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A Design Environment Ontology for Stakeholder-developed Decision Support Tools in the Australian Dairy Industry

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Abstract

A significant number of decision support systems (DSS) are available for rural applications. However, many of these have low adoption rates because they have been developed with little end-user engagement, limited ease of use by farmers, and the identified gap in understanding significant problems between the DSS developers and the potential end-users in the development process. A useable development environment that prioritises end-user engagement can be expected to reduce the known DSS development difficulties and to improve the development of appropriate decision support tools. To date however few significant attempts have been made to outline sophisticated models for a design environment that offers an adaptable and effective solution for end-user DSS development. This paper describes ongoing work in ontology construction and knowledge elicitation part of the development of an end-user enabled design environment (EUEDE). In general the EUEDE will assist rural business stakeholders to build their own target-relevant decision making tools. We describe in the first instance, the ontology for EUEDE that will allow dairy stakeholders to outline domain-specific decision making scenarios that will lead to the building of relevant DSS.

Keywords

Design environment, DSS, dairy industry

INTRODUCTION

The main limitations of traditional decision support tools in the development of rural applications are the resistance of farm operators in using the tools for decision making, the contrast between individual farming practice and actions, and optimum expert recommendations that may not fit the practical requirements of farmers (Kerr, 2004; McCown, 2002). Some stand-alone DSS appears to become obsolete with decision-making requirement in rapidly-changing rural environments: McCown (2002) has discussed a number of relevant cases. Therefore, there is a need for research on improving the development process of decision support systems (DSS), which will embody usable industry specific knowledge for end-users in their industry context. The purpose of this paper is to report on ontology development for such an end-user enabled design environment in which the rural industry operators can use their industry specific knowledge to build the required and target-specific decision support tools. The design philosophy for this development accepts the human centered paradigm (Gammack *et al.*, 1992) in which human (industry key players) skills, knowledge and contextual judgments are vital in the decision-making process, rather than the machine centered DSS model (Gammack *et al.*, 1992). Pragmatically, this implies that the end-users can exercise their own choices in the context of use, their subjectivity and operational knowledge into building their target-relevant DSS.

According to the artificial intelligence literature, ontology defines a formal explicit description of concepts using basic terms and relationships as well as the rules for combining the terms in a problem domain (Lambrix and Edberg, 2003; Noy and McGuinness, 2001). While abstraction of ontology is similar to the definition of conceptual model, Liddle *et al.* (2003) differentiate ontology from the conceptual model by (1) especially focusing on extended definitions of relationships and concepts and (2) having the explicit goal of reuse and sharing knowledge by defining a common framework and vocabulary. In the recent years the ontology development for formal specifications of the terms and relations has been established and extended into many problem areas. The approach is used to build explicit understanding on the structure of complex problems such as in bioinformatics (Baker *et al.* 1999; Lambrix and Edberg, 2003), World Wide Web design (Crampes and Ranwez, 2000; Liddle *et al.*, 2003; Sunagawa *et al.* 2003), medical informatics (Achour *et al.*, 2001; Gennari *et al.*, 2002; Musen 1998). However, a few attempts have been made in the problem area of rural application development. As rural business contains numerous changing situations and the relevant decision making

parameters requires consideration during system development, our attempt is to outline a knowledge sharing and reusable problem ontology model for effective decision making that will be a vital contribution into the development of a generic template of our proposed end-user enabled design environment (EUEDE). This will allow end-users to build their specific and target-relevant DSS.

Perez and Benjamins (1999) describe ontology as allowing the capture of domain knowledge at a generic level. It can compress problem solving methods that specify generic reasoning of knowledge that it can configure new knowledge from existing and reusable ontology components. In this paper, we argue that the generic ontology development in the dairy domain can have applicability to other rural businesses for building DSS.

LIMITATION IN TRADITIONAL DSS DEVELOPMENT

Previous research has identified that a large number of DSS in the rural sector have limited end-user uptake and limited use of relevant contextual knowledge (Hayman and Easdown, 2002; Kerr and Winklhofer, 2005; Lynch *et al.*, 2000). Although end-user development of spreadsheet is common. Wagner (2000) found that there were very few successful end-user expert systems development projects and this was due to development difficulties associated with the third party analyst/developer's needed to identify requirements and system design. This implies that traditional system development requires technical users' involvement that appears to discourage end-user uptake. In addition, expert system development with traditional software tools, for example spreadsheet development involves some issues that are problematic. These include the need for computer experience and skills in application development. Development of these skills is time consuming and, in general, rural industry end-users produce system solutions that are not of a high quality and are usually error prone. Kreie *et al.* (2000) described many cases of application developed by end-users that has found higher error rates and suggested for end-users training in system analysis and design methods for improving the application quality. For instance, Panko and Sprague (1998) reported that there were error rates from 10% and 25% in real world spreadsheet applications based on audits they conducted.

Other problems associated with solution software developed by end-users include a lack of alignment with decision needs and difficulty in finding errors. These systems generally do not have any customising options for modifying, sharing, and reusing knowledge. This is especially the case in the agricultural context, where there are many changing and influencing factors, constraints, and conditions that need to be considered when developing these types of customizable decision support tools. For example, Hayman and Easdown (2002), and Kuhlmann and Broderson (2001) comment that DSS adoption is limited by poor engagement with end-users, despite good practices in system development and accessibility in the agricultural domain. In addition, problems with end-users developed applications are always questioned in relation to quality and extra training needed for efficient system development (Kreie *et al.*, 2000). Kreie *et al.* (2000) indicates that it is important to overcome the quality and extra training requirement issues with end-user enabled system development. Rafea *et al.* (2003) propose a knowledge acquisition tool in which the industry end-users can create and maintain their knowledge base with knowledge reusability in the target domain. This approach only offers a task specific knowledge acquisition system for solving problems such as irrigation and fertilisation scheduling rather than on how task specific knowledge can be useful for building expert decision support tools in the target domain. In contrast, our approach aims to provide a problem ontology for the end-users to enable them to acquire goal specific decision making knowledge for their own relevant issues.

This paper is organized in the following manner. The next section describes previous ontology based design environments. The following section describes previous ontology approaches used in different problem domains and the undertaken process in our development of problem ontology. The ontology construction section describes the construction of the outlined problem ontology in the selected domain of milk protein enhancement in the dairy industry. Finally, the discussion and summary section presents a brief case description on the development undertaken in this project.

PREVIOUS ONTOLOGY BASED DESIGN ENVIRONMENT

The uses of ontology classification in developing significant knowledge based systems have been outlined in the previous literature (Achour *et al.*, 2001; Crubezy *et al.*, 2004; Gennari *et al.*, 1994; Musen, 1992). Many of the ontology based design environments have been proposed in the medical informatics field for medical experts (Achour *et al.*, 2001; Gennari *et al.*, 2002; Musen 1998). For instance, Gennari *et al.* (2002) describe the current version of protégé II (Musen *et al.* 1995) as an environment for knowledge based systems development. This tool is designed for developers to enable them to build user interface and develop problem solving in the development of knowledge base system rather than for general users. Protégé II encompasses options such as reusable problem solving method and knowledge acquisition facilities for building a knowledge base. This tool is neither an expert system itself nor a platform for building expert systems (Gennari *et al.*, 2002). It is classified

as a platform for building knowledge based systems. The work done by Achour *et al.* (2001) has several limitations such as: the system only functions as a knowledge acquisition tool; there is no expert graphical presentation as output (except two expert forms shown as alert and consultation); there is no clear description on the database of how they link to the user interface; the only options for reuse and sharing are in the domain ontology rather than reusing the problem solving methods; and there is no design environment approach presented.

These tools also focus the knowledge acquisition process for the development of the medical knowledge base systems for medical experts only, rather than for general users. Although this type of tool facilitates the creation and maintenance of a knowledge base by domain experts such as developers, it reduces the general user's activities in system development rather than encouraging general users to develop their own systems. The proposed ontology construction of EUEDE differs from the previous work in that it will provide an option to build decision support systems for non-technical computer users in rural industries. In this design environment ontology the end-users will not only be allowed to reuse and share their domain knowledge but also to outline the problem scenario, customise the problem solving methods and produce expert output options in the problem domain.

ONTOLOGY APPROACH

The development of a problem ontology involves a complex process of knowledge acquisition that requires sophisticated methodologies, although its maturity with respect to these principles is still in question (Blazquez *et al.*, 1998). Until now, a few methodologies for ontology development based on domain independent principles have been proposed. In addition, most of the ontology principles are similar. For instance Uschold *et al.* (1996) proposes a methodology that sets out steps such as purpose identification, building ontology, evaluation, and documentation. This methodology is similar to the traditional system development approach, which is not involved with any knowledge acquisition and conceptualisation activities that can be applied into our ontology development. Similarly, Blazquez *et al.* (1998) suggests three main categories of activities such as project management that include planning, control and quality assurance; development oriented activities that include specification, conceptualisation, formalisation, and implementation; and support activities that include knowledge acquisition, evaluation, integration, documentation and configuration. This methodology also appears useful for traditional system development rather than development of knowledge based system, although it has included a knowledge acquisition phase in the support activities. Staab and Studer (2001) describe a methodology for an ontology based knowledge management system, which has followed five major steps. These steps are a feasibility study, ontology commencement, refinement, evaluation and maintenance. Another methodology for task based ontology development reported by Mizoguchi *et al.* (1995) involves four different phases. These are the extraction of task units, organisation of task activities, analysis of task structure and organization of domain concepts. The study by Mizoguchi *et al.* implies that scope and purpose identification for ontology development has been skipped or assumed to be completed previously. The above-mentioned literature indicates that these methodologies commonly start from the step for identification goals/purpose of the ontology and the need for domain knowledge acquisition. However, this can only happen after a significant amount of knowledge is acquired (Lopez *et al.*, 1999). We engaged an approach called METHONTOLOGY (Fernandez *et al.* 1997) for ontology development, which advocates the use of a structured informal representation to support the ontology development (Bally *et al.*, 2004). This methodology involves different steps such as knowledge acquisition, conceptualisation (in form of informal representation), implementation and evaluation. This methodology supports a prototyping based life-cycle for evaluating, which is recognised in our ontology development. To utilise this methodology, we modify and add the steps for building problem ontology in the domain of milk protein enhancement. These steps are knowledge acquisition, conceptualisation, evaluation, specification, and implementation.

A process for ontology development which derives information on activities or goals that is to be carried out when building the ontology is important (Bally *et al.*, 2004; Blazquez *et al.*, 1998). We identified that the scope of ontology development is to develop generic and reusable decision making components that enable the user to outline their decision-making scenarios in the problem domain. The following development process builds the problem ontology in the domain of milk protein enhancement. Figure 1 illustrates the process of the ontology methodology. Below we have listed the five steps for the process of building the problem ontology.

Knowledge acquisition

This step requires expert knowledge for the problem ontology to be collected. Decision-making parameters are identified and documented from different protein dominant instances such as cow's dry matter intake, feed management, and breed management.

Conceptualisation

A preliminary ontology is sketched by defining categories, terms, relationships and their relevant instances. Problem schema diagram, category table, terms definition table and relationship definition table are then constructed. This is an important step that enables the representation the initial ontology to the domain expert for evaluation purposes.

Evaluation

The sketched ontology is presented to the domain experts to prove reusability options and for the verification against user requirements. Provided feedback helps to reach a consensus for acceptance as problem ontology for template of EUEDE.

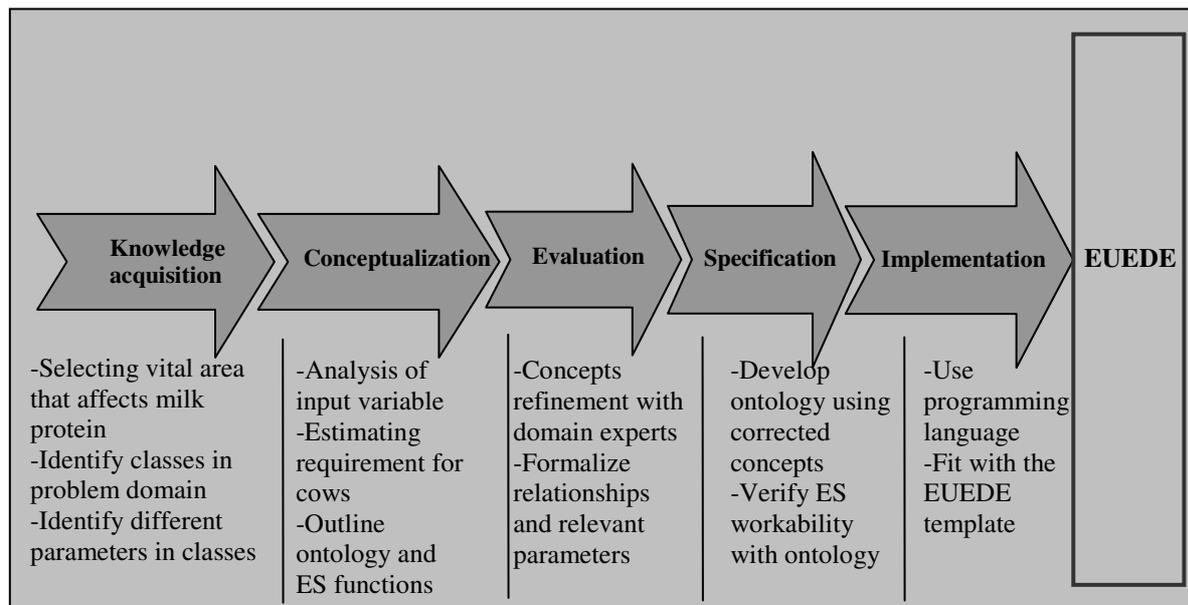


Figure 1: The ontology development process

Specification

This step involves a complete identification of relevant decision-making parameters in different classes with appropriate weight assigned to their relationships. A detailed knowledge base is prepared to communicate the ontology and to reach a clear consensus on the reusable problem ontology before converting into formal representation.

Implementation

A formal ontology representation language is used to implement the programming part of the EUEDE. In this step the generic template of the ontology allows us to discover the generic problem domain that allows changing, modifying and adding parameters, relationships and instances for different problem aspects. This will be the basic building blocks for the generic template of the EUEDE.

ONTOLOGY CONSTRUCTION

The main reason for ontology construction is to enable sharing and reuse of domain specific knowledge although it is also important to share a common understanding of the information structure, explicit domain assumptions and analysis domain knowledge from operational knowledge (Achour *et al.*, 2001; Duineveld *et al.*, 2000; Noy and McGuinness, 2001). In this project we started constructing the problem ontology keeping in mind that the elicited expert knowledge will be used at a generic level.

Knowledge Elicitation

Our approach is to elicit the expert knowledge on milk protein enhancement through a series of focus group meetings with dairy stakeholders such as dairy farmers, dairy experts, dairy company personnel and dairy extension officers. From these focus groups we identified six main factors associated with milk protein enhancement. These factors were considered relevant and were approved by all dairy stakeholders. They were dry matter intake in feed, feed values, feed management, herd management, heat stress management and breed

management. These factors provide an effective list of decision-making parameters and their impacts on milk protein enhancement. They allow us to acquire in depth expert knowledge and are used as building-blocks for the problem ontology.

Based on these six main factors in the dairy milk protein domain, we convened three focus group meeting discussion sessions on cow nutrition each of two or three hours duration. In these sessions we covered the impact on milk protein of feed dry matter intake, metabolisable energy content, and other feed values, farm management including the impacts of selected feed items, feed processes, feed use and limits imposed, and heat stress and breed management, including the impacts of heat stress and breed types on milk protein. The first focus group session incorporated skilled personnel such as dairy nutritionists, experienced dairy practitioners and dairy farmers. The second focus group session incorporated skills from personnel such as experienced dairy practitioners, dairy physiologists, and dairy farmers. The third focus group session incorporated skilled personnel such as a dairy breed specialist, experienced dairy practitioners and dairy farmers. The elicited expert knowledge allowed us to identify the required decision making parameters, their impacts and relationships with different instances leading to the development of the general problem ontology.

Construction of problem ontology

In the first stage of ontology development we collected a list of decision making parameters that are most important for a dairy farmer to consider for decision making purposes. We created a table based of the essential parameters (table 1). A problem schema diagram is developed based on those parameters/terms, which is helpful for identifying the relationships in different instances. Figure 2 shows the problem schema diagram. The identified six main aspects (we renamed them as classes for terminological consistency in the ontology) are related to our problem domain because they have different impacts on the milk protein enhancement in dairy operations. We defined the relationships as “depends on”, “is a”, “has impacts” etc. Each type of relationship has a rule or set of rules which creates an impact on the main classes. To formulize the rules two types of relationships have been identified. These are mathematical function based relations and the textual function based on relations. Mathematical functions in relationship are based on quantitative parameters that are to be computed for making expert decisions. For example the total dry matter intake required for dairy cows in kg = (live weight * 3)/100.

Terms	Description
Live weight	Cow's average body weight. It is measured in KG numerically
Stages of lactation	Cow's stages of lactation have impacts in three different stages
Type of breed	Cow's breed type is cow's generation type
Type of farm	Area type of farm. For example steep, flat etc. It has impacts on energy requirement for maintenance
body condition score	It is important for judging a cow's nutritional status and indicating energy balance
Distance between shade and feeding area	It impacts on energy requirement for body maintenance. The level of energy balance has impact on milk protein
Total produced milk	Total liter of milk produced in farm is a parameters for estimation of total energy requirement
Level of heat stress	Heat stress has impact on milk protein. It is a management factors to protect cows from environmental impacts

Table 1: An example for glossary of terms

On the other hand, textual relations are based on qualitative values of parameters that define relationships between parameters. For example water intake in relation to milk protein:

IF water intake level is low THEN the expert outcomes for water intake will be warning level A (crisis level) in feed management in order to reduce heat stress;

IF water intake level is medium THEN expert outcomes for water intake will be warning level B (not satisfied level) in feed management in order to reduce heat stress; and

IF water intake level is high THEN the expert outcomes for water intake will be warning level C (satisfied level) in feed management in order to reduce heat stress.

Relationship	Formulas/ rules
Has impacts	If digestibility is more than 80% then Target feed has impacts with X unit based on mathematical relations
Depends on	If feed item is forage then feed values can have X amount of impacts , based on mathematical relations
Is a	If fine grinding is a process for corn with 80% digestibility, it has Y amount of impacts to the protein level, based on textual relations

Table 2: An example of relationship table with different rules

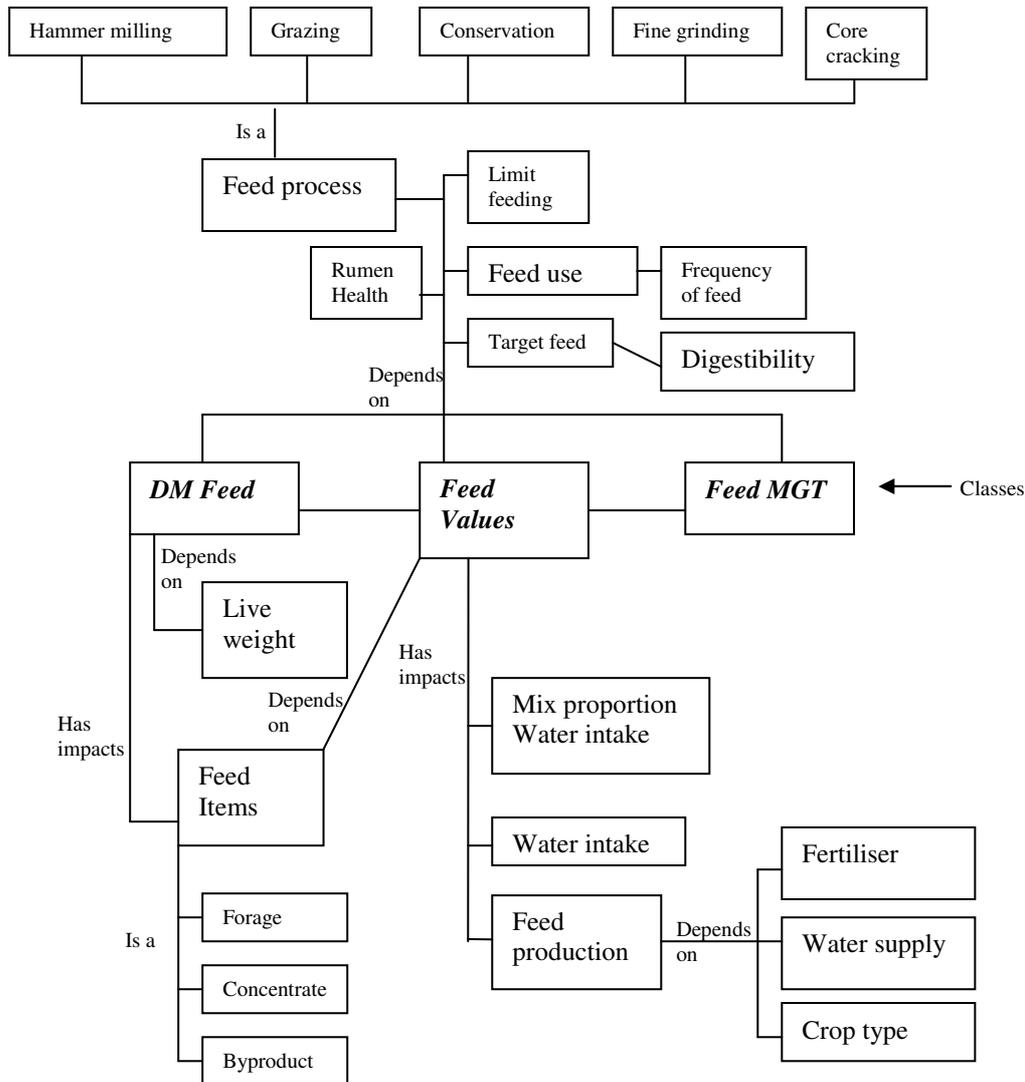


Figure 2: Example of problem schema for the problem ontology (NB: Three classes out of six have been shown in this diagram)

Table 2 shows the example of relations that will be used as problem solving rules. We use a bottom up design method as the decision-making rules are to be resolved first. For example the bottom relationships will be processed first to estimate requirement levels and current status towards evaluating expert outcomes. The most effective impacts shown in the problem schema diagram (Figure 2) would be considered for identifying the scope for milk protein improvement. The final two stages, (specification and implementation) are currently being completed. Below table 3 illustrates concept dictionary of the problem ontology for our case.

Concepts	Synonyms	Instances	Instance Attributes	Relationships
Feed vales	Estimation	Physiological	Type of farm	Has impacts

estimating (required ME, CP, NDF estimation)	factor 1	Farm MGT Breed	Type of breed Body condition score Distance between shade and feeding area Total produced milk Level of heat stress	Depends on Can be
DM estimating	Estimation factor 2	Physiological Farm MGT	Average body weight Lactation stages Body condition score Seasonal effect Digestibility Level of heat stress	Has impacts Depends on
Herd management Estimation	-----	-----	-----	-----
Feed management factors Estimation	-----	-----	-----	-----

Table 3: Example of concept dictionary in the domain of milk protein enhancement

DISCUSSION AND SUMMARY

DSS developments in rural industries have been largely disappointing to date due to technological constraints which appear as rigid options to end-users. It is because of a great range of changing decision requirements and the need for use various rules of thumb specifically in the dairy sector that often might not be suited to traditional DSS design methodologies. Sharing and reusable provisions for end-users can reduce the contrast between individual farming practice and the relevant technological actions. As mentioned earlier, ontology development is an established and workable concept in medical informatics and bioinformatics. Unlike other domains, ontology based development can be considered as a progressive way towards practical approaches for developing and delivering specific and target-relevant DSS in rural sector. Because of its generic capability, this approach reduces technological rigidity in DSS development in rural application.

In this paper, we described an ongoing ontology development process of a generic design environment in which rural business operators such as dairy farmers will be assisted in building their own decision making tools using their own specific knowledge. Ontology development is an iterative process that allows us to reuse and share domain knowledge such as parameters, instances and the rules in the different decision making situations. It is important that this conceptual ontology architecture is applicable to other rural livestock-based businesses. This can be done by changing the parameters, instances and relationship in different classes. However, further research effort is needed to prove the concept in practice. Practically, this development will reduce the need for sophisticated analysis, modeling skills and knowledge for building task specific knowledge acquisition tools using professional computing techniques in complex domain applications. The adoption of this tool will also contribute to reducing complexity in traditional DSS development for rural application development. This system will offer an improved way of customisable problem solving in decision making that leads to improved practices, individuals' involvement and performance. Furthermore, this system promises to make end-users such as dairy farmers' life much easier with their development of decision making tools for their specific business operations.

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