Computing and Informatics, Vol. 35, 2016, 914–940



# IMPROVING KNOWLEDGE ACQUISITION IN COLLABORATIVE KNOWLEDGE CONSTRUCTION TOOL WITH VIRTUAL CATALYST

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**Abstract.** Noctua is a web tool to assist in Knowledge Acquisition and Collaborative Knowledge Construction processes. Noctua has an innovation: a Virtual Catalyst designed to facilitate the task of eliciting and validating knowledge. The Virtual Catalyst queries participants, proposing new knowledge, seeking confirmation to the knowledge already elicited, and showing conflicting opinions. The Virtual Catalyst takes into account participants' profiles in order to automatically ask them questions related to each one's field of knowledge or interest. This paper presents Noctua and its Virtual Catalyst. The tool was submitted to experimenta-

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tion and the analysis of the results showed that the primary goal of increasing the rate of knowledge construction was achieved (up to 144 % in the rate of knowledge creation), and also showed some unexpected beneficial outcomes.

**Keywords:** Knowledge acquisition, collaborative knowledge construction, virtual catalyst

**Mathematics Subject Classification 2010:** 68T30, 68T50, 68U35

## 1 INTRODUCTION

Domain modelling is an activity present in a great number of projects, essentially being a collaborative activity. The Collaborative Knowledge Construction (CKC) is characterized by a concomitant aggregation of knowledge from several participants into a common repository [1]. The collaborative construction of knowledge happens when multiple participants contribute to increase the number of interpretations by inserting new knowledge, comments, changes and additions on a shared information base. According to [2], knowledge construction is characterized by an increasing number of interpretations of a piece of information inside an information base. Such a base is simultaneously expanded by the search and the transformation of the information. A new interpretation can take the form of an explicit comment, but it can also be accomplished by means of transforming and integrating representations inside the information bases.

The process of Knowledge Acquisition (KA) is basically characterized by people playing two basic roles: domain experts, who possess knowledge about a specific domain, and knowledge engineers whose mission is to capture that knowledge and represent it in a way that it can be used by computational systems [3].

This paper presents a web tool called Noctua, which can be used for both KA and CKC. Noctua has a new component called Virtual Catalyst (VC). According to Oxford Dictionary [10], catalyst is someone "that causes a change". The main goal of it is to increase the rate of knowledge construction. The VC helps to overcome some obstacles inherited from the KA process such as the lack of expert's available time and the difficulty of eliciting and representing knowledge. The catalyst also helps surpassing barriers innate to the CKC process such as authorship registration and knowledge validation. The general idea is to insert into the collaborative process a virtual participant who plays the role of the catalyst.

Noctua allows participants to define and develop concepts as well as express their operations, avoiding the need to rely on pre-existing knowledge hierarchies or the use of computer programming-like syntaxes. The web tool operates with conceptual knowledge, represented by Knowledge Pages [1] and procedural knowledge, represented by Production Rules [7].

This article is divided as follows: Section 2 presents the concepts used in this work; Section 3 shows Noctua's features and Section 4 presents the Virtual Catalyst. In Section 5 we present some experiments with Noctua. Finally, Section 6 presents our conclusions and Section 7 suggestions for future work.

## 2 FUNDAMENTALS ON COLLABORATIVE KNOWLEDGE CONSTRUCTION

This section concerns essential topics involved in this work such as KA and CKC. We start defining knowledge and the process of KA.

### 2.1 Knowledge and Knowledge Acquisition

As stated by Brachman and Levesque [36], the concept of knowledge is not totally "demystified". For the purpose of this research, knowledge may be considered as information combined with experience, context, interpretation and reflection, as defined in [4] and [5].

The process of Knowledge Acquisition (KA) may be defined as "the transfer and transformation of problem-solving expertise from some knowledge source to a computer program" [6]. It has been recognized as both an art and a bottleneck in the construction of knowledge-based systems [7]. In industry, KA can preserve valuable knowledge that could be lost when domain experts leave the company.

The elaboration of a glossary of terms used by domain experts should be one of the first steps in the design of knowledge-based systems. Knowing expert's vocabulary is a fundamental task in KA. In [8], authors state that "an adequate design of a cognitive system depends on the existence of a common vocabulary". In order to obtain this vocabulary and the domain knowledge itself, one could use one of the two techniques presented in the next paragraphs.

The interview is one of the most popular KA techniques, despite criticisms on its efficiency [9]. Unstructured interviews have fewer restrictions and are more generic and more common in the beginning of the KA process. Structured interviews, on the other hand, are formal, planned in advance, and may be more focused on specific topics.

Creating scenarios is another KA technique, in which experts are stimulated to make their knowledge explicit. Milton in [1] suggests the creation of scenarios that depict or envisage real situations. In describing their actions in such situations, experts make explicit their knowledge which can be captured by the knowledge engineer. In a variation of the scenarios method, also described by [1], the idea is to present scenarios with potentially inconsistent or missing information to the expert. The expert's attitudes to obtain information by questioning inconsistencies (or not recognizing them) should be used by the knowledge engineer to make the domain expert's knowledge explicit.

### 2.2 Collaborative Knowledge Construction

The idea of knowledge as a product of collaboration suggests the key roles of peer mediation and shared practice ([11] and [32]). Knowledge is thus seen as the result of collaboration between the members of a discourse community.

Ramalho and Tsunoda in [12] state that the information and communication technologies have created new spaces and forms for the construction of knowledge. This scenario changed the traditional learning systems, breaking space-time barriers and turning the most diverse environments into learning spaces. Systems for collaboration (or collaborative software) make use of the internet to foster communication and information organization, providing tools that facilitate the coordination inside groups of participants [35]. Among several collaborative systems, we may cite blogs, mailing lists, forums, social networks, chats, wiki tools, and other systems to interact synchronously or asynchronously.

Some researchers propose to combine the best ideas from the social web and semantic web ([38], [39], [40] and [43]). As stated by Gruber, the social web is an ecosystem of participation, where value is created by the aggregation of many individual user contributions. The semantic web is an ecosystem of data, where value is created by the integration of structured data from many sources. The result could be named "collective intelligence", combining the social web with knowledge representation and reasoning techniques of the semantic web. Some applications emerge from this combination. PlWiki is a semantic wiki architecture that provides a strong knowledge representation and reasoning with Horn clauses-based representation [40]. KnowWe (Knowledge Wiki Environment) is another example. The system enables domain specialists to build knowledge-based consultation systems collaboratively on the web [41]. AceWiki is a prototype that allows a semantic wiki using controlled natural language make ontology management [42]. AceWiki integrates the OWL reasoner Pellet and ensures that the ontology is always consistent. Sentences in ACE (Attempto Controlled English) can automatically be translated into first-order logic, OWL, or SWRL.

These projects have shown that people with little background on knowledge construction are able to add formal knowledge, without being instructed or trained in advance. Studying those projects, one may conclude that some Noctua's features are present in those works. However, the most important contribution (novelty) of Noctua is its capability of stimulating participants to make their knowledge explicit (the Virtual Catalyst), presented in Section 4.

The collaboration via web has also some disadvantages. Pettenati and Ranieri in [13] suggest that the distance collaboration has deep social problems related to trust and reputation of the participants. Even if a culture of the group is developed, the group would still face difficulties concerning knowledge representation and management. The difficulty of representing the group and the competence of each member as well as the lack of face-to-face contact may weaken the sense of belonging to the group and quickly lower the motivation to cooperate.

According to [14], the participation of people in communities of CKC is not, in fact, spontaneous, but driven by factors such as direct awards, gains from enhanced reputation or personal influence power, personal satisfaction with perception of them, on its effectiveness and reciprocity. To enable a participation it is necessary to create a climate of trust, a sense of community, and a perception of recognition. These authors [14] suggest a maximum effort to make visible the actions of each participant and their perceived value in the development of the collaborative process. This is what they call Social Translucence.

Novak and Wurst [15] believe that knowledge is created and reproduced through social relationships and interaction based on spontaneous participation and self-motivated choice, common goals such as shared needs and problems.

During the collaboration, conflicts of opinion among the participants are likely to happen. In order to understand this issue, we present a brief overview in the next section.

### 2.3 Negotiation and Construction of Consensus

The construction of knowledge within a collaborative process requires that all participants understand the shared knowledge representation and are able to express themselves by using it to show their agreement or disagreement with other participants and to evolve, somehow, to a consensus or a final decision [2].

A collaborative tool must have rules about how knowledge might be proposed, changed or deleted. Dieng and partners [16] described the CO4 protocol in which, when someone proposes a change in the knowledge, if there is no disagreement, the modification is performed. On the other hand, if there is any disagreement, the modification is not made. Anyone who disagrees should comment, explaining his motives. All participants are invited to comment and submit alternative proposals. The discussion ends when the rejected proposal is removed or when the disagreement is withdrawn.

According to Herrera and Fuller [17], negotiation is a key aspect in the process of CKC because it is a collaborative process and building consensus among the participants is a condition for the evolution of the knowledge within its life cycle. Those authors developed a negotiation model that encompasses some predetermined actions such as: request for explanation, suggestions for modification, and adoption of a position by vote.

Up to this point, we discussed KA/CKC systems features considering a passive tool. However, the VC that we present in Section 4 characterizes Noctua as a proactive tool. In order to act in an intelligent way, the catalyst needs to know about the participants. The semi-automatic construction of the profile of each participant and its use are discussed in the next section.

### 2.4 Construction of the Participant's Profile

According to Nabeth et al. [14], an artificial intelligent agent should be able to infer the profile of each participant based on the observation of his behaviour during collaboration. Then it should use these profiles to determine how to intervene proactively and interact differently with each participant in order to improve his participation. According to the authors, the importance of building these profiles lies in the fact that people do not adopt new attitudes immediately, but over a series of stages: awareness, interest, trial, and finally, adoption. Therefore, they propose that the intelligent agent classifies each participant as belonging to one of these stages and acts differently according to this classification.

In order to build a CKC tool, we have studied the desirable characteristics of such a tool. The next section presents the most important characteristics of a tool for CKC.

### 2.5 Building a Collaborative Tool for CKC

According to [18], a tool for CKC must have three basic characteristics: a tool for recording interviews, a discussion forum and a local memory. Noy et al. [19] presented users' reviews that compare the characteristics of several collaborative tools. They listed some desirable features, such as:

- An ease to use web interface;
- The capacity to show the reliability of each knowledge piece and each participant;
- The capacity to allow disagreements and discussions about the knowledge under construction.

Lomas et al. [20] considered the possibility of synchronous and asynchronous collaboration as well as information about the authorship to be important characteristics in a collaboration tool. Other important features cited by them are: adequate communication tools, easy-to-understand interface, voice communication, image sharing, collaborative construction of documents, social interaction and geographic information locating the participants.

Noy et al. [21] also presented some desirable characteristics of tools for collaborative development of ontologies. We think that these features would be welcomed at any CKC tool:

- Tracking the changes undergone by the knowledge during its construction and keeping all the related comments and discussions;
- Managing old versions of knowledge, with the possibility to restore them for further changes and to discard newer versions, as well as to compare two versions;
- Automatic identification of conflicting knowledge and mechanisms to resolve conflicts;

- Users with the power of mentoring, who have the final word in possible conflicts of knowledge.

  In the same work [21] the authors distinguish tools on the following criteria:

- Synchronous or asynchronous editing;
- Continuous editing or periodical archiving;
- Mentoring or not (with respect to the validation of knowledge);
- Monitoring or not (indicating the mediate or immediate acceptance of contributions).

In view of the considerations presented in this section, we have designed a system for CKC containing a Virtual Catalyst, as shown in the following section.

## 3 NOCTUA: A WEB TOOL FOR CKC

This section presents the general characteristics of Noctua (available at `http://projetos.dia.tecpar.br/noctua`). Figure 1 schematically shows the main elements that constitute Noctua. Those elements are fully described in [22]. In order to better understand Noctua's operations, we present the most important ones in the next sections.

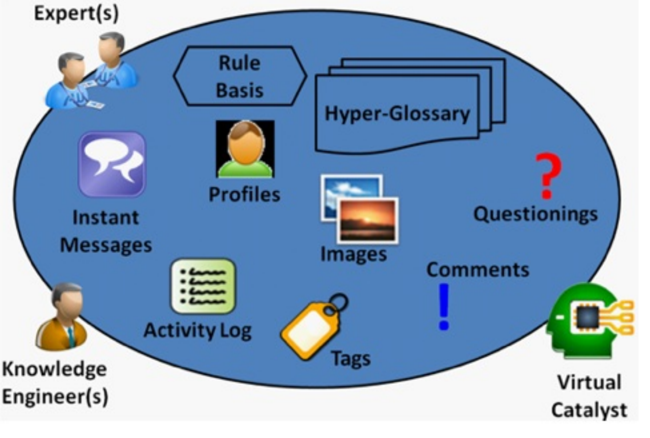


Figure 1. Noctua's main components and users

### 3.1 Noctua's Projects

Once registered, Noctua allows every user to create KA/CKC projects. Every project starts out empty. This allows participants inside each project to work in their own area of knowledge and to express themselves in their own specific way, focus, and desired depth. By default, the knowledge within each project is shared among the participants of the project, but it is invisible to other participants (users registered on Noctua). However, the knowledge in a project can be made visible to all internet users, if the owner of the project decides so.

### 3.2 Knowledge Representation in Noctua

Noctua allows the construction of two kinds of knowledge, according to a classification presented by Milton [1]:

- Conceptual Knowledge: tells what something is;
- Procedural Knowledge: tells how to do something.

Noctua represents Conceptual Knowledge using Knowledge Pages (KP), which describe the knowledge by means of natural language texts and pictures. KP for specific subjects may contain mandatory topics: if they are related to countries, they should necessarily cite, for instance, each country's name, area, official language, capital and population. In our system, users can create KP templates to be used inside a project. Supposing that the project is about books, it could have a template for books (in which necessary information are: title, authors, publisher, date, etc.) and another template for authors (containing: name, birth date, picture, etc.). Other templates could be added such as publishers and bookshops.

Procedural Knowledge is represented by Production Rules. A production rule is a two-part structure comprising an antecedent set of conditions which, if true, causes a consequent set of actions (or conclusions) to be taken [36]. In Noctua, a rule has the following format:

- if <list of conditions>
- then <list of conclusions>

If there is more than one condition, they are understood conjunctively, that is, they all have to be true for the rule to be applicable. Each condition can be positive or negative. A rule is considered applicable if there are values for all the variables in the rule so that all the antecedent conditions are satisfied by the current working memory.

Figure 3 presents a production rule in Noctua.

The design and representation of rules is still an active area of research. The reader refers to [37] for further information.

Both representations were chosen because of their similarity to natural language which allows people unfamiliar to computers easily express their knowledge, as well as understand the information expressed in those formats.

In addition, users may create entries in a hyper-glossary. Entries are attached to rules or to other entries.

### 3.3 Features of the Collaborative Tool

To meet the requirements and overcome the difficulties presented in Section 2 (especially in Subsection 2.5), Noctua allows the owner of each project to classify users according to their roles:

- **Internet users:** users that can view (but not collaborate with) the content of public projects;
- **Participants:** besides acting as Internet users, they can create, edit, delete, comment and question knowledge as well as read and send instant messages within the projects they collaborate;
- **Tutors:** besides acting as participants, tutors can admit and exclude project participants and decide on disagreements that have not reached consensus;
- **Owner:** the owner is the user who created the project. Besides acting as a tutor, the owner may admit and exclude tutors, define project characteristics (as its name, whether private or public, whether active or inactive, among others). The owner may also nominate other participants as co-owners of the project.

The tool makes a forum available to every Knowledge Page and Production Rule. In these forums (bottom of Figures 2 and 3), participants may comment and question the validity of the knowledge. A questioned knowledge (for instance, a rule that someone disagrees) becomes immediately "invalid" so the disagreements must be discussed until a change in the knowledge occurs or the question is withdrawn. If consensus is not reached, the matter may be finally resolved by a tutor.

Noctua allows all knowledge to be tagged by the participants. Tags facilitate searching and grouping concepts or rules into sub-areas of a project. Besides, collaborative tagging forms a folksonomy that reflects the participants' knowledge about the domain and can be helpful in building richer domain models in a consensual way [23].

The Social Translucence is guaranteed by several aspects in the tool, such as: the registration and the disclosure of the authorship of all knowledge pieces within a project; direct contact with other participants; and the disclosure of all project events such as creation and modification of knowledge parts, comments, tags and questions, which allow participants to follow everything that goes on in the project. It is important to highlight that any information of a project becomes public, only and if only, the owner of the project explicitly allows that (by setting up a project as public).

Each project has a common space for instant messaging. Messages are written by participants and by the tool itself. The tool reports events such as the creation, edition and deletion of entries and rules.

These characteristics make possible to put into practice many of the aspects described as desirable in a collaborative tool by the authors cited in Section 2:

**Interface:** Figure 2 shows a snapshot of a screen containing a Knowledge Page.
On the left, there is a window for instant messages which can be used by the

knowledge engineers and domain experts to perform on-line interviews that may partly replace the need for face-to-face interviews mentioned in Section 2.1. On the right, a Knowledge Page is shown, with texts and images about a certain concept. At the bottom of the screen, the comments and disagreements are shown;

**Collaboration and Interaction:** Noctua allows synchronous and asynchro-nous collaboration, offers forums and instant messaging to help participants to reach the consensus and a mentoring coordination for conflict resolution;

**Social Translucence:** the system keeps record and publishes information about the authors of every knowledge piece, and all the participants of each project;

**Reliability:** Noctua considers all non-questioned knowledge as reliable. This means that all knowledge that is under consensus is reliable;

**Automatic hyper linking:** words inside Knowledge Pages are automatically transformed into hyperlinks whenever they coincide with the names of other Knowledge Pages or equivalent words (such as plurals, synonyms, acronyms, etc.) provided by participants. Noctua also shows as hyperlinks the logical interconnections between Production Rules, in the case that a conclusion of a rule is used as condition by another rule. In doing so, Noctua integrates all the existing knowledge within a project, whether it is represented as a Production Rule, or as a Knowledge Page.

Figure 3 shows the right part of the screen with an example of a Production Rule.

Silva Jr. et al. [8] establish a set of basic functions desirable in a groupware to support collaborative ethnography. If those functions are adapted to KA or to CKC, it is possible to see that Noctua embodies all of them:

- Creating, updating and closing KA/CKC projects;
- Recording users' profiles (and actively using them);
- Assigning users to activities (projects and roles);
- Recording notes and historical data (forums and instant messages);
- Creating documents (Knowledge Pages and Rules);
- Supporting discussion and negotiation (by questioning knowledge and also in forums and instant messages);
- Supporting awareness of the level of participation and contribution (by logging the authorship of every knowledge and by showing statistics of each one's participation);
- Supporting multimedia elements (text and image);
- Supporting awareness mechanisms for both synchronous and asynchronous interaction, informing about contributions added by the members (instant messages from the system and project statistics perform this role).

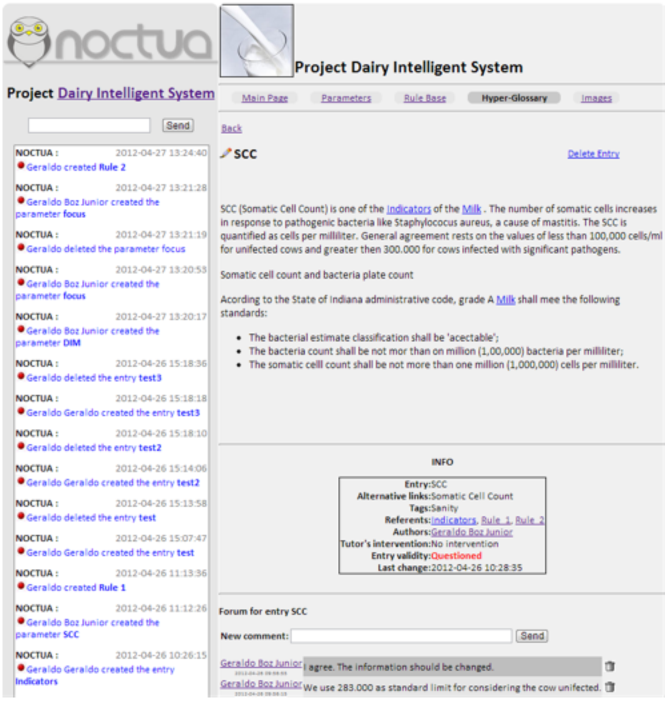


Figure 2. Instant messages and Knowledge Page

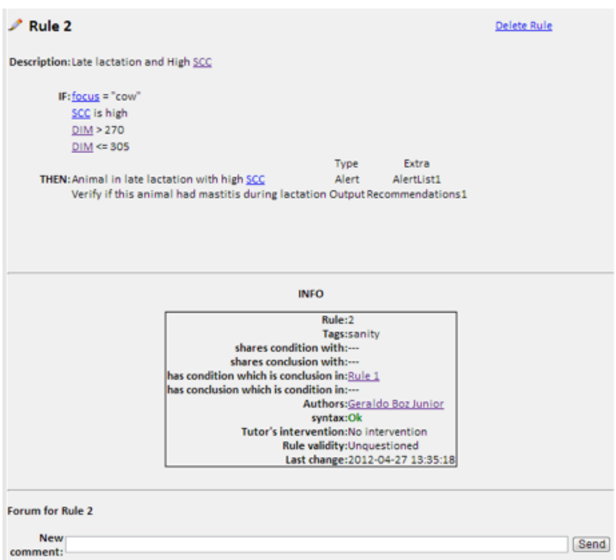


Figure 3. Production Rule

Finally, next section presents the main component of Noctua: the Virtual Catalyst.

### 3.4 The Virtual Catalyst

The Virtual Catalyst (VC) stays in touch with participants (domain experts and knowledge engineers) taking into account the knowledge pieces to which they contribute.

The catalyst's main goal is to stimulate participants to make their knowledge explicit. This is done by asking them automatically generated questions and requiring their opinions, as shown further in this paper. Acting as a newcomer among domain experts, sometimes the catalyst could ask impertinent questions, but sometimes its questions could require experts to rethink their concepts, so they may not only make their knowledge explicit, but also wider. In Section 5, we show that the VC effectively influences experts during knowledge elicitation. Figure 7 shows that 84 % of rules were created or modified by its questions.

Regarding the Knowledge Pages, the VC could suggest, for example, that the participant defines a concept, writes more about it, presents an image about the concept or establishes a connection between two concepts.

If the catalyst focuses on Production Rules, it presents to the participants new combinations of conditions and conclusions, trying to form new rules. It can also restate existing rules exactly as they are so they may be validated by participants other than those who created the rule.

The catalyst presents a screen containing a presumed knowledge (rule or some information on a concept). Such knowledge, however, can be an exact copy of a validated knowledge in the database or be a knowledge piece modified by the removal or the insertion of information related to other knowledge piece. To decrease the chances of making uninteresting questions, the catalyst seeks this information among knowledge containing the same tags as the one being changed. In fact, when applied to rules, this technique creates scenarios that can be used as described on Section 2.1.

Some of the possible forms of stimulation based on information in Knowledge Pages are shown in Table 1.

The stimulation can be based on Production Rules, as well. Rule elements can be combined in several forms to create questions to the participant. One possible combination is shown in Figure 4.

Concerning the rules, the VC may act in several ways. One of them is to show a rule to the user and ask him/her something about it. The showed rule, however, may be a valid existing rule or a tentative one, built by the catalyst by using pieces from other rules. The catalyst uses many techniques for building tentative rules:

- Take a valid rule as it is (but not mentioning this to the user);
- Take two rules, mix some of their conditions and conclusions into a new tentative rule;

| |
|---|
| Could you write something about <concept X>? |
| What the text below is related to? |
| In the entry on <concept X> it is written: <phrase A>. Do you agree with that? |
| Which of the following statements apply to <concept X>? |
| Is there a feature common to <concept X> and <concept Y>? |
| In the page about <concept X>, is it possible to make some reference to <concept Y>? |
| Is there a tag to be inserted (or deleted) on the entry <concept X>? |
| Could you send an image related to <concept X>? |
| See the image below. Is it related to <concept X> or to <concept Y>? |
| See the image below. It is related to <concept X>. Do you agree with that? |

Table 1. Excerpt of stimuli for knowledge creation

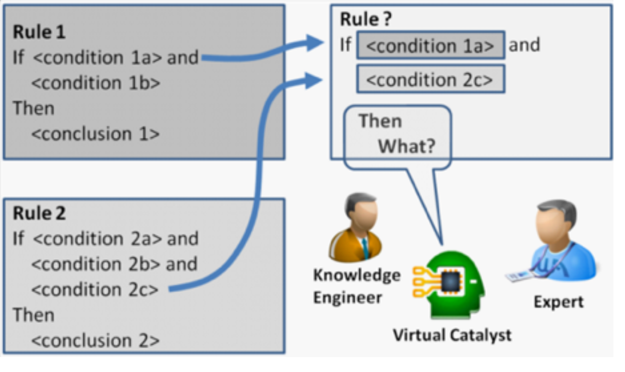


Figure 4. Trying to create a new rule

- Take a rule and delete some of its conditions;
- Take a rule and insert a condition or a conclusion from other rule.

The basic instigation question in these cases is: "See the rule below. Do you confirm it?" Depending on the answer, there are five possible ways for the catalyst to behave:

- If the user confirms an existing valid rule, then the catalyst registers the user's approving opinion;
- If the user confirms a tentative rule, then a new rule is created;

- If the user refutes an existing valid rule, then the status of the rule becomes "questioned";
- If the user refutes a tentative rule, then the catalyst shows him/her what had been eliminated or included in the tentative rule;
- If the user answers "I don't know", then the catalyst shows the answer it was waiting for and goes on to another question.

Alternatively, a tentative set of conditions may also be used to ask the participant to think forward, not only confirming or refuting what is written, but trying to find a new valid conclusion (see Figure 4). The question, in this case, is:

- What is possible to conclude if these conditions are fulfilled? (Then what?)

Asking for a new conclusion can also be done by using an established conclusion as a condition in a tentative rule. This leads to the creation of new layers of rules, i.e., rules which conditions are conclusions from other rules. The question asked in this case is:

- Ok, I know that X concludes Y. Now, what can be concluded from Y?

Additionally, if the catalyst shows the user an existing rule, other kinds of question are possible:

- See the rule below. Is it possible to insert a new conclusion in it?
- See the rule below. Do you think that any of its conclusions must be deleted? Which one?
- See the rule below. Is it necessary to insert a new condition to validate it?
- See the rule below. Is it possible to delete one of its conditions while keeping it still valid?
- Is there a tag to be inserted (or deleted) on the rule below?

Noctua invites all users to provide, in their profiles, information about their expertise and interests. This information gives the first clues to the VC on what this user may collaborate. The tool also tracks user's actions and log their collaboration such as creating new rules, new entries in the hyper-glossary, questioning the validity of a rule or even making simple comments in a forum. Additionally, the tool registers whenever users confirm or refute a knowledge piece and even when they say "I do not know". All this information is used by the VC to choose which questions to ask and which ones not to ask to each user.

To compose each question, the catalyst takes into account the users' profiles drawn up along the collaborative process. Thus, it queries each participant on subjects in which he has already shown interest or to which he has already contributed.

Figure 5 shows a situation in which the catalyst takes a conclusion from an existing rule and queries the user about the possibility of creating a new rule, using that conclusion as a condition for this new rule.

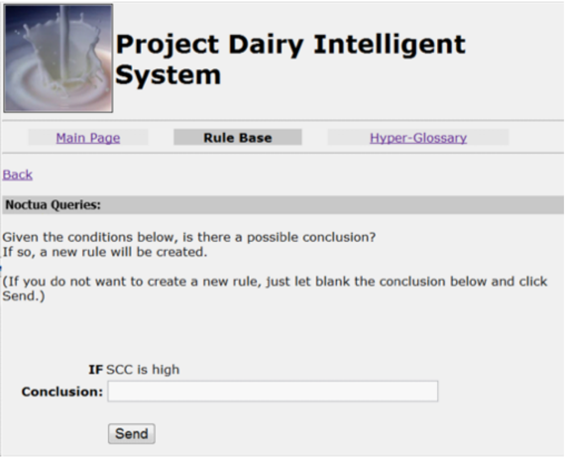


Figure 5. Noctua's Catalyst querying the user

## 4 TESTING THE TOOL

Several short-term experiments were conducted to evaluate the tool. They were performed by several groups of students from the Pontifical Catholic University of Paraná (PUCPR, Brazil) and by groups of diverse background from the Paraná Institute of Technology (TECPAR, Brazil), which has one of the most important group developing industrial intelligent systems in Brazil. They had developed many industrial Expert Systems for companies such as Petrobras, the Brazilian oil company (see [24] for details).

In order to involve a larger number of experimenters, generic themes like restaurants, hotels and movies were chosen for these experiments. Each experiment was carried out by a group of 15 to 35 people, with a large range of age and background. The idea was to create rules that could be used in an intelligent system capable of suggesting one of these sites, according to preferences and restrictions of the user.

The evaluation focused on the efficiency of the catalysis (i.e. the speed boost in the production of knowledge), in its effectiveness (i.e. the quality of the knowledge generated by the catalysis) and in how useful the experimenters perceived the tool.

In each experiment, the collaborative work lasted about two to three hours, divided into two sessions with a 15 minutes interval between them. In each session, all the experimenters used Noctua as a tool for editing knowledge, using or not the VC. At the end of the second session all participants received an evaluation form (a questionnaire) in which they could express their views and impressions about the tool, specially the VC. As reported by [25], questionnaire is present in all relevant methods published to evaluate usability [26].

### 4.1 Noctua's Usability

According to Hartson [27], the central concept in Human-Computer Interaction is usability, defined as ease of use plus usefulness. One of the initial concerns when evaluating usability is the type of measures provided by the chosen method. Dix et al. [29] describe these as quantitative or qualitative, explaining that quantitative are usually numeric based and can be easily analysed using statistical techniques. Qualitative are non-numeric and relate to user preferences and attitudes. The usability measures suggested in [34] and [28] are effectiveness, efficiency and satisfaction.

Noctua's Virtual Catalyst (VC) was considered as useful by 85 % of the experimenters, but 41 % of them also reported that sometimes the tool asked confusing questions. Although this was the only negative aspect mentioned by the users of the tool, it points to the need to keep improving the algorithm that generates the VC's questions.

Regarding satisfaction, Noctua was considered by 91 % of the experimenters a tool that facilitates the collaboration. Additionally, as it will be shown in this paper, it helped to increase the speed of the knowledge construction, so it may be considered as useful. Taking into account that most of the experimenters were using the tool for the first time and that they were taught about its operation for only 30 minutes before the experiment, Noctua may be considered as easy to use. So it is possible to say that Noctua has good usability. Moreover, it was the first version of Noctua that was tested and there is much to be done about its interface and its behavior. We are already working on a second version of it.

Many users (85 %) also cited that they perceive as important that they could collaborate at any time over the internet and (82 %) that they could use the tool to exchange instant messages.

### 4.2 The Virtual Catalyst in Action

As we mentioned, in each experiment, the collaborative work lasted about two to three hours, divided into two sessions. The results in this section refer to data taken only from those experiments in which the VC was used in one session and not used in the other.

In each experiment, the VC asked from 359 to 1449 questions to the experimenters. There were 11 types of questions that asked users to create new rules, new rule parts (as new conditions, conclusions, descriptions or tags) or asked them to offer their opinion on existing (or non-existent, tentative) rules. 35 % of these questions produced new knowledge (new rules, rule parts or opinions). The best return rate was obtained by the questions that asked user's opinion about a rule: 88 % of them produced opinions. These opinions are reviews that add reliability to those rules because they were evaluated (and approved) by people other than their authors. When the experimenters were not using the VC, they rarely looked at each other's work not even to give their opinion.

Figure 6 shows us interesting data concerning the VC effectiveness. Without the participation of the VC, 90 % of the rules were the result of solitary work (although the experimenters were side by side at their computers). As we can observe in Figure 6, when Noctua's users worked with the VC, 65 % of the rules were generated as result of two or more participants' work (41 % + 18 % + 5 % + 1 %). In those experiments, the VC transformed merely simultaneous works into real collaborative processes. We can see in Figure 6 that, without the VC, none of rules were coauthored by more than two authors. After switching on the VC, 24 % of rules were written by at least three authors.

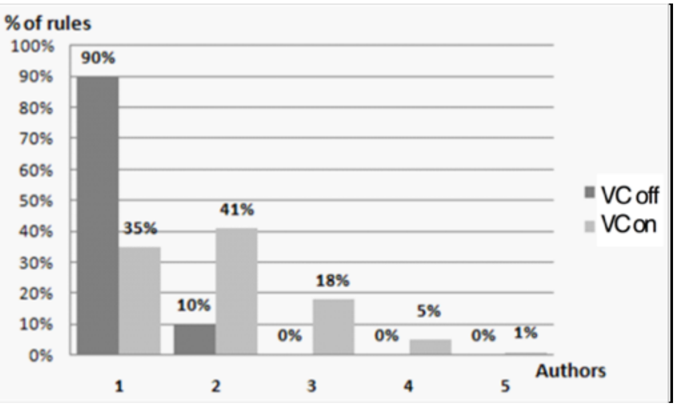


Figure 6. Quantity of users that coauthored a rule

Figure 7 shows the amount of rules containing some rule part created by the answer given by an experimenter to a question made by the VC.

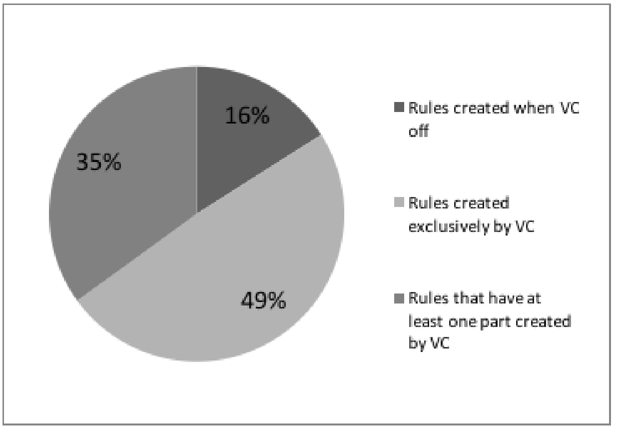


Figure 7. Rules creation: the Virtual Catalyst's participation

The VC was used only in one half of each experiment but 84 % of the rules were created or modified by its questions.

These results show that the VC played a major role in the collaborative process of each experiment.

### 4.3 The Speed Boost

The main goal of experimenting Noctua was to verify whether or not the VC is capable of speeding up the knowledge production. In order to do it, four kinds of experiments were performed:

- experiments in which the VC was not used;
- experiments using the VC all the time;
- experiments in which the VC was used only in the first session; and
- experiments in which the VC was used only in the second session.

The experiments that used the VC during all the time or did not use it at all showed similar results (Figure 8): relatively constant rate of knowledge creation along the entire experiment, disregarding the time interval between the two sessions and an initial learning curve in which the experimenters were still getting used to the tool.

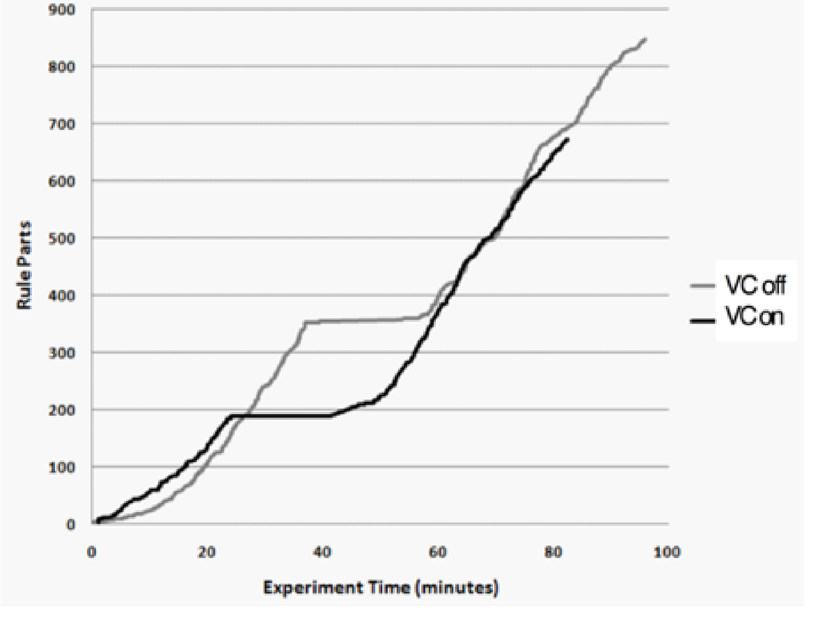


Figure 8. Rate of knowledge creation: experiments using or not the Virtual Catalist (VC)

In another experiment, experimenters used the VC during the first session and did not use it in the second session (Figure 9). The average rate of knowledge creation increased only 2 %.

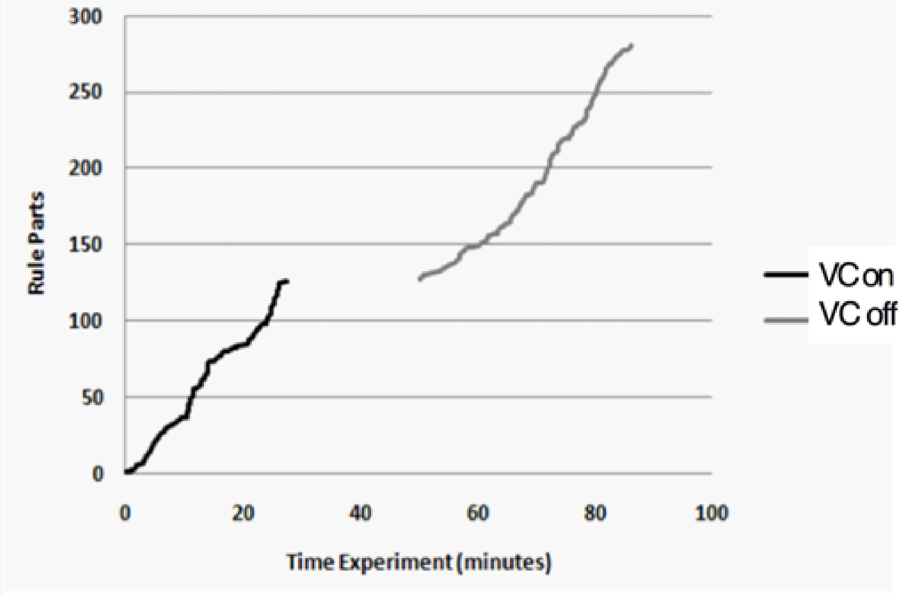


Figure 9. Experiment: first part with Virtual Catalist (VC), second part without the Virtual Catalist (VC)

Finally, there were experiments in which the users did not use the VC in the first session, and did use it during the second one (Figure 10). This case showed a significant increase (up to 144 %) in the rate of knowledge creation. It was also observed that the increase in the creation rate of rule parts was greater than the increase in the creation rate of rules. This means that the VC helped the users not only to create more rules, but those rules had more content then those created without the catalyst's help.

### 4.4 Rule Concatenation

According to Fernández et al. [30], "depth" is a parameter that indicates the quality of an ontology. In an ontology, the depth of a class is given by the amount of sequential super classes it has. Adapting this concept to a rule base, it is possible to determine the depth of a given rule by counting how many rules must be sequentially triggered in order to fire it. When the conclusion of a rule is used as a condition in another rule, this characterizes a logical concatenation of rules and this allows us to establish the level of depth of each rule. Deep rules are those which contain at least one condition that is a conclusion in another rule.

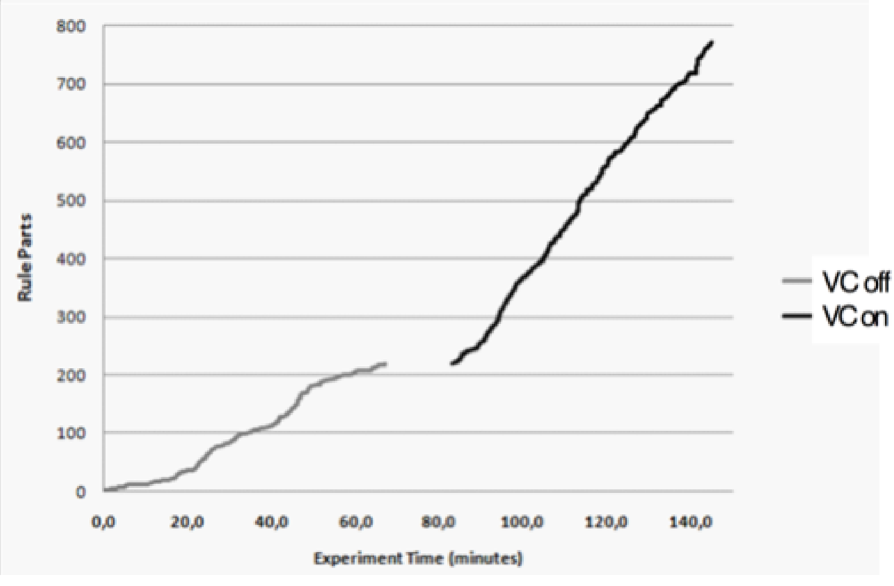


Figure 10. Experiment: first part without Virtual Catalist (VC), second part with Virtual Catalist (VC)

In the experiments performed to test Noctua, 79 % of the deep rules were created by means of questions asked by the VC. The concatenation of the rules allows us to represent them as a graph in which the nodes are rules and the edges are logical connections between them (one's conclusion is other's condition). The resulting graph for one of the experiments is shown in Figure 11. This graph was obtained by representing those logical connections in tool called Episthema [31]. With this kind of graph, it is possible to visually recognize groups of rules. The groups for this case are shown in Figure 12. Rules were clustered using their connections to each other.

Each group is associated to a restaurant, a type of food or a price range. The groups marked with dashed lines exist thanks to deep rules created by the catalyst's questions. The connections and the clusters allow establishing relations between the concepts. In this case, for instance, it is possible to identify a relation between Japanese food restaurants and Mexican food restaurants: "There are some Japanese food restaurants that also serve Chinese food. Some Chinese food restaurants have prices in the range 3, as some Mexican food restaurants".

## 5 CONCLUSIONS

This paper presents Noctua, a tool for knowledge acquisition and collaborative knowledge construction that uses Knowledge Pages and Production Rules to represent knowledge. Noctua uses the construction of glossaries, virtual interviews (by

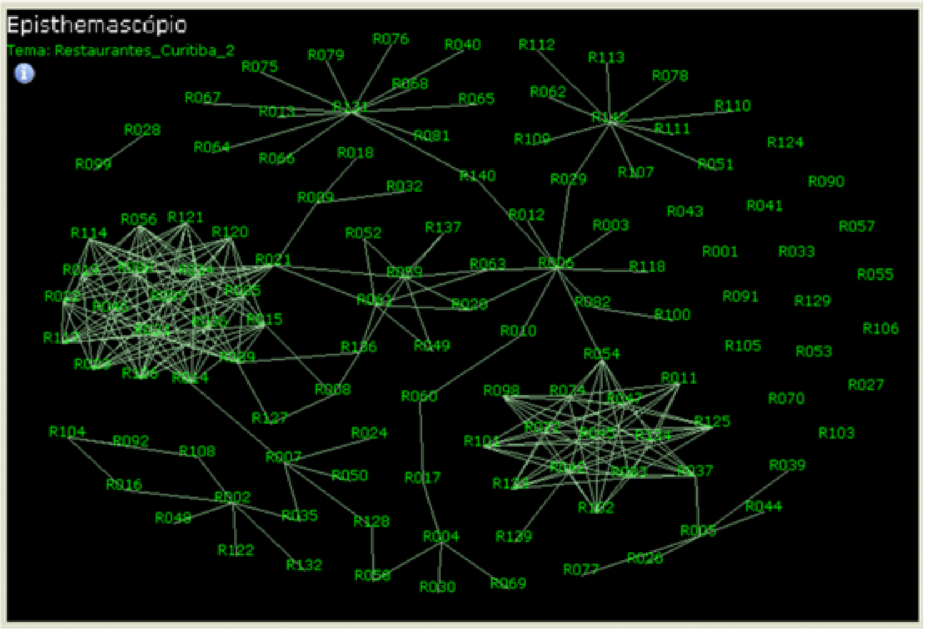


Figure 11. Logical connections between rules

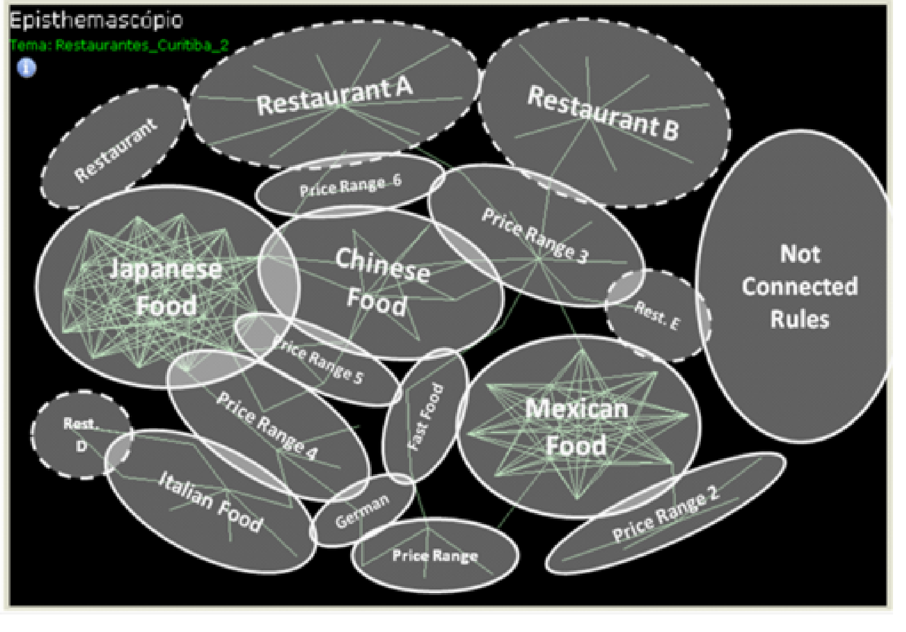


Figure 12. Groups of rules

means of instant messages) and creation of scenarios as knowledge acquisition techniques. It does not require users to have any computer programming skills. Terms inside an entry are automatically hyperlinked to other entries so the set of Knowledge Pages constitutes a hyper-glossary. Logical interconnections between Production Rules are also automatically recognized and displayed as hyperlinks. The rule base and the hyper-glossary form an integrated hyperlinked knowledge base. In order to make the collaboration more effective, Noctua also makes available forum and instant message tools as well as a feature to help opinion conflicts solving.

The very innovation, however, is the insertion of an artificial element called Virtual Catalyst in the KA and CKC processes. Regarding the Production Rules, the catalyst proposes new rules and modifications in the existing rules by means of exploring new combinations of existing rule parts. As for the Knowledge Pages, the catalysis acts in many ways such as the request for images or definitions and the attempt to associate concepts using mutual references or common characteristics. In both cases (rules and entries), the catalyst also helps the knowledge validation by asking each participant his opinion about what was posted by others.

The insertion of the Virtual Catalyst in the KA/CKC intended to make these processes more effective, favouring the production of knowledge.

The results of the experiments showed that this primary goal was reached: the VC boosted the knowledge creation rate especially when it was used after a previous non-catalysed session with Noctua. In this situation, the observed speed boost varied in a range from 50 % to 150 %. In other situations, such as using only the catalyst, for example, there was no significant change in the rate of knowledge creation.

The VC was effective in its participation in the knowledge construction process. The overall balance shows that 49 % of the rules were created by its questions and 84 % of the rules have at least one element inserted by the VC.

Some unexpected positive results were also obtained: the VC helped improve the quality of the rule base when it induced the creation of deep rules, i.e. rules containing conditions that are conclusions in other rules. In some experiments 100 % of the deep rules were created by questions asked by the VC.

The VC improved the collaboration itself. Without the VC, the experimenters did not really collaborate with each other. They were all working in the same subject, in the same room or connected by the internet, but each one was focused in his own job. As a result, 90 % of the rules with no interference of the VC have only one author and no rule has more than two authors. On the other hand, 65 % of the rules amended by the VC have two or more authors. In some experiments, there were catalysed rules with up to seven authors. In addition, 63 % of opinions confirming or refuting rules were obtained by questions asked by the VC. Therefore, the VC helped not only increase the quality of the rule base but also its reliability.

Finally, 91 % of Noctua's experimenters considered that it made the process easier and 85 % found its questions helpful to create knowledge.

Therefore, Noctua and its Virtual Catalyst allowed the participants to increase the rate of knowledge creation, the effectiveness of the collaboration, the quality and the reliability of the elicited knowledge.

## 6 FUTURE WORK

In the near future, several possibilities will be explored:

- The algorithm that generates the questions could be improved, implementing new types of questions, avoiding repetitions and, depending on the situation, quitting the random questioning and adopting predetermined sequences of questions that allow users to follow a more intuitive line of reasoning;
- With regard to the logical-syntactical validation of the rules, future work could develop several warnings related to rule loops, to similar or repeated rules, to disconnected rules, and unused input variables, for instance. Additionally, there could be an automatic recognition of rule groups and tags that could be attached to them;
- As the collaboration evolves, to evaluate each participant in order to identify levels of confidence related to each one could help the VC to organize knowledge to produce new rules; Providing Noctua by an inference engine would allow domain experts to immediately test the rules they produced;
- Aesthetic and functional improvements in Noctua's interface, such as ubiquitous use of JavaScript features, in order to facilitate the editing, and graphical representation of knowledge. According to Hartson [27], graphical representations of large volumes of data help make sense of its meaning;
- Further incentives to collaboration, such as e-mail messages informing the author of a rule that it was altered or refuted, and integration with social network platforms that allows people to "follow" or to "like" a Noctua project.

These new features should be encapsulated in a mobile application which could lead to an even more effective collaboration. Alvarez et al. [33] describe a collaborative process performed by means of mobile devices with an application that allows asynchronous offline collaborative work. If this feature is added to Noctua, it could lead to an even more effective collaboration, because experts could give their contributions at anytime from anywhere.

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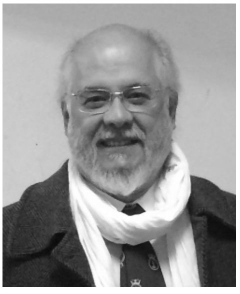

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