic annotations, the content-based retrieval hinders the user's understanding of the semantic information in the model, making it hard to grasp the design intent or reuse the model.

For better reuse of the model, this paper proposes a reuse method for mechanical product development knowledge based on CAD model semantic markup and retrieval (MPDK-CADSM&R), aiming to reduce the semantic gap between the underlying features of the model and the high-level semantics of human.

2 THE FRAMEWORK OF THE MPDK-CADSM&R REUSE METHOD

The design intent was investigated in three dimensions, namely, modelling information, analysis information, and manufacturing information. Figure 1 shows the user scenarios discussed in this research.

When a designer needs to learn about the design intent and reuse the existing products, he/she can retrieve models or annotations by filtering and grouping, and view the specific model with annotations on the 3D annotation management system. In this way, the designer may comprehend all three dimensions of the design intent, and make full use of the CAD model with few changes and high productivity.

Figure 1. User scenarios

The annotation management system was created via the secondary development of UG (See Chapter 5 for more details). It has many functions, including synchronization, filtering, grouping, search, and visualization.

In view of the limits of 3D marking and the desired functions, the framework of the MPDK-CADSM&R reuse method was established from the following aspects (Figure 2):

At the theoretical layer, the author investigated such theoretical knowledge such as design intent, 3D annotation, 3D model retrieval and XML.

At the method layer, two aspects are tackled in this research: the CAD model 3D marking method and the semantic-based 3D model retrieval method. The semantic tree of CAD model based on design intent was built from the three dimensions: design information, analysis information and manufacturing information, laying the content basis for 3D annotation. The semantic tree and the 3D annotation files work together to support semantic retrieval.

At the application layer, the proposed method was implemented in two steps. The first step is called 3D marking. In this step, the design intent was divided into the said three dimensions, the model annotation and offline annotation were realized in the semantic annotation module, and the annotation information XML file was generated for downstream users. The second step is called semantic-based 3D model retrieval. In this step, the nodes were matched by semantic tree model in the semantic model retrieval module, and similar 3D models were returned. The returned CAD models with design intent could effectively promote the accumulation and communication of design knowledge.

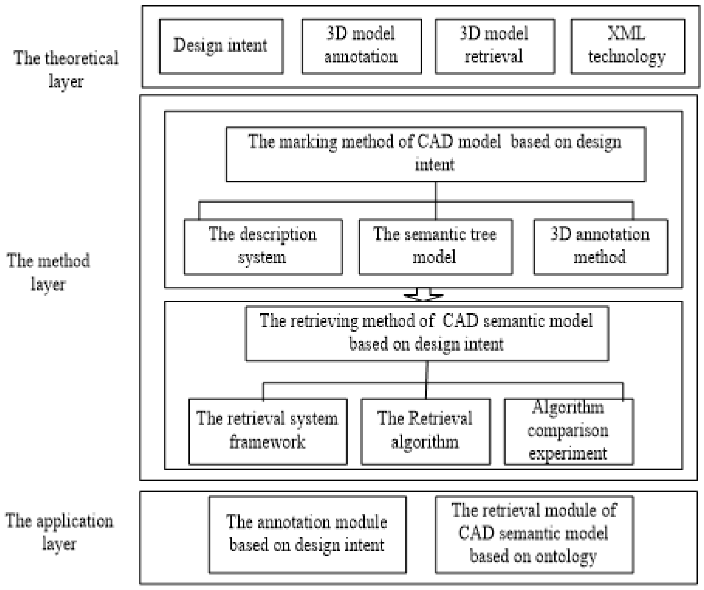

Figure 2. The framework of the MPDK-CADSM&R reuse method

3 CAD MODEL SEMANTIC MARKUP

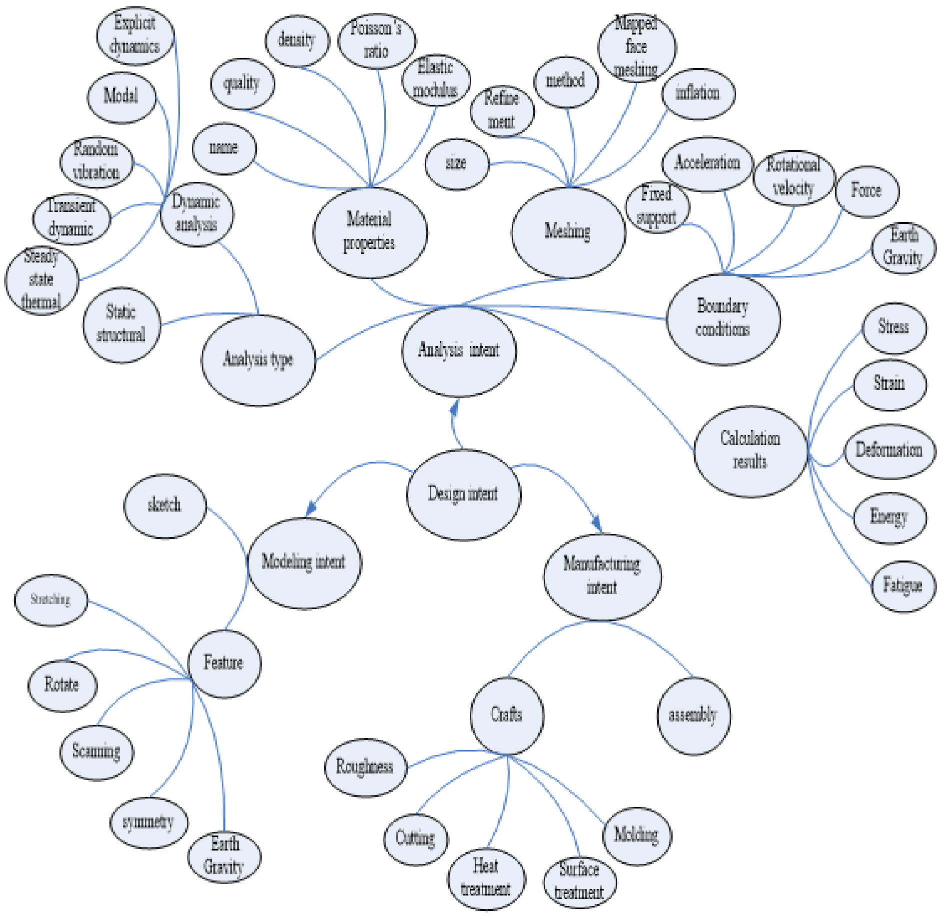

Figure 3. The ontology semantic tree

The design intent refers to the purpose and intention of the designer in the problem-solving process. Being a mirror of design decisions and principles (Wang et al., 2015), the design intent involves multiple levels of concepts that reflect the design objectives, expected functions, constraints, structural programs, etc. Since every product needs to meet certain functional requirements, the design intent must be demonstrated throughout the product lifecycle (Wang, 2010).

With the mapping from intent domain, feature domain to information domain, the previous research on design intent used to create a 3D model ontology semantic tree (Figure 3) based on modelling, analysis and manufacturing information (Jiang et al., 2011). However, such an ontology semantic tree cannot cover all design intentions, and should be extended in light of the actual application.

The key to design intent annotation lies in the association between the annotation and geometric model. The correspondence may be one-to-one, one-to-many or many-to-one. The mapping between annotations and the model is realized in two steps. First, select the relevant features and derive the unique and invariant handle for each feature; second, record the annotations and their corresponding handles in an external database table.

There are two ways to store 3D annotations based on design intent: direct annotation in the CAD model, and the storage in an external XML file. The annotation management mechanism proposed in our previous research was introduced to manage 3D annotations based on design intent in UG PMI module.

4 CAD MODEL SEMANTIC RETRIEVEL

From the aspects of modelling, analysis and manufacturing information, the 3D model was described by the target search term and model semantic annotation. Then, the author explored the semantic similarity between the target search term and the semantic annotation in the model library. The specific process is as follows.

Firstly, the retrieval index was built according to the ontology of the semantic model. Then, the user entered one or more target terms through the index, such that the system traversed the semantic tree nodes to find the same or similar nodes. Finally, the similarity of nodes was calculated by the similarity calculation formula, and the similar 3D models were returned to the user.

As shown in Figure 3, the ontology semantic tree is built on the annotation information of the design intent in three dimensions: modelling, analysis and manufacturing information. Similar to the ontology semantic tree, the semantic trees of 3D models in the database were established in the three dimensions, forming the semantic tree model. The semantic tree model does not necessarily contain all the information of the ontology semantic tree. These semantic trees pave the way to semantic-based CAD model retrieval.

According to the retrieval process in Figure 4, the user can input one or more target terms $\mathrm{Q}(\mathrm{q}_1, \mathrm{q}_2, \ldots, \mathrm{q}_\mathrm{k})$ by the index. Then, the system will compare the similarity between the search terms with the model semantic annotation, obtain similar semantic annotation terms, and return them to the user.

The semantic similarity comparison was carried out as follows:

(1) The system traverses the model semantic tree, and matches each element in the target retrieval set with the tree node. When the target retrieval term is the same with a node of the model semantic tree T, the system will record the similarity degree of the node and the target term as 1, and return the corresponding semantics of the node N_i and its child node N_{ic}. If there are$m$ child nodes, the similarity $S_c$of each child node is$1/m$. In this case, the number of returned annotations is denoted as p.

(2) If the target search term q_i is not the same with any node in the semantic model trees, the system will find a node which has the same or similar semantic as q_i based on the ontology semantic tree, and return the node and its child nodes (n), denoted as $\mathrm{C}'(\mathrm{c}_1, \mathrm{c}_2, \ldots, \mathrm{c}_{\mathrm{k}'})$. Then, the C'will be taken as the new target term and matched with the tree nodes by the same method. The corresponding annotation information to the node and its child node are returned. In this case, the number of returned annotations is denoted as p'.

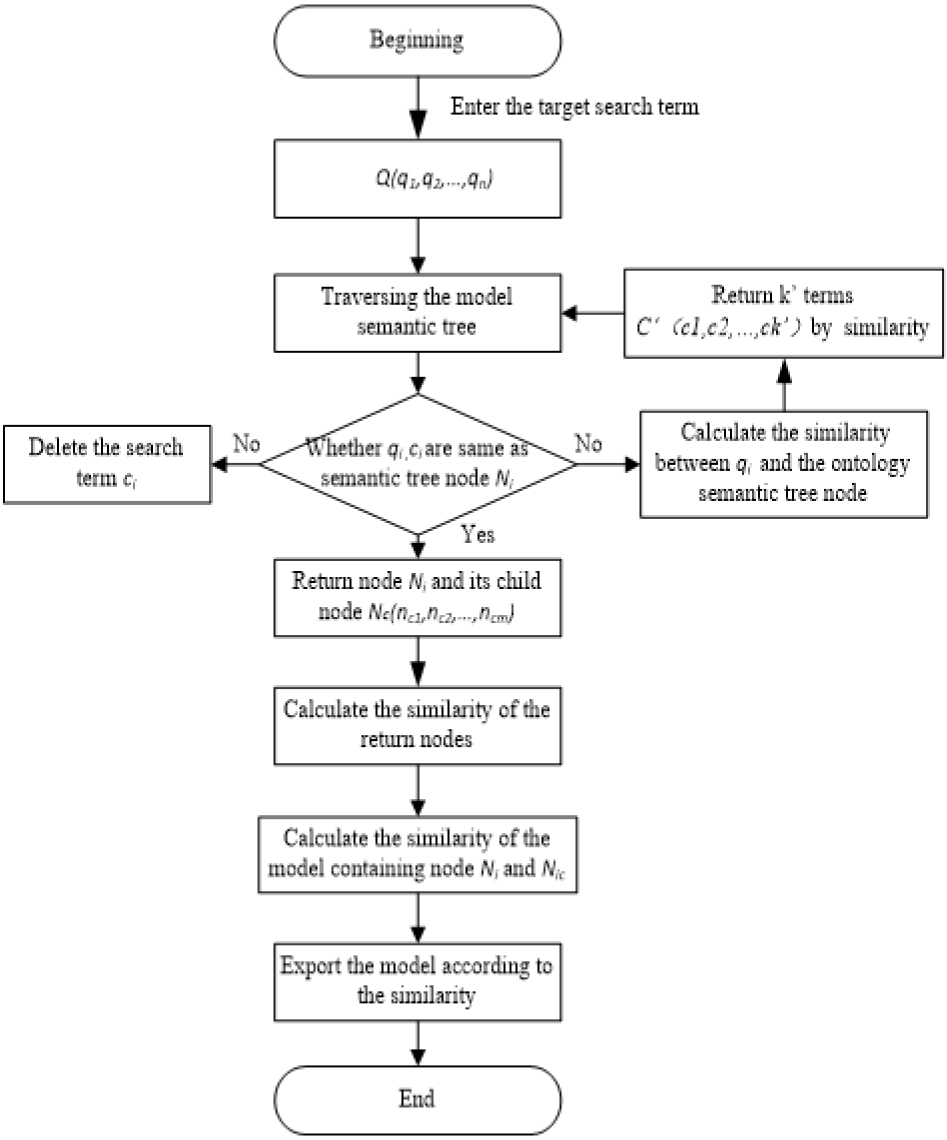

Figure 4. The retrieval process

The hierarchical relationship method was adopted to derive the similarity between the search term q_i and the nodes on the ontology semantic tree. Following this method, the semantic similarity was calculated based on the relationship between the upper and lower positions of terms. The correspondence between target terms and model semantic annotations was determined in reference to (Jiang et al., 2011). For the search term q_i, the system calculates the information content icvalue based on the number of nodes on the ontology semantic tree:

$$\mathrm{ic_{wn}}(\mathrm{c}) = \log(\frac{\mathrm{hypo(c)+1}}{\mathrm{max_{wn}}})/\log\left(\frac{1}{\mathrm{max_{wn}}}\right) = 1 - \frac{\log(\mathrm{hypo(c)+1})}{\log(\mathrm{max_{wn}})} \quad (1)$$

where the function $hypo$ returns the number of hyponyms for a semantic concept; max_{wn} is a constant set to the maximum size of the concept in its class; the denominator is the concept with the maximum amount of information; the final result ic value falls in the range of [0, 1].

The semantic similarity between terms c_i/c_j is calculated as follows:

$$\mathrm{sim_{jcn}}(\mathrm{c_i}, \mathrm{c_j}) = 1 - \left[\frac{\mathrm{ic_{wn}}(\mathrm{c_i}) + \mathrm{ic_{wn}}(\mathrm{c_j}) - 2\times\mathrm{sim_{res}}(\mathrm{c_i}, \mathrm{c_j})}{2}\right] \quad (2)$$

where $sim_{res}(c_i, c_j) = \max_{c\in S(c_i,c_j)} ic_{res}(c)$;$c_i \in W$;$c_i \in S$. Then, the semantic similarity of each term in set $\mathrm{C}'$is:

$$\mathrm{S_{C'}} = \mathrm{sim_{jcn}}\times\mathrm{S_c} \quad (3)$$

The 3D model retrieval system returns the 3D model set $\mathrm{M}(\mathrm{m_1}, \mathrm{m_2}, \ldots, \mathrm{m_n})$ and the model similarity value is the sum of the semantic similarities of the $p + p'$ returned annotations:

$$S_{model} = \sum_{t=1}^{p} S_{C_t} + \sum_{u=1}^{p'} S_{C_u} \quad (4)$$

The sum is positively correlated with the closeness between the model annotation and target term.

5 THE SYSTEM PROTOTYPE

The UG secondary development refers to the design of applications targeted at the exact needs of enterprises or users. For this purpose, UG software provides UG/Open API, a program tool of secondary development for enterprises or users. The API functions of UG software helps to achieve interactive operation between software and the outside world. Inspired by UG secondary development, this paper introduces a system developed in Visual Studio 2012 C# platform, aiming to effectively manage and view 3D annotations. The menu interface of the annotation management system is illustrated in Figure 5. The main functions of the system are introduced below.

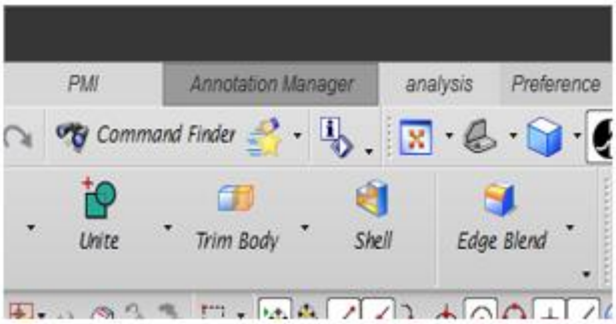

Figure 5. The menu interface of the annotation management system

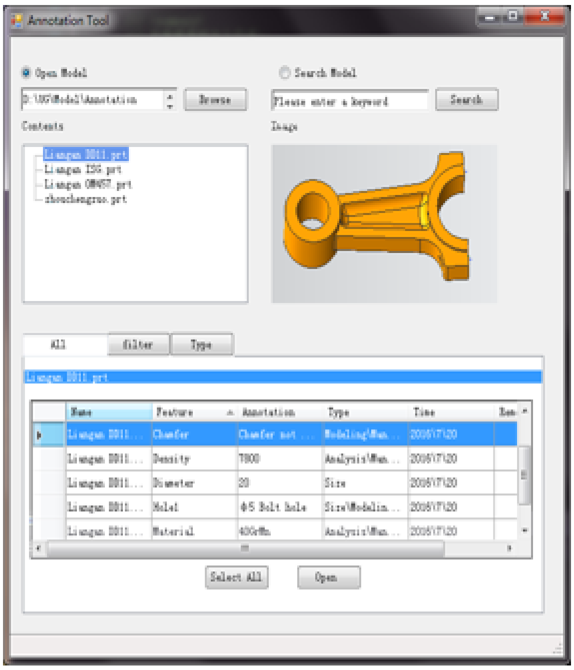

Figure 6. The retrieval function interface

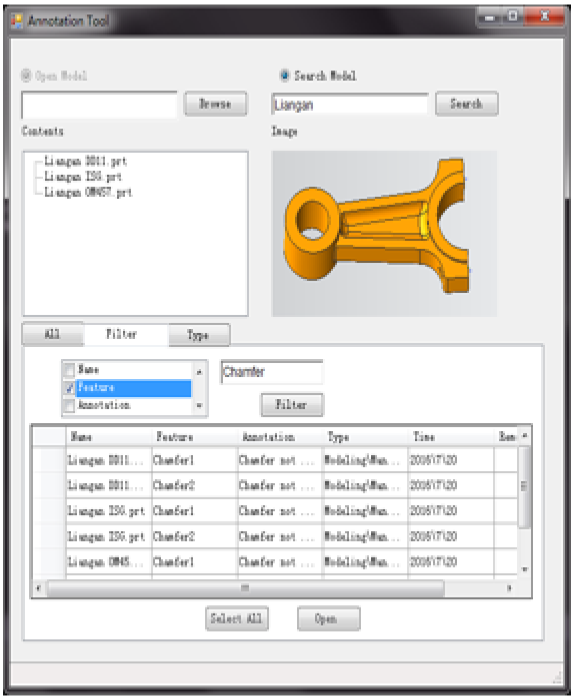

Figure 7. The filtering function interface

(1) The retrieval function: The user can search for all related geometries and geometric features of an annotation by entering the keywords or model of the annotation; conversely, he/she can also search for relevant 3D annotations by inputting the name of geometric feature or geometric entity (Figure 6).

(2) The filtering function: The user can choose to view the name, feature, content, type, time and other attributes of the retrieved annotation. This function can instantly locate the CAD model and its associated annotation information, and improve the readability of annotation (Figure 7).

(3) The grouping function: The modeller, analyst and manufacturer are allowed to divide the design intent into modelling, analysis and manufacturing information.

The three functions can be called at the same time. For example, if an analyst wants to find out the stress state of an axle-bearing hole, he/she needs to enter a keywords “axle-bearing” in the Search Model checkbox; then, the Contents list will display all axle-bearings stored in the database; after that, the analyst should select Feature in the Filter checkbox, enter another keywords “Hole”, select Analysis in the Type checkbox, and click the Filter button; next, all information retrieved from the database will be shown in the following list.

If the user prefers to view the specific annotation of a model, he/she needs to select the one, several or all annotations from the list, and click the Open button. In this case, the model will be displayed in the UG with specific annotations. The display is clear and intuitive.

Figure 8 and Figure 9 depict the returned 3D models with annotation information respectively based on semantic retrieval and keywords search. It is clear that the semantic-based retrieval method returned more 3D annotation information than the keywords search. This means the former method can more accurately reflect the retrieval intent of the user.

Figure 8. The search results based on semantics

Figure 9. The search results based on keywords

In addition, the semantic-based retrieval method, based on the semantic ontology model, described the exact modelling, analysis and manufacturing information, and returned both the 3D models and the design intent information for the reuse of design knowledge. By contrast, the keywords search method only returned the matching results and often failed to retrieve the similarity model from the perspective of design knowledge. Due to the limited annotation information in the search results, the keywords search method cannot effectively support the reuse of product design knowledge.

6 CONCLUSIONS

To overcome the low efficiency of product development and enhance the reuse rate of design knowledge, this paper develops a CAD model reuse method based on 3D model annotation and retrieval (MPDK-CADSM&R). Firstly, the author put forward the CAD model annotation ontology based on design intent. Then, a 3D CAD model retrieval algorithm is created based on design intent, and verified through comparison with the retrieval method based on keywords. Finally, a system prototype of the MPDK-CADSM&R is developed on Visual Studio 2012 C# platform via UG secondary redevelopment. The research findings shed new light on the improvement of CAD model reusability.

7 ACKNOWLEDGEMENTS

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