

Model-driven Elicitation of Ontology Pragmatics for Evolving Critical System

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ABSTRACT

Evolving Critical Systems such as HAZOP use knowledge that may evolve thus putting pressure to update continuously. This work proposes novel ontology meta-model to drive elicitation. The assumption used is that pragmatic ontology design supports evolution. The problem is lack of method that produces pragmatic ontology of standard expectation. Both model and technique are evaluated qualitatively using theoretical analysis. The result shows promising use in development of a knowledge-based system with pragmatics character.

Keywords: ontology engineering, pragmatics web, knowledge elicitation, model-driven systems, evolving critical system.

I INTRODUCTION

Industry 4.0 has growing requirements for virtualization of processes (Yang, Duan, Shah, & Chen, 2014; Zanni - Merk, 2016). One such systems is the Evolving Critical System (ECS). ECS is a category of software-intensive systems that change over time without risk (of failure or loss of quality) in environments that demand flexibility (Hinchey & Coyle, 2010).

An example ECS is HAZOP diagnostic in petrochemical plant. It is critical because of its strategic importance. The input streams need almost real-time detection of hazard and operability issues (Huo, Mukherjee, Shu, Chen, & Zhou, 2016).

A good knowledge-base can support the issue by itself evolving to the need of the environment (Gotttroy, 2003; Hinchey & Coyle, 2010; Pattuelli, Provo, & Thorsen, 2015). Addressing the challenge of evolving knowledge construction will make knowledge-driven system more common in the future. (Corcho, Poveda-Villalón, & Gómez-Pérez, 2015; Pattuelli et al., 2015; Rautenberg, Ermilov, Marx, & Auer, 2016)

Specifically, ontology pragmatics has been identified as an area of research to construct effective ontology for task-based challenges. Ontology developed using pragmatics dimension is slimmer yet claimed to be highly utilized (Teitsma, Sandberg, Schreiber, Wielinga, & Hage, 2014).

Ontology has two dimensions, i.e. semantics and pragmatics. Whereas semantics are descriptive knowledge, pragmatics are knowledge about task and context surrounding the task.

Constructing ontology that is pragmatic is a new but growing area of study. Pragmatics elicits for minimal but necessary knowledge from the environment to complete critical tasks such as integration. Very few papers cover pragmatics aspect of ontology (Casanovas, Rodríguez-Doncel, & González-Conejero, 2016). This is probably due to lack of general acceptance of what pragmatics' definition. As the consequence, there is inavailability of effective elicitation methodology.

This work summarizes the definition of pragmatics in ontology and proposes elicitation method for pragmatics. The final goal is to produce knowledge-driven effective integration of knowledge extracted from the environment.

II STATE-OF-THE-ART

Various works have asserted the benefits of ontology as the starting point for development or as foundation of systems for semantics and integration (Dodani, 1996; Wyssusek & Klaus, 2005; Yun-hui & Run-liu, 2013).

A. Evolving Critical System

Evolving Critical System (ECS) are typically software-intensive systems that change over time. Its essential feature lies in evolving without risk (of failure or loss of quality). However, Hinchey and Coyle had asked a pressing question, "which processes, techniques and tools are most cost-effective for designing and implementing an ECS". (Hinchey & Coyle, 2010).

Kasabov (2003) presented Evolving Connectionist System (ECOS) framework which allows data mining to use context provided by ontology to integrate evolving context, information and data. The approach uses a class of constructive neural networks that learn via structural growth and adaptation (Kasabov, 2007).

B. Knowledge-based System

The current trend of system development is incorporating soft computing in system design using knowledge to improve accuracy of knowledge tasks (Teitsma et al., 2014). The knowledge component

contains domain facts, rules and procedures, which collectively provides specific expertise needed by the software system.

Ontology plays a key role in evolving knowledge. The output quality of knowledge-based task becomes feedback for learning. Ontology becomes both reasoning and storage artifact to preserve the new knowledge learnt (Garcia, Gomez-Romero, Patricio, Molina, & Rogova, 2011; Pattuelli et al., 2015; Tom Heath, 2011).

Several works proposed ontology to facilitate integration. Sanya & Shehab 2014 proposed modular architectural ontology design that resolves the complex relationship between organisation strategy, processes and technology in an engineering design (Sanya & Shehab, 2014). Casanovas et al 2016 proposed pragmatics as formal representation of user needs and context to facilitate automated collective management of knowledge (Casanovas et al., 2016).

C. Knowledge Elicitation

A challenge in knowledge management is capturing the right knowledge for the purpose of the system (Hooi, Hassan, Abrik, & Shariff, 2016; Yang et al., 2014) (Sottara, Correale, et al., 2014). The process of acquiring knowledge is summarized in Figure 1.

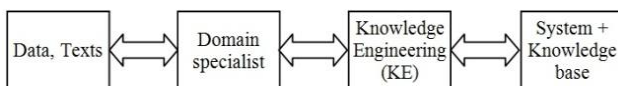


Figure 1. Knowledge Acquisition Process (Smith, 1985)

Generally, knowledge engineers can build different ontology versions of the same body of knowledge as long as they satisfy predefined quality criterion (Brank, 2005). This is often evaluated by checking if a system can rely on the ontology to answer domain-related questions (Gawich, Badr, Hegazy, & Ismail, 2012; Mariam Gawichh). Competency questions are user-oriented interrogation. The answer should be easily determined by browsing through the ontology. (Chungoora, 2016)

D. Pragmatics as Consideration in Knowledge Elicitation

Knowledge base is typically designed for high reusability, typically as an upper ontology and domain ontology (Noy, McGuinness, & Hayes, 2005). Whilst this may serve well for interoperability through shared generalization, these ontology types often do not hold sufficient details for usability in software applications.

On the other hand, expert systems are typically very detailed but lacking generalization. Thus, reusability is limited due to narrow scope of knowledge define.

This creates a knowledge gap that requires intermediary ontology to close the gap, see Figure 2. A few researches have proposed pragmatics ontology (Sottara, Bragaglia, Pulcini, Mello, & Luccarini, 2014) (Dufresne, Leonard, & Gerace, 2014). Semantics alone is not sufficient to overcome the shortcomings (Novoa, 2013).

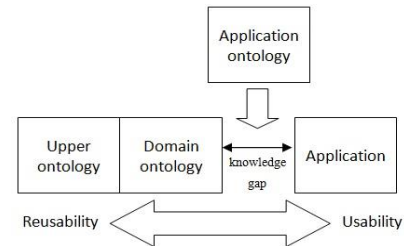


Figure 2. Bridging Ontology And Application.

E. Defining Pragmatics

The notion of pragmatic was mentioned by Gruninger (Gruninger, Bodenreider, Olken, Obrst, & Yim, 2008) and elaborated by Giboin (Giboin, Denis, & Snoeck, 2011). Ever since, various works have defined pragmatics in the context of systems designed. A general trait is that pragmatics is semantics with intended use and contextual dependency (Mazak & Wally, 2014). Bechara and Ven (Bechara & Ven, 2007) described pragmatics as emphasis of specific task-based knowledge to guide actions successfully.

The ramification of this definition is reducing scope of knowledge to actable knowledge. Captured concept or idea must have meaning with practical consequences. (Goldkuhl, 2004)

III METHODOLOGY

Systematic evaluation using perspective-based reading are carried out on cited papers in the field of ontology engineering. to identify best practices in knowledge engineering as the design principles. A model is built based on the principles. An elicitation technique is proposed from the experience. This is done by merging software engineering techniques with unique considerations derived from the model.

A. Establishing Principles of Pragmatics Elicitation

Elicitation's principles is drafted using similiarity between knowledge elicitation and requirement elicitation. This allows best practices and learning from software engineering to be applied in knowledge engineering. The principles are derived by observing the differences between requirement and knowledge, and coming up with propositions to tackle unique issues. For example, the lifespan of requirement is longer than knowledge. Knowledge may be extended or evolve to include new knowledge driven by changes in the environment.

This study proposes the following principles for pragmatics elicitation, based on rationals given in Table 1: -

- a. *Principle 1 (P1)*: Scope of elicitation should be driven by pragmatics. Ontology is limited to only essential concepts needed for completion of a task or a set of tasks at present. These concepts are either actionable or triggering actions.
- b. *Principle 2 (P2)*: Elicitation should consider future reusability. New concepts should be mapped to existing concepts at lowest granularity possible. New concepts should be made by composed by existing concepts.
- c. *Principle 3 (P3)*: Ontology engineering is iterative. An ontology is drafted, refined and let to evolve. Elicitation of a new ontology is done by developer. The following evolutionary elicitation should be automatic.
- d. *Principle 4 (P4)*: Elicitation should consider both structure and reasoning of ontology to ensure compatibility.
- e. *Principle 5 (P5)*: Ontology engineering should be compatible with software engineering.

Table 1 summarizes corresponding epistemology of each principles outlined above:

Table 1. Rational of Proposed Pragmatic Principles

	Rationales	Reference
P1	Pragmatic design improves knowledge utilization by providing criteria to identify useful concepts. The trend is towards slimmer ontology.	(Casanovas et al., 2016; Hooi et al., 2016; Mazak & Wally, 2014)
P2	Reusability is a well-established requirement. The challenge is to manage the balance between usability and reusability.	(Harmelen, 2011)
P3	Knowledge requirement needs to be done throughout organization's lifespan because it is expected to evolve with changes in the environment. Revision is iterative.	(Balaf, 2003; Smith, 1985)
P4	Ontology pragmatic requires reasoning of the ontology structure.	(Fritzsche et al., 2016; Meilicke, Stuckenschmidt, & Tamilin, 2016)
P5	The phases in ontology engineering are noted to be coherent with software engineering in order to allow both to be developed in sync.	(Orbst, 2011)

B. The Pragmatics Concept in Linked Data

Pragmatics ontology is a specification of what, why and how a new piece of knowledge should be treated. This is done by providing description of key events for analysis in process flow. This includes specification of triggers which change object states or prompt user action.

The output of the proposed pragmatics elicitation results in a Linked Data (LD). LD, regardless of

application (diagnostic, predictive and prescriptive) or domain, functions by linking data among processes. This can be implemented as mapping of data to knowledge.

A knowledge-based architecture relies on a generic reasoner to find, evaluate and generate links between data and concepts. This requires translating the problem, environment events and processing rules into ontology. In semantics, this would be in ontology that represents description of entity and hierarchy of its relationship with other entities.

This study suggests a novel representation in the form of causal arguments. The reasoner will then be able to link the causal arguments representing processes. See Figure 3, processes are now seen as causal chains. Linking related arguments from different chains at process level forms a new chain or graph of arguments as outputs. The output is a generated path or graph that can be analyzed for a specific application goal.

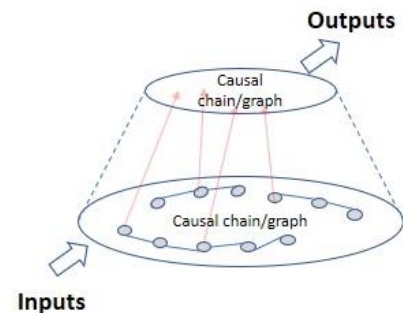


Figure 3. Automatic Connection Of Processes

C. Ontology Design Pattern for Pragmatics

Ontology Design Pattern (ODP) is a collection of ready-made modelling solutions for creating and maintaining ontologies. This work introduces a novel category of ODP suitable as foundation of causal linking in KBS. Labelled as pragmatic ODP (p-ODP), its structure and behaviour are based on pragmatic principles. See Figure 4.

p-ODP is expected to guide ontology development (by developer) and to update ontology automatically thereafter. p-ODP is designed for eliciting knowledge tuples needed for integration to form process flow.

In p-ODP design, Event entity is used as a proxy of role. Event contains properties for role analysis, context and mapping. A role is a duplet composed of an event and a predicate. As an a priori role, the event changes entity state. As a posteriori role, the event is triggered by an entity to generate action (query, update, recommend, link, delink)

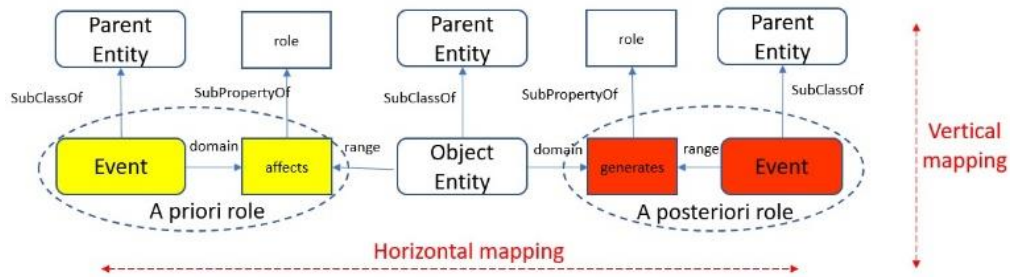


Figure 4. The Proposed Graph Representation of p-ODP

D. Methodology to Acquire Proposed Elicitation Technique

Conventionally, elicitation begins by seeking a motivation scenario and competency questions from a domain expert in interviews. Then, further knowledge is gathered based on the competency questions. Analysis establishes the concepts and relationship. The result is an ontology.

A good ontology should be able to provide concepts that sufficiently answer the competency questions. However, competency questions are subjective. As such, the resulting ontology may not be of consistent quality. This makes automatic ontology construction difficult because lack of systemization. Furthermore, it is hard to assure that the ontology is of pragmatics quality.

Thus, a more structured metamodel-oriented elicitation methodology is proposed, see Figure 5. This works claim that this approach provides systemization of elicitation and ensuring pragmatics by design, which can be measured by higher utilization of captured concepts in the ontology.

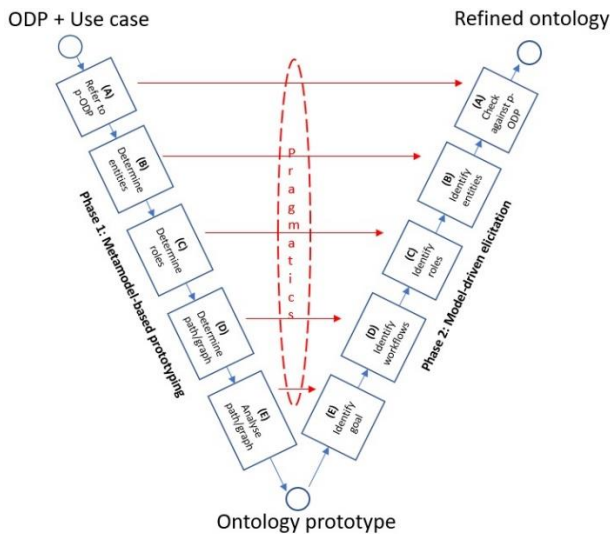


Figure 5. V-model Of Pragmatics Elicitation

The V-model of elicitation is based on proposed p-ODP structure. Using this structure requires knowledge engineer to identifying and organize

concepts and relations in certain structure. The proposed structure is a tuple of affecting_event/entity/generating_event. The generated_event can be mapped with affecting_event of another tuple. This is in phase 1 of the V-model.

In phase 2, the generated ontology is used to elicit knowledge from the environment, i.e. workflows. Ontology provides conceptualization of the workflows for analysis. The concepts and relations in ontology can be used to solicit knowledge from the environment.

Note that the steps in phase 1 and phase 2 mirror each other. The details of each step in phase 1 is elaborated in Table II.

Table 2. Steps in Phase 1 Metamodel-based Prototyping

Step	Description
(A)	Refer to p-ODP. It will be used as a checklist when analyzing a motivational scenario prior to structured interview.
(B)	Determine entities – identify entities associated with the motivational scenario. Prioritize according to level of activity.
(C)	Determine roles – For each entity, determine both a priori and a posteriori roles. The a priori role is any action received from other entities or environments. The a posteriori role is any action it generates on itself or environment. Identify the change of states a role cause, or if it solicits information or advocate any recommendation. Each role is identifiable by event. Each event alters the state of a resource it is providing custodian to. Determine if context attributes such as time and place are necessary. Identify the default values. Unknown values are flagged for elicitation.
(D)	Link roles to form path and graph based on role relationship.
(E)	Analyse path/graph – Determine if the path or graph generated make any sense. Compare it against the motivational scenario's use case goal and desired stucture and behaviour.

IV RESULT AND DISCUSSION

A. Proposed Pragmatics Elicitation Technique

The proposed pragmatic elicitation is derived from theoretical reverse engineering of the knowledge prototype. It is theoretical because the prototype is

worked out as a design on paper (or by using software tool).

Theoretical design involves speculative thinking. This work has identified ideas (as p-ODP) and formally reasons the predictions of generated ontology from it.

An advantage of identifying the elicitation contents early through prototyping allows for acquisition of a more detailed knowledge early in system design. The reason the proposed elicitation technique is presented as a template instead of specific questions has its merit. It allows higher degree of flexibility for choice of elicitation methods: -

- Interviews were conducted with domain experts to acquire the big picture of strategic knowledge requirements. Pragmatics elicitation guides a more consistent and structured collection. Because some knowledge is collected upfront, experts can be solicited for validation of recommended competency questions.
- To gather more details, a questionnaire form can be distributed to more targeted audience. The pragmatic elicitation provides useful concepts and terminology that can be validated in the form.

Proposed phase 2 model-driven pragmatics elicitation in Figure 5 is further elaborated in Figure 6.

<ol style="list-style-type: none"> 1. Analyse a use case to search for actors and functions. 2. Acquire workflow, competency questions and answer samples from expert actor for the functions. 3. For each workflow: <ol style="list-style-type: none"> 3.1. Identify key steps in workflows. 3.2. Identify events. 3.3. For each event: <ol style="list-style-type: none"> a. Identify entities and state of entities. b. Associate with roles that trigger processing. c. Maps event to entity states and vice-versa. <ul style="list-style-type: none"> • Link Event -> predicate -> entities. • Link Entities -> predicate -> event 4. Identify taxonomy of each entity for classification and ontology enrichment.
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Figure 6. Pragmatics Elicitation Template

The proposed pragmatics elicitation can also be implemented in query agent for continuous revision of the knowledge base throughout its life. This is in tandem with pragmatic elicitation's potential use in Evolving Critical System. A reason why elicitation should be iterative throughout the lifespan of a system is to allow the system to extend its lifespan by picking up new knowledge required for its future tasks, thus an evolving system. Another reason why continuous elicitation may be beneficial is continuous refinement and elimination of errors that may be introduced during development.

B. Evaluation of the Model

The proposed pragmatics elicitation methodology is novel in idea as well as implementation. As such, the methodology is also presented as a result in this work, see Figure 5. The V-model of pragmatics elicitation involves two phases that mirror each other by pragmatics principles discussed earlier.

We have evaluated the elicitation against a set of principles. Achieving the principles are used as yardstick of success. Table 3 relates how the steps in the proposed elicitation technique satisfies pragmatic principles. Recall Table 1 in how these principles are established and justified.

The proposed elicitation is recommended for ontology that is shallow and horizontal. Ontology for workflows and processes would be suitable. Furthermore, the use of p-ODP as basis of elicitation would allow high-level abstraction of elicitation. This allows this technique to be used for different domains. Example ECS domains are electrical safety reviews, process safety reviews and manufacturing line operations.

A limitation of this elicitation is it is not suitable for taxonomy or hierarchical ontologies.

Table 3. Evaluation Against Pragmatic Principles

Pragmatics principles	How does the V-model fulfill Pragmatic Principles?
P1	Met. Uses p-ODP which outlines the generic concepts useful for connecting concepts and relations.
P2	Met. Meta-ontology p-ODP ensures standard abstraction of all linked concepts in the ontology design. It ensures the elicitation captures the required information to achieve the goal.
P3	Met. The V-model generates elicitation template that can be implemented by agents as part of the system's learning.
P4	Met. Meta-ontology p-ODP is designed with structure that is implementable and precessable by reasoners of both RDF and OWL.
P5	Met. The elicitation template guides competency questions that can be made part of the general software requirement elicitation.

C. Future Work

Although ongoing work has successfully produced ontologies based on the proposed pragmatic elicitation p-ODP, methodology and templates, the result would be more convincing by supporting it with empirical result. Future work will publish the quantitative analysis on the effectiveness and feasibility.

V CONCLUSION

This work proposes novel pragmatic ontology design pattern and elicitation technique to support Linked Data (LD) with pragmatic ontology model for systems that require knowledge-base that evolves. The work places a claim that emphasis on

pragmatics design in ontology will allow LD application form better connections dynamically. This contributes to ECS whereby an agent can continuously elicit knowledge to revise or extend the Linked Data knowledge-base. Proposed p-ODP and elicitation helps development of ontology with consistent pragmatics. The work has also introduced a novel elicitation methodology that uses reverse engineering approach of p-ODP prototype.

The work has produced theoretical basis and arguments of validity. Empirical analysis of ontology qualities in meeting pragmatics expectation will be future works.

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