Towards a Visualisation Process for Ontology-Based Conceptual Modelling

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Abstract. *Visualisation of models by means of graphical representations plays a critical role in ontology development and maintenance. Tools are essential in understanding models and generating explicit, better usable and communicable knowledge. In this respect, we introduce a knowledge visualisation process for the integration of visual representations, logic-based reasoning and metamodelling for interoperability of languages. The intention behind this work is to offer a trade-off between these dimensions in the context of a semantics-aware tool. We provide means to stimulate interest in such tools for designing both conceptual models and ontologies based on the effectiveness of graphical modelling languages for expressing them.*

1. Introduction

Visualisation of models by means of graphical representations in CASE tools plays an essential role by enabling users to understand models, relate their concepts and generate explicit, better usable and communicable knowledge. Usually, graphical notations are based on EER [Gogolla 1994], UML [Booch et al. 2005] or ORM [Halpin and Morgan 2008], which in turn promote usability of tools and interoperability of models. Moreover, visualisations help humans in the cognitive process in order to make better decisions. In this respect, a computer-supported visualisation process undertakes the challenge of transforming data into insights, where data is any symbol or fact not yet interpreted and insights ranging from findings and summaries to patterns, relationships, comparison and anomalies, among others. However, diagrams can lead to great insights or consequences, but also to lack of them that can be hidden to users in complex diagrams, causing inconsistencies or anomalies. Hence, to equip CASE tools with capabilities to automatically explore, compose and check models would be highly desirable. This can be achieved through formal systems that admit decidable reasoning and allow application domains to be represented with. Thus, a visualisation process in a CASE tool is essential for conceptual modelling and coordinating the reasoning on the graphical models.

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There exists a subtle difference between the concepts of information visualisation [Ware 2004, Card et al. 1999, Andrews et al. 2011, Chen and Golan 2015] and knowledge visualisation. Both focus on enabling visual reasoning, however, knowledge visualisation is more sophisticated since "examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons" [Burkhard 2005], which in turn it is tightly related to the typical usage of conceptual models [Embley and Thalheim 2011]. With regard to this issue, Burkhard proposes an abstract model based on the usage of visualisations to integrate new knowledge into recipients' knowledge according to their backgrounds. The aim is to analyse and define the effect of providing visual representations, what is relevant to be visualised, the most efficient ways to do it, their audience and the recipients' interests. On the other hand, visualisations are also key in social interpretations that define the pragmatic quality of conceptual models . In spite of the fact that many quality frameworks exist [Moody 2005], Krogstie et.al. [Krogstie and Solvberg 2000] specifically highlight the effects of participants on domains modelling, where this kind of quality is analysed in depth by relating social and technical interpretations to models. Pragmatic quality concerns the effects of choosing from among possible ways to express a single meaning.

As a consequence, we claim that a knowledge visualisation process for ontology-based conceptual modelling is needed in a tool. Such a process focuses on the following main objectives. First, the integration of visual representations and logic-based reasoning capabilities, which is still incipient in state-of-the-art environments and whose formalisation has been already defined in our previous work [Braun et al. 2015]. Second, the definition of what is relevant to be and how should be visualised. Lastly, the usage of graphical representations as a source to evaluate the quality of models and their correspondence with the domain under modelling. Concretely, in this paper, we propose a schematic view and initial baselines of a knowledge visualisation process to be implemented into a tool by splitting its components in data, conceptual and logical levels and explaining how the parts of this process interact. Currently, we are developing a tool supporting this process [Gimenez et al. 2016], in addition to a methodology for ontology evolution with pattern-based extension rules [Braun et al. 2015, Braun and Cecchi 2015] and an ontology-based metamodel [Fillottrani and Keet 2016].

This work is structured as follows. Section 2 explains the motivation of this work and some preliminary concepts. Section 3 presents related works focusing on existing visualisation processes and the graphical-logical integration in state-of-the-art tools. Section 4 details our knowledge visualisation process, which is discussed in section 5. Finally, we conclude and sketch future directions in section 6.

2. Motivation and Context

Conceptual modelling can be considered as a cognitive activity, which is related to the process of knowing, understanding and learning conceptual models. Persons who interact by means of cognitive systems are able to comprehend huge amounts of data since humans are gifted with a flexible pattern finder coupled with a decision-making mechanism [Ware 2004]. In this context, visualisation has a crucial role helping to perceive properties and patterns that have not previously captured. Moreover, it allows to identify problems about data and focus our attention on the domain being modelled, decreasing the cognitive load of users. Quality aspects in conceptual modelling should be also considered because of

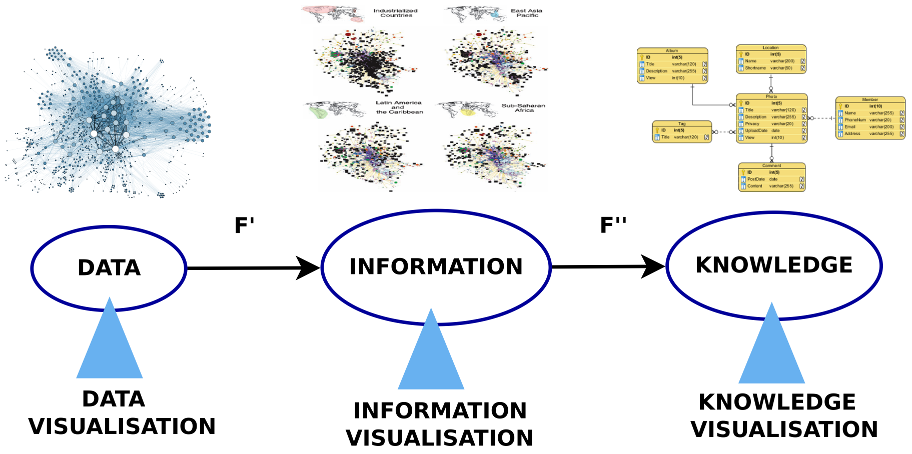

Figure 1. Viewpoints about visualisations. F' and F'' represent any transformations between data, information and knowledge.

their effect on the end product. Evaluations of the correspondence between a real domain and its conceptual model is based on social and technical interpretations, which in turn define the pragmatic quality [Siau and Tan 2005, Krogstie and Solvberg 2000]. Therefore, the human cognition plays a central role in the quality of models and visualisation is an effective manner to improve it by reducing the cognitive effort to interpret them.

According to Card [Card et al. 1999], visualisation is "the use of computer-supported, interactive, visual representation of data to amplify cognition". Consequently, visualisation is key to obtain "good" conceptual models [Moody 2006], for which we must consider "good" visual notations [Moody 2009] and their proper semantics [Harel and Rumpe 2004]. Moreover, it allows to comprehend large amount of data, perceive properties not anticipated and errors, and facilitate hypothesis. In this context, data consists of isolated and not interpreted symbols and facts, while becoming information when is interpreted and processed, assigning meaning to data. Knowledge is more sophisticated since it is information "cognitively processed and integrated into an existing human knowledge structure" [Keller and Tergan 2005]. From now on, it is possible to distinguish among visualisation levels [Masud et al. 2010], as schematised in Fig. 1. Data and information levels are very close since they refer to use graphical representations to provide visual insights in sets of data abstracted in some schematic form. Nevertheless, information visualisation is restricted to a computer-supported way [Card et al. 1999, Ware 2004]. Unlike the previous ones, knowledge visualisation uses visual representations to transfer, create and share knowledge.

A formal representation of a domain conceptualisation can be done by means of ontologies in order to evaluate concrete representations of the world, in terms of a specific conceptual modelling language [Guizzardi 2005] and its capabilities for decidable automated reasoning, if any [Calvanese et al. 1998]. As a result, ontology-based conceptual modelling is essential to define high quality models decreasing time and costs, and assisting users in design and maintenance tasks. In spite of this, non-deterministic and preferences-oriented characteristics of modelling processes make it difficult to put formal systems and graphical representations together into methodologies for modelling activities in a tool. In turn, tools are desirable to help modellers with the design of realistic applications based on the fact that this "semantics-aware" approach is boosting some DB technology vendors, such as Oracle Inc., to empower their existing software with ontological reasoning [Horrocks 2011]. However, some criteria for avoiding "graphical redundancies" in visualisation of new explicit or implicit constraints due to reasoning should be also considered. Such criteria should take into account the impact of the visual representation of diagrams on users' ability to understand them without leading to more-complex models [Burton-Jones et al. 2012].

3. Related Works: Visualisation Processes and Tools

Along this work, we have surveyed visualisation processes or models from these dimensions: data, information and knowledge. Firstly, processes proposed in [Ware 2004, Card et al. 1999, Andrews et al. 2011] are classified as information visualisation ones. Ware's iterative process defines four stages and feedback loops, consisting of data collection from social and physical environments, its transformation into something understandable, graphics algorithms that produce an image and the human cognitive system. Data transformation concept is also kept in [Card et al. 1999]. However, this last one includes an additional mapping from data into a relation description of it together with a view transformation, whose aim is to create new views of visual structures by specifying graphical parameters. Lastly, the process presented in [Andrews et al. 2011] is also based on [Card et al. 1999], but defines a more specific visual mapping function F with these properties: computable, invertible, communicable and cognisable. All of these approaches agree on users' interaction with each steps in the process to modify resulting visualisations. Most widely, Chen et.al. [Chen and Golan 2015] analyse processes from different viewpoints. Initially, they define two spaces, perceptual and cognitive, and computational, in order to differentiate data from information and knowledge in these both spaces. A typical process provides a similar concept of data transformation and users' interactions as means to control these transformations. Secondly, an additional supporting pipeline is added to display input data after processing them, based on the hypothesis that both the amount of data and the visualisation techniques are growing. In a third approach, visualisation is assisted by knowledge, where experts' knowledge about domains or techniques is used, in addition to reasoning, to control the original pipeline and interactions of users. Finally, the last approach from van Wijk [van Wijk 2005] proposes a theoretical point of view to define what a good visualisation is. His objective is to examine the value of visualisations in terms of how much knowledge is increased, but no novel model has been introduced.

On the other hand, we have also analysed state-of-the-art tools by considering their capabilities to visualise models and their alignment with the concept of integrating graphical models with logic-based reasoning. Many tools for conceptual modelling exist, but we will only consider ICOM [Fillottrani et al. 2012], OntoUML [Guizzardi and Wagner 2012], NORMA [Curland and Halpin 2010] and Hozo [Kozaki et al. 2002]. Although ICOM is currently deprecated, its underlying methodology is closer to ours. It allows users to design multiple ontologies in EER or UML and is fully integrated with a very powerful Description Logics (DL) [Baader et al. 2003] reasoning server, which acts as an inference engine. ICOM reasons with (multiple) diagrams by encoding them in a single DL KB and showing graphically results of any deduction. The tool displays models by showing/hiding attributes in classes and associations, roles names and constraints. It also allows arranging diagrams in the screen, but without supporting automatic layout. Zooming is also provided. Secondly, OntoUML is a pattern-based and ontologically well-founded version of UML, whose meta-model has been designed in compliance with the ontological distinctions of a well-grounded theory, named Unified Foundational Ontology (UFO). Currently, OntoUML is supported by Menthor Editor[1], which provides a simple and integrated set of features such as syntactical verification, visual simulation, model checking, model inference, automatic semantic-anti-patterns detection and correction, validation of parthood relations and ontology patterns. Particularly, logic-based validations are supported by Alloy [Jackson 2002], allowing simulations on specifications for checking consistency. However, its integration with the graphical language is missing. OntoUML editor includes zooming and capabilities to align models and show/hide attributes of elements. Lastly, NORMA (Natural ORM Architect) supports the fact-oriented modelling (ORM) language and provides greater expressive power and semantic stability than those tools provided with EER or UML. Validation of models is partially tackled by automated verbalisation and live-error checking, both of which supply efficient feedback to modellers. Recently, though, an interface for external reasoning has been developed to discover inconsistencies, redundancies and derivation rules [Sportelli 2016]. NORMA offers drag and drop, zoom and related features, but other ones as automatic layout are missing. Alternatively, users can align objects by dragging the mouse to select them, then align these shapes from a layout toolbar. Finally, considering tools for ontology design, the well-known Protégé [Knublauch et al. 2004] also integrates graphical aspects with reasoning, but it is partially restricted to consistency checking and new IsA relationships. This is implemented into plug-ins such as OWLViz[2], while is missing in OntoGraf[3]. Similarly, Hozo is an environment for building and using ontologies based on a theory of role-concept, contributing to building reusable ontologies. The tool is composed of an Ontology Editor with a graphical interface for browsing and modifying ontologies; an Ontology Server to manage them; and an Onto-Studio interface for helping users to design an ontology from technical documents through a built-in methodology.

4. A Knowledge Visualisation Process for Ontology-Based Conceptual Modelling

Aimed at putting the theory into practice, we have adapted both visualisation processes proposed by Ware and by Burkhard integrating them into a new knowledge visualisation process for graphical ontology-based conceptual modelling. We also have incorporated a theoretical framework for enabling a "back and forth" graphical-logical transformation process (a.k.a. graphical-logical mapping) and an ontology-driven metamodel to interoperability of languages. All of these parts interact through, and are to be implemented into, a graphical tool. Before explaining our process in depth, we introduce the knowledge visualisation process definition in the context of this work.

Definition 1 *A* knowledge visualisation process for ontology-based conceptual modelling *is a computer-supported transformation of ontological facts, possibly extracted from data, into insights by means of a graphical-logical mapping, in order to capture knowledge from real domains; understand it by discovering relationships, patterns, anomalies and explanations; and communicate it among users.*

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[1] `http://www.menthor.net/`

[2] `http://protegewiki.stanford.edu/wiki/OWLViz`

[3] `http://protegewiki.stanford.edu/wiki/OntoGraf`

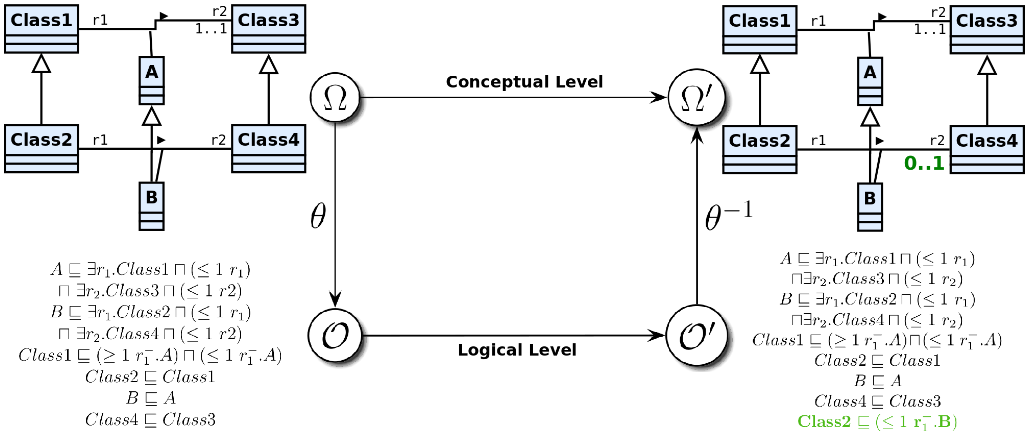

Figure 2. Graphical-Logical Mapping schematic view. Ω and Ω' are consistent diagrams iff $\mathcal{O}$ and $\mathcal{O}'$ are also consistent ontologies in a target logic [Berardi et al. 2005]. In this scheme, new constraints inferred from logic-based reasoning, are highlighted.

Our visualisation process is a computational and iterative loop for converting domain facts or insights into a visual form that users can interact with. The first step is to describe these facts as a conceptual model in a well-defined modelling graphical language. The second step, the core of this process, is to map visual forms into a logical artefact (a.k.a. ontology), and vice versa, enabling decidable reasoning procedures for checking models. The third step involves to display visual models together with reasoning results associated to them in the graphical language itself. Finally, closing the visualisation loop, the resulting diagrams are interpreted by users, who are thus assisted along the modelling process generating new insights. Additionally, users can manipulate models by interacting with visual representations and explore different ways to encode a graphical language, although this last capability is restricted to logic-skilled users.

The mapping at the second step is the core of our process, and is schematically depicted in Fig. 2. Its aim is to coordinate different ways to encode graphical primitives of a language into a decidable logical formalism [Braun et al. 2015]. Formally, we have identified a set of graphical elements independent of any language and introduced a mapping function θ. This function is defined as the union of the logical representations that encode each graphical element. Therefore, Ω is a *consistent graphical model* if $\mathcal{O}$ is a consistent ontology generated through θ in a target logic. Likewise, Ω' is a new consistent graphical model if the ontology $\mathcal{O}'$ is also consistent. From Ω and Ω', and their respective underlying ontologies $\mathcal{O}$ and $\mathcal{O}'$ through θ and θ^{-1}, we define the integration of the graphical support with reasoning by rendering reasoning results in the same visual notation. At conceptual level, this mapping closes the diagram, however, its validation requires establishing a correspondence between the graphical models. Lastly, we do not intend to formalise a new encoding to conceptual modelling languages such as [Berardi et al. 2005], but we introduce a complementary formalisation to coordinate them in the context of a graphical-centric tool.

4.1. Knowledge Visualisation Process Diagrammatic View

As depicted in Fig. 3, our visualisation process is split into data, conceptual and logical levels. Data level includes ontological facts, possibly extracted from data, related

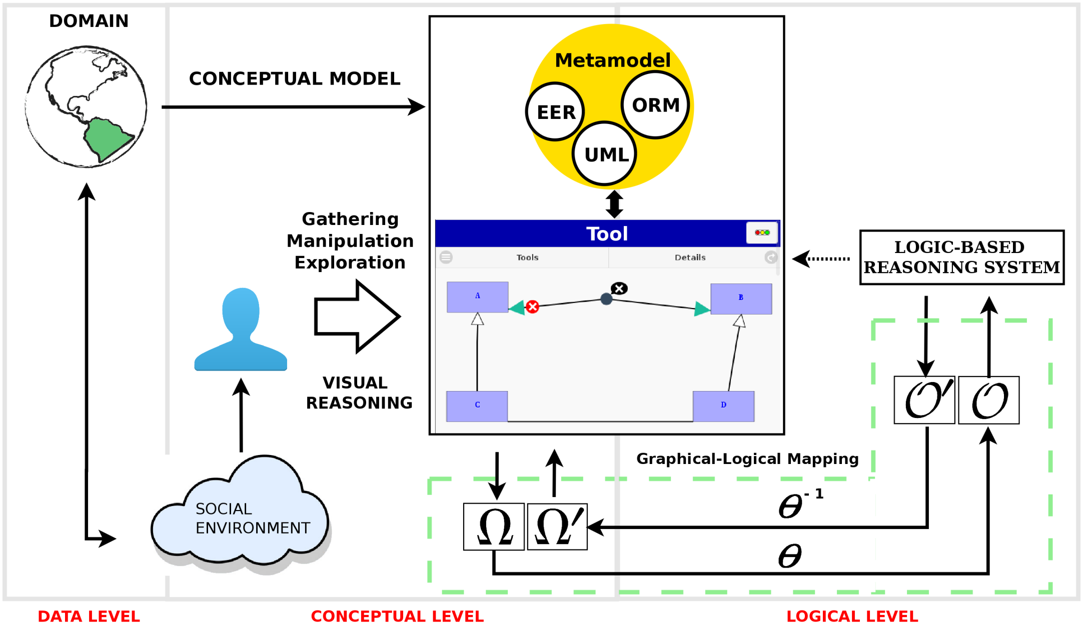

Figure 3. Knowledge Visualisation Process diagrammatic view.

to domains to be represented in a conceptual model, which are also affected by users' interpretations about reality, represented as social environment. Conceptual level involves users in concept gathering and exploration of different logic-based formalisations to encode diagrams. Moreover, this level concerns the manipulation of visual models by a graphic engine. Finally, the logical level includes the graphical-logical mapping providing a formal support for and guiding the modelling process. We will analyse each part of this process in turn.

Firstly, **gathering** involves users to collect and represent domain aspects in a graphical syntax, where the social environment plays a key role in this loop since it determines what is to be collected and how to interpret it. Interaction with reasoning systems helps in exploring, composing, and checking models by making explicit to users its overall semantics, which in turn is another source of concept gathering. This should be done by the graphical-logical mapping together with an off-the-shelf reasoner that can be then queried about diagrams properties. Similarly, the definition of textual knowledge in ontologies also allows to represent more expressive features of ontology languages, but some readability is lost. Secondly, **manipulation** considers visual handling by a set of graphical interface options in a tool. Our criterion is based on the cognitive effort measured in time and involved in each navigation technique ranging from minimal effort such as object fixation and saccadic eye movement to medium effort as hypertext and queries and high effort, which includes zooming, walking and flying techniques. This classification has been proposed in [Ware 2004]. Another feature as automatic layout is responsible for automatic arrangement of graph elements by computing certain rules in such a way that a clear and aesthetically pleasing result is achieved. On the same hand, brushing allows information to be revealed on some data dimension by making a continuous mouse movement and taking about few seconds. No less important, we will also provide interoperability of graphical languages validated by a metamodel to enable different views of the same model. Lastly, **exploration** enables to define or choose new algorithms to encoding features of other conceptual and object-oriented data models. Consequently, since expressiveness could be increased, new ways of reasoning could be supported as well. However, although this is unfriendly for users not skilled in logic, it will be considered in the visualisation process.

To use EER diagrams for databases, UML for application layer and ORM for other business aspects is a typical scenario in the context of information systems. However, users' preferences for certain languages over others and the increasingly complexity of systems require a mechanism to unify the back-end in a tool showing linkable conceptual modelling languages in its interface. Based on this hypothesis, an ontology-driven metamodel has been designed and formalised in [Fillottrani and Keet 2016] to enable different domains views by means of logic-based reconstructions and inter-model assertions. Currently, its specification unifies UML v2.4.1, EER and ORM2. As a result of this formalisation, a conceptual model for a domain is defined as a graphical instance of the ontology-based metamodel in the **Tool**. This tool orchestrates each part of this process by providing a user-oriented graphical interface. Its aim is to allow users to design diagrams adopting standard conceptual modelling languages. To this end, it employs complete logical reasoning to verify model satisfiability, infer implicit constraints, suggest new ones and assist users in modelling process. Moreover, since it is based on a deduction-complete notion relative to diagrams graphical syntax, users will visualise original models graphically completed together with all deductions expressed in the graphical language itself. The leverage of automated reasoning is enabled by a precise definition of each visual diagrams element, which are internally translated into a logical formalism, capturing typical features of conceptual models. Therefore, the underlying **ontology** obtained from the current graphical model admits decidable reasoning procedures to detect relevant formal properties of the diagram. This interaction between both conceptual and logical levels is coordinated by the **graphical-logical mapping**, which is independent of any graphical modelling language and any logic-based formal system for encoding models. As a consequence, the use of graphical languages, their properties and the relationships derived from logical inference enable the visual reasoning. The result is a high bandwidth channel from the tool to the user by means of the visual display with interactions as part of a methodology for producing cognitively efficient designs.

5. Discussion

The main motivation of this work is to bridge the gap between end-users, domain experts, their understanding about domains and graphical modelling tools. The objective is to satisfy communication and reusability challenges, theorising and implementing a knowledge visualisation process for ontology-based conceptual modelling. This process will give visual representations of models expressed in a standard conceptual modelling language, allowing users to improve their models and in turn the final product quality. Visualisation will permit to introduce quality aspects for establishing the semantic correspondence between domains and conceptual models, the syntactic one between models and languages and the impact of social interpretations from users about the real world. Its aim is to discuss the visual syntax of a language and its semantics at the same level. Moreover, to identify "graphical redundancies" and logic-based automated design tasks, which can help in obtaining effective diagrams in an interactive tool. In this way, we intend to stimulate interest in these ”semantics-aware” technologies to be considered as tools for researchers and companies.

To answer questions such as *how to pick the suitable visual representation for a diagram?* is hard from a strictly formal point of view since not only involve to analyse syntax and semantics of visual languages, but also the cognitive effectiveness [Moody 2006], in addition to quality aspects [Krogstie and Solvberg 2000]. Even supposing that we have already tackled these issues, a limit between the size of models and the tool capabilities to visualise them requires to consider another dimension in this analysis. Consequently, a visualisation process coordinating a trade-off between these dimensions, is imperative. In this direction, we should take three of the principles for producing effective diagrams [Moody 2006]: discriminability, manageable complexity and graphic simplicity. All of them are tightly related to the size of the models from different perspectives. The size of diagram elements and their proximity impacts in both perceptual and cognitive limits decreasing the abilities to discriminate between elements. Finally, according to some studies, humans can discriminate between around six categories of graphical conventions, which is exceeded by UML, but can be solved by increasing the number of visual variables with others than shape [Lohse et al. 1995].

Existing graphical-centric tools such as OntoUML and ICOM are equipped with reasoning systems, but in both the integration with the graphical syntax is limited regarding the visual representation of reasoning results. In particular, OntoUML addresses this limitation by identifying anti-patterns derived from the ontological analysis of UML. This allows to disambiguate models converging on a clear understanding of them. Visual reasoning is also inherently enabled since OntoUML is a graphical-centric tool. Users edit their diagrams interactively through its graphic engine. However, the underlying visualisation process remains incomplete because of the lack of integration visual with reasoning. In contrast, ICOM does render the reasoning results in its own graphical notation, which is a quality aspect and a manner of gathering knowledge about implicit constraints. Indeed, this feature is quite powerful due to reasoning on multiples diagrams. Typical tasks of modelling are graphically provided by ICOM together with an user-friendly interface to manipulate diagrams. More expressive descriptions of concepts can be also authored in a textual manner, but they are visualised as a single primitive. Although this allows to increase expressiveness, this capability makes reasoning results difficult to understand. ICOM does close the visualisation loop, but it has been deprecated together with its complementary technologies, DIG protocol and the graphic engine. NORMA is also equipped with a powerful graphic engine, verbalisation of models and live-error checking, enabling visual reasoning and gathering of new constraints. Thus, its visualisation process is partially completed considering the recently developed DL-based inference engine. Finally, Hozo focuses on visual aspects helping to bridge the gap between ontologies and domain experts, but without considering reasoning as part of its process. One of the main contribution of Hozo is to manipulate ontologies by generating conceptual maps for exploring them from different viewpoints.

To sum up, none of the surveyed tools completely implement a knowledge visualisation process because generally the integration of diagrams with reasoning is limited. Actually, no graphical-logical mapping has been previously formalised in the context of a graphical environment. Moreover, they do not consider quality aspects either making more relevant the objectives of our process. Hence, a knowledge visualisation process to take advantage from cognitive systems is highly desirable in any modelling tool. In this respect, the evaluation of our process is ongoing and to this end, we are developing the modelling tool schematised in Fig. 3. Its name is **crowd** [Gimenez et al. 2016] and is being jointly supported by both Universidad Nacional del Comahue and Universidad Nacional del Sur of Argentina. This tool follows the baselines specified in the previous section and currently, a not yet public prototype version runs on a client-server architecture. It also supports OWLlink [Liebig et al. 2011] communication and satisfiability checking on simple UML diagrams encoded in $\mathcal{ALCQI}$ DL [Berardi et al. 2005]. Both **crowd** and the whole knowledge visualisation process will be evaluated by applying a quality framework and laboratory experimentation with industrial-scale diagrams.

6. Conclusions and Future Works

In this work, we have introduced the concept of, and schematised, a knowledge visualisation process for ontology-driven conceptual modelling, whose objective is to provide effective visual models with a well-defined semantics to generate insights and communicate them to involved end users. We have also described the interaction between its main components by highlighting the integration of visual representations with a graphical-logical mapping into a tool as well as quality aspects and metamodelling. The intention is to formalise baselines to be followed by a ”semantics-aware” tool and thus assist users in conceptual modelling and ontology editing. In this respect, we are developing our own tool, named **crowd**. In the future, we plan to extend the visualisation process to cover more quality aspects and usability aspects, and release the first beta version of our tool. We will evaluate the usage of visualisations as a step towards guaranteeing the quality of the model designed using the tool.

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