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A rule-based knowledge system on semantic web for collaboration moderator services

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The success of a virtual organisation's (VO) operations is vitally dependent on interoperability and close collaboration between allied organisations and enterprises. This paper proposes a semantic web rule-based knowledge system applied to collaboration moderator service (CMS) to enable semantic integration of heterogeneous data for the moderation of shared knowledge among cooperative VOs. The proposed approach also shows how the new generation of the CMS supports collaborative working by: enhancing interoperability across different enterprise information systems, monitoring the activities of partners within the collaboration to identify opportunities for enhanced collaboration and raising awareness of potential misunderstandings or conflicts between partner strategies or decisions. Therefore, the semantic knowledge systems of CMS can function on a platform that supports interoperability and collaborative activities within VOs. A case study is conducted to illustrate the feasibility of the proposed model and the test results confirm its suitability.

Keywords: collaboration moderator service; knowledge based systems; semantic web rule language (SWRL); Java expert system shell (JESS)

1. Introduction

The global financial tsunami since the third quarter of 2008 has had a drastic impact, with many enterprises experiencing a deep plunge in their sales revenues, though signs of a modest recovery were beginning to show late in 2009. The global economy is subject to cyclical peaks, and the agility paradigm and the agile virtual enterprises/virtual organisations (VEs/VOs) concepts have been seen as a practicable corporate strategy in this turbulent marketplace. However, the successes of a VO's operations are vitally dependent on interoperability and close collaboration between allied organisations and enterprises. Furthermore, in any teamwork activity, communication and moderation have become key issues in enhancing the efficiency of virtual organisational co-operation. This paper proposes a semantic web rule-based knowledge system applied to collaboration moderator service (CMS) to enable semantic integration of heterogeneous data for the moderation of shared knowledge among co-operative VOs. The proposed approach also shows how the new generation of the CMS supports collaborative working by: enhancing interoperability across different enterprise information systems, monitoring the activities of partners within the collaboration to identify opportunities for enhanced collaboration and raising awareness of potential misunderstandings or conflicts between partner strategies or decisions. Therefore, the semantic knowledge systems of CMS can function on a platform that supports interoperability and collaborative activities within VOs.

CMS is an evolution from earlier moderator systems and represents a new generation of moderator concepts to support VOs. Moderator technologies which consist of specialist software systems to support collaborative working by raising awareness of the priorities and requirements of other contributors, have been previously reported in the MOSES research project (MOSES 1992–1995, Harding *et al*. 1996) and the Mission project (MISSION 1998–2001, Harding *et al*. 2003). The CMS are one of several proposed Interoperability Service Utilities (ISUs) currently being researched as part of the European (SYNERGY 2008–2011) project. The overall aim of SYNERGY is to provide enhanced support for networked enterprises (which are likely to be small and medium enterprises, SMEs) in the successful, timely creation of, and participation in, collaborative VOs. CMS can function on a platform to support the VO in the SYNERGY integrated system (Popplewell *et al*. 2008). Figure 1 shows the CMS along with other services attached to an ISU service platform. CMS will utilise the functionalities provided by other services like Partner Knowledge Management Services (PKMS), in order to execute its own functionalities.

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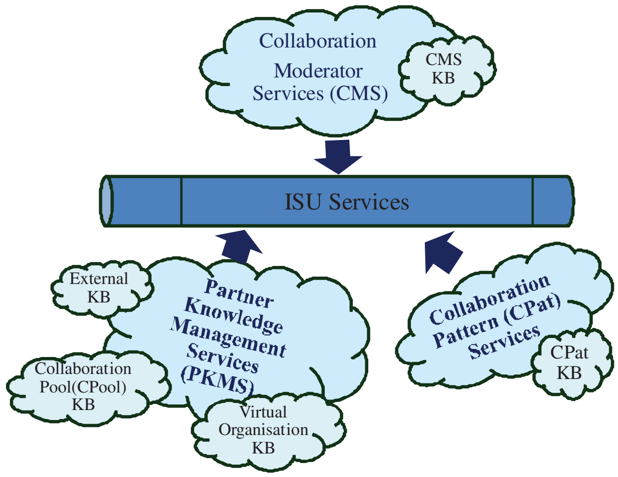


Figure 1. SYNERGY ISU service platform.

For example, when the CMS is required to acquire knowledge about a potential partner and how the moderation activities for the potential partner need to be carried out, it may utilise some of the existing knowledge about the partner. Such knowledge may have been collected by other services like the registry within PKMS. This re-use, rather than duplication of information, helps to ensure that there is a consistency in the information.

The basic functionality of the CMS can be exploited in many ways providing various services as follows:

- Raising awareness of a potential business opportunity to users.
- Alerting users of a short-fall of competencies that are required to avail the business opportunity.
- Raising awareness if other users/partners are available, with complementary or equivalent competencies, to participate in exploiting the business opportunity.
- Monitoring an active project and alerting changes to objects of interest to the project partners who might be affected by those changes.
- Raising awareness of lessons learnt, etc.

2. Knowledge- and rule-based representation of knowledge-based systems

Knowledge-based systems are systems founded on the methods and techniques of artificial intelligence (AI) or expert system (ES). According to definitions provided by the AI/ES professionals (Genesereth and Fikes 1992, Walker *et al*. 1987, Hangos *et al*. 2001, Giarratano and Riley 2004), the basic components of the knowledge-based systems include user interface, knowledge base and inference engine, as illustrated in Figure 2.

There are two different types of user interface in knowledge-based systems. The most commonly used is the 'end-user user interface' which connects users and supplies facts ('facts' are data, observations, examples, prototypes, actions or statements to describe a particular object; Hangos *et al*. 2001) or other information into the knowledge base through the inference engine, receives expert advice for problem solving or expertise in response. The other is the 'developer's interface', which is designed to work directly with the meta-knowledge of the structure and content of the knowledge base where the facts are stored. Genesereth and Fikes (1992) pointed out that the importance of meta-knowledge justifies its inclusion within a knowledge model that provides a structured representation of the content and of a learning environment.

Some AI professionals (Walker *et al*. 1987, Randall *et al*. 1993) think it would be best to represent knowledge in the same way that it is represented in human language, or to represent knowledge in the form of the human mind. Various artificial languages have been proposed for representing knowledge to structure information, these include frame languages, first-order logic, or description logics (DL). They are typically based on logic and formal language and usually fall into the domain of ontologies.

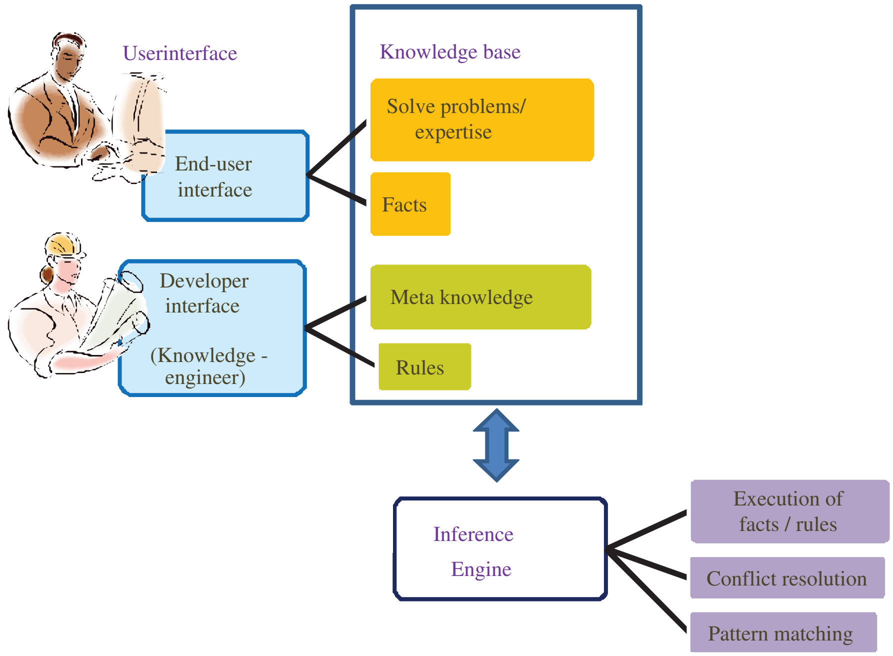


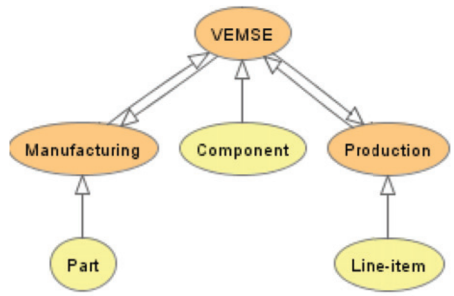
Figure 2. The structure of the knowledge-base system.

Gruber (1993) states that an ontology refers to a formal specification of a conceptualisation. In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members). Swartout *et al.* (1997) related ontology to knowledge bases by defining ontology as a hierarchically structured set of terms for describing a domain that can be used as a skeletal foundation. Specifically ontology engineering involves the production of a domain model with taxonomic hierarchies of classes.

In the electronic document world, several researchers (Lassila *et al.* 2000, McGuinness and van Harmelen 2004) have used languages to represent instantiated ontologies and to structure collections of data and sets of inference rules for semantic browsers on the web. The World Wide Web Consortium (http://www.w3.org/2001/ sw/) have been involved in the development of semantic web standards built upon XML syntax to provide a mechanism for exchanging data over the Internet using semantic web standard languages, such as resource description framework (RDF), RDF schema (RDF-S), and web ontology language (OWL). RDF and RDF-S allows users to define concept taxonomy and some simple relations. OWL facilitates greater machine interpretability of Web content than that supported by XML, RDF, and RDF-S by providing additional vocabulary along with a formal semantics. For example, OWL provides built-in ontology mapping support, whereby, a particular class or property in one ontology can be the same as a class or property in another ontology. With OWL it is possible to state that two classes are the same (owl:sameClassAs), equivalent (owl: equivalentClass) or disjoint (owl: disjoint With). Figure 3 shows, for example, the concept that a *Manufacturing: Part* has the same meaning as the concept *Production: Line-item*. These two different identifiers exist within different models, but have the same meaning. They can therefore both be mapped to another equivalent class in a third agreed ontology, shown here as the Component class in the agreed *VEMSE: Component* ontology.

However, Matheus *et al.* (2005) illustrated that OWL does not have sufficient capability to fully represent complex knowledge. For example, there is no way in OWL to define the relationship of 'uncleOf (X, Y)' which requires knowing that X is male, X is a brother of Z, and Y is a child of Z. This 'joining' of relations is outside of the representational power of OWL. One way to represent knowledge requiring joins of this sort is through the use of the implication (→) and conjunction (AND) operators found in rule-based languages. Then the rule for the uncleOf relationship appears as follows:

$$\text{brotherOf}(X, Z)\ \text{AND}\ \text{childOf}(Y, Z) \rightarrow \text{uncleOf}(X, Y).$$




```
<owl:Ontology rdf:about=“”/>
<owl:Class rdf:ID=“Component”>
<rdfs:subClassOf rdf:resource=“#VEMSE”/>
</owl:Class>
<owl:Class rdf:ID=“Part”>
<rdfs:subClassOf>
<owl:Class rdf:ID=“Manufacturing”/>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID=“Line-item”>
<rdfs:subClassOf>
<owl:Class rdf:ID=“Production”/>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about=“#Manufacturing”>
<owl:equivalentClass   rdf:resource=“#VEMSE”/>
</owl:Class>
<owl:Class rdf:about=“#Production”>
< owl:equivalentClass  rdf:resource=“#VEMSE”/>
</owl:Class>
<owl:Class rdf:ID=“VEMSE”>
<owl:equivalentClass  >
<owl:Class rdf:resource=“#Manufacturing”/>
<owl:Class rdf:resource=“#Production”/>
</owl:equivalentClass  >
</owl:Class>
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```

Figure 3. OWL mapping into the common ontology model (VEMSE).

The integration of OWL knowledge representation and semantic web rule-based representation has been an active area of research (Matheus *et al*. 2005, O'Connor *et al*. 2005a). The research reported in this paper relates to the development of the knowledge systems for the CMS. In a fully functional CMS, the knowledge base must contain knowledge about individual partners in the VO (i.e. SME_Partner) including their capabilities and items of interest. CMS must be able to reason about these and for this purpose the semantic web rule language has been selected.

In the semantic web community the semantic web rule language (SWRL), provides a Horn clause rules extension to OWL that overcomes many OWL limitations, and this has been used for integrating OWL and rules. SWRL is the standard rule language of the semantic web and provides the ability to write Horn-like rules expressed in terms of OWL concepts to reason about OWL individuals. However, O'Connor *et al*. (2005b) point out that the SWRL specification does not impose restrictions on how reasoning should be performed with SWRL rules. Initially SWRL had no inference capabilities and required rule engines to reason with the SWRL rules stored in an OWL knowledge base. They therefore integrated the JESS rule engines to perform inference with SWRL rules. In our research, the same approach as O'Connor *et al*. (2005b), is adopted to investigate the use of SWRL to develop complex knowledge population (KP) and knowledge acquisition (KA) structures for the CMS applications and implement a JESS-based reasoner for analysis of the CMS knowledge.

3. The knowledge systems of CMS

A particular objective of CMS is to promote intelligent knowledge sharing and collaboration between partners within VOs. This is necessary to increase mutual understanding and awareness between partners and minimise the

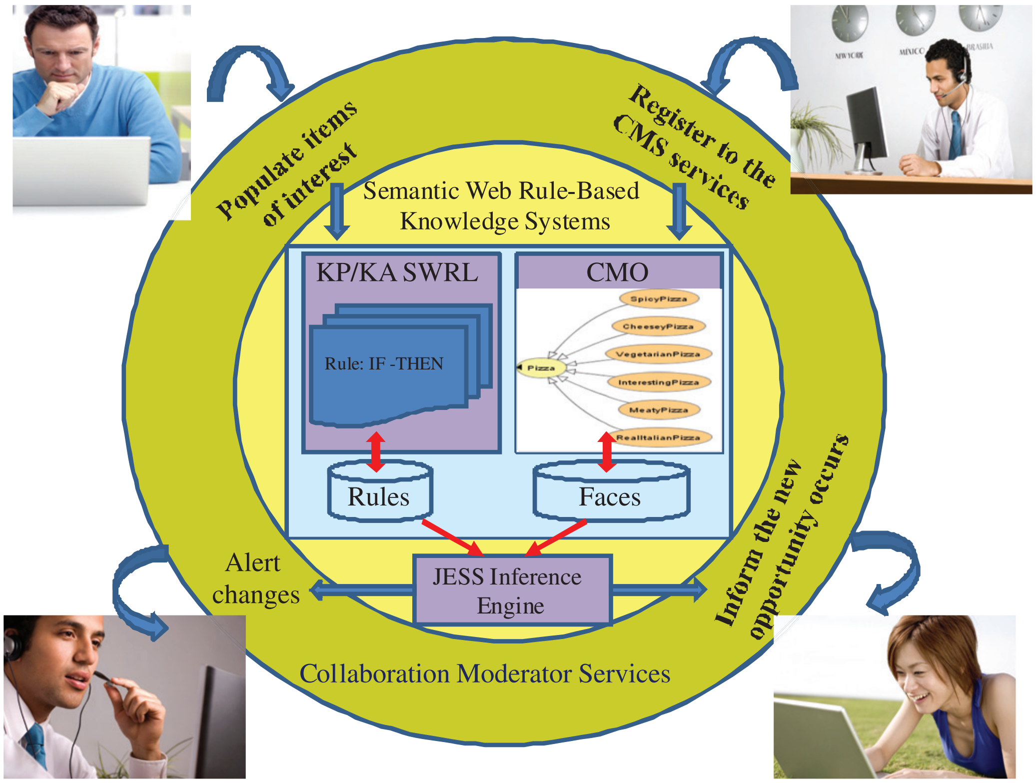

Figure 4. The system framework for Collaboration Moderator Services (CMS).

risks of detrimental impact to the VO of misunderstandings in decisions made by individual partners within the VO. The CMS therefore has quite a complex role within a SYNERGY service platform and the proposed architecture of CMS consists of several types of interacting module which each have different functions ranging from knowledge acquisition and update, subscription and profile management, real time moderation to knowledge mining for learning. The purpose of this research and paper is to assess the concept of a semantic web rule-based knowledge system applied to CMS. This semantic web rule-based knowledge system is based on an ontology model, SWRL and JESS inference engine technology, and a simplified architecture for CMS will be considered in this research. This consists of three CMS modules, as shown in Figure 4:

(1) Collaboration moderator ontology (CMO) model.
(2) Knowledge population/knowledge acquisition (KP/KA) SWRL rules.
(3) JESS inference engine.

The methods and tools which should be provided by the three CMS modules are listed and briefly described as follows:

- Analyse and identify a possible moderation process between the partners (SME_Partner) of a SYNERGY virtual organisation (VO), based on the functional requirements of the prototype CMS (Swarnkar *et al.* 2010)
- Define and develop the domain knowledge of VO moderation activities as classes, attributes or properties and instances for collaboration moderator ontology (CMO) model which will be briefly discussed in Section 3.1.
- Convert the CMO into a formal knowledge representation language (e.g. OWL), using the protégé http://protege.stanford.edu/ ontology editor tool as domain knowledge.

- Develop prototype versions of the KP/KA rules in SWRL with 'if-then' rules statements, and JESS reasoning engine to represent example operational knowledge.

3.1 *The structure of collaboration moderator ontology (CMO) model*

The objective of the CMO model is to support the moderation process of CMS within the prototype VOs environment proposed in this paper (which is a stand-alone version of CMS rather than a full SYNERGY ISU service platform). CMO is complex as projects undertaken by VOs are generally performed by multi-discipline project teams. The draft version of the structure of the CMO has six top-level classes, CMS_VO, Knowledge_Acquisition, Knowledge_Population, Moderator, Business_Concept and Manufacturing_ System_Engineering (MSE) ontology.[1] The MSE_Ontology class is an equivalent class to the CMS_VO class. These six classes are the abstract classes, so each represents a hierarchy of subclasses which are detailed and classified according to their main characteristics. Figure 5 shows elements of the top-level class structure and part of their sub-classes using Protégés' OWLViz plugin.

3.2 *Knowledge population/knowledge acquisition rules*

In normal operation, the CMS monitors the activities of partners within the collaboration to identify opportunities for enhanced collaboration or potential conflicts or misunderstandings between partner strategies or decisions. Further, as one of the goals of VOs is to become operational quickly, the time consumed by the set-up phase must be reduced to a minimum. At the same time it is important that the outcome of this phase leads to a formally correct and executable agreement between appropriate partners. Hence, it is important for virtual opportunity-based organisations to find appropriate members in the early stages of their formation. The CMS should therefore be able to capture and acquire knowledge about the potential collaborators both prior-to and when a suitable business opportunity is identified. Thus, the CMS requires knowledge population/knowledge acquisition functions to acquire

Figure 5. The structure of CMO model.
Note: CPV (common procurement vocabulary) codes have been specially developed by the European Union for public procurement.

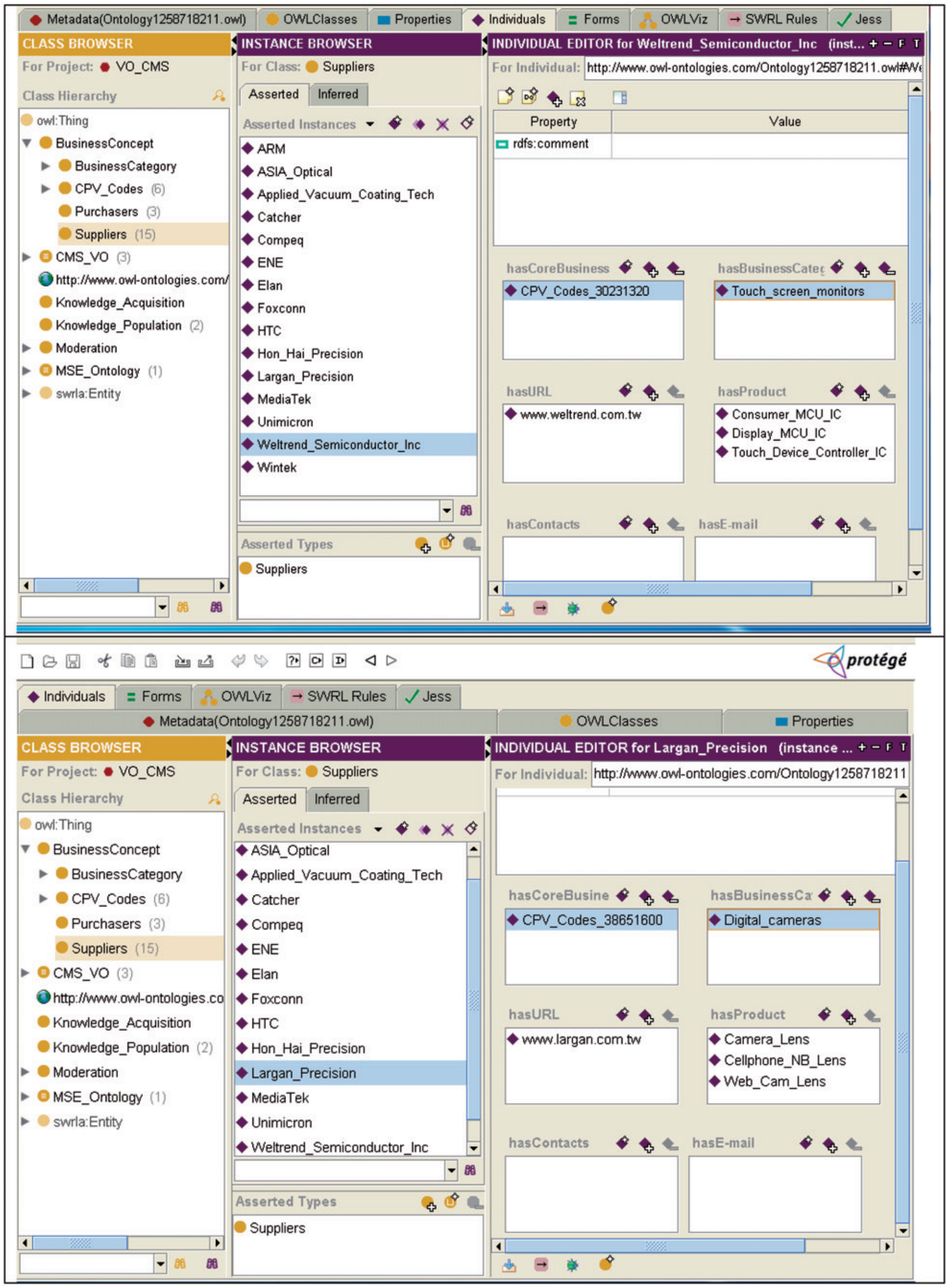

Figure 6. The face (database) of the CMO's suppliers class.

relevant knowledge about users (i.e. VO partners or the VO as a whole) in order to be able to support the above various activities that are involved in the CMS's normal operation. The operation of the knowledge population/ knowledge acquisition SWRL rules process is now demonstrated through the following case study of CMS monitoring for business opportunities and identifying appropriate collaborative business partners.

3.3 *JESS inference engine*

The SWRL editor initially had no inference capabilities. In this research, the JESS rule engine was therefore integrated with Protégé-OWL to perform inference with the SWRL rules. JESS is a rule engine for the Java

Table 1. The intelligent mobile phone supplier chain.

Intelligent MP main components	Suppliers	Supplier's core products
CPU chips	ARM	ARM Cortex-A8/A9 processor
Communications chipsets	MediaTek Inc.	Bluetooth, GPS, WLAN, Baseband processor, Medium access control (MAC)
Digital cameras	ASIA Optical Co.	Optical components Lens, laser products, DSC
	Largan Precision Co. Ltd	Cell phone/NB lens web cam lens, camera lens
Printed circuit boards (PCB)	Compeq Co. Ltd	Rigid-Flex
	Unimicron Co. Ltd	Rigid-Flex HDI PCB, FPC
Touch screens	Applied Vacuum Coating	ITO PC, shaping glass
	Elan Microelectronics Corp	Smart-touch screen ICs,
	ENE Technology Inc.	USB card reader ICs
	Weltrend Semiconductor Inc.	Touch device controller IC Display MCU IC Consumer MCU IC
	Wintek Corporation	ITO glass
Connectors	Hon Hai Precision Ind. Co.	Accessory parts, B to B connector
Metal casings	Catcher Technology	PC/NB/cell phone cases
	Foxconn Technology Co.	Mobile phone enclosure Consumer electronics products

platform, which consists of a fact base, rule base, and an execution engine and is often referred to as a Java expert system shell.

4. Case study

The example considered here is a virtual collaborative network of enterprises operating cross-border alliances between small-to-medium businesses in manufacturing intelligent mobile phones. This case study is provided to demonstrate the proposed model of the CMS service, which facilitates participation within the network and raises awareness of the potential opportunities for doing collective cross-border business. In order for the network of enterprises to take advantage of the SYNERGY services, any prospective partner needs to register with the SYNERGY Platform, using PKMS services, and become a member of an appropriate collaboration pool (CPool). In this case study, an example CPool of 50 enterprises with varied competences, skills and core business, has been extracted from the Taiwan Stock Exchange listed companies (http://emops.twse.com.tw/emops_all.htm). Table 1 lists part of the example CPool, showing the main components of intelligent mobile phones, their suppliers and these supplier's core products.

In the example above, the CMO was used to develop the fact base (from this CPool). Figure 6 shows the CMO's suppliers class has 15 facts. Weltrend Semiconductor Inc. is one of the suppliers which has core business represented by CPV_Codes_30231320 and belongs to the core business category of touch screen monitors. On the other hand, Largan Precision has core business of CPV_Codes_38651600 and the core business category is digital cameras.

The CPool is managed by a CMS_VO co-ordinator who is subscribed to the CMS and has defined 'business opportunities' as one of their items of interests. The CMS_VO coordinator has created a new VO called CMS_082901_2010 and named Smart_Phone_Components, and requests that CMS makes the VO aware of new business opportunities specific to CPV_Codes_30231320 and CPV_Codes_44322200, as illustrated in Figure 7.

When a suitable business opportunity is identified, the CMS requires KP/KA functions to acquire relevant knowledge about users (i.e. potential VO partners or the VO as a whole) in order to be able to support the search and pre-selection stage for appropriate VO members. Figure 8 shows one of the knowledge rules (Rule_SME_Partner) as an advanced matchmaking engine which complements the deferred selection of a prospective CMS_VO potential partner, called SME_Partner.

During this research, example knowledge about SME_Partner has been captured and applied using the knowledge rule base comprised of the SWRL rules and a simple inference engine. This prototype knowledge has been tested manually, by using Protégé and the JESS inference engine in a simulation of the operation of the VO.

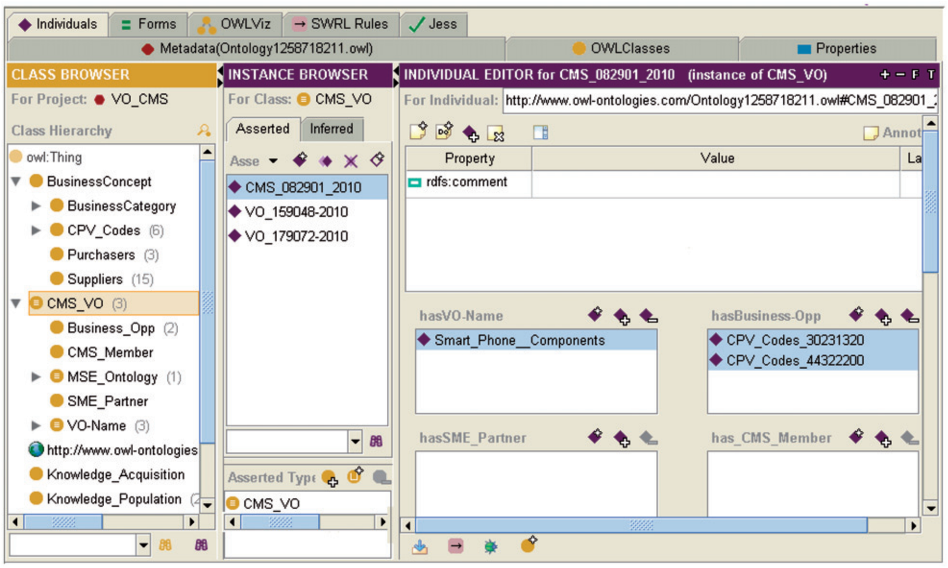

Figure 7. The face (database) of the CMO's CMS_VO class.

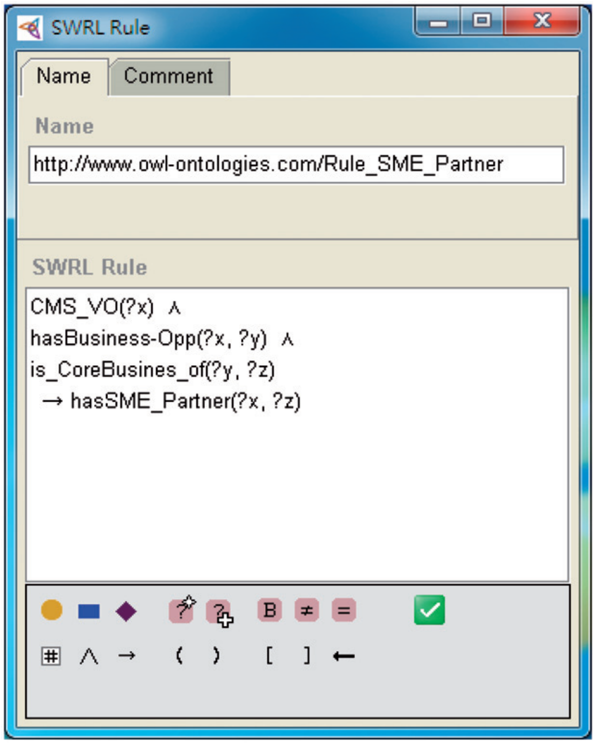

Figure 8. One of the knowledge population rule (Rule_SME_Partner).

A Protégé plug-in for running JESS: JessTab provides a JESS console window, for mapping instances to OWL facts, SWRL rules, JESS and functions for knowledge-base operations as shown in Figure 9.

Conjunction with the knowledge rule (Rule_SME_Partner) and the JESS inference engine are used to find a prospective SME Partner for the VO and this could result in the selection of Applied Vacuum Coating Tech, ENE,

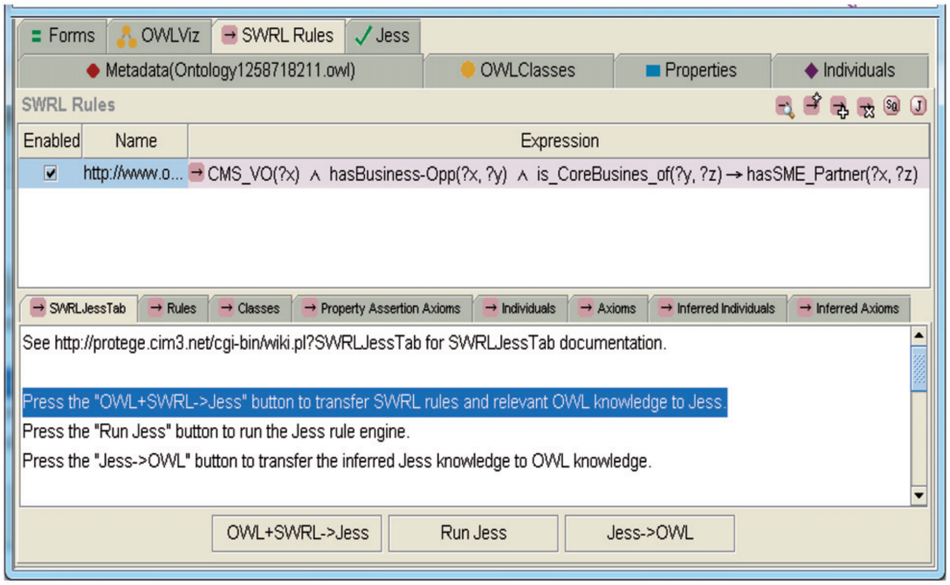

Figure 9. The OWL facts, SWRL rules and JESS operation.

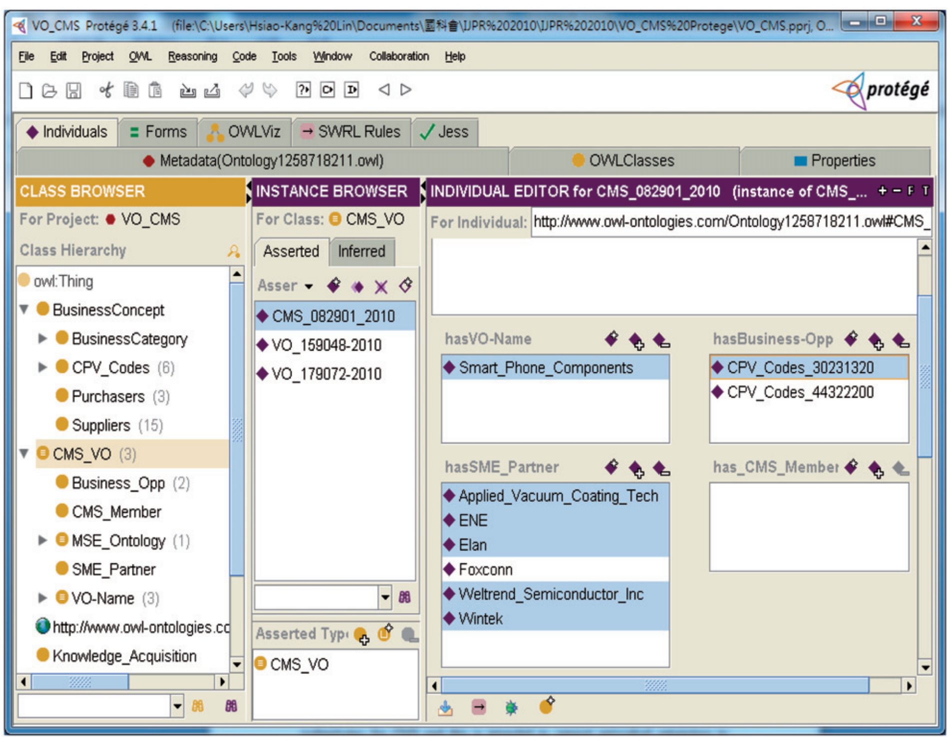

Figure 10. The prospective SME_Partner result.

Elan, Weltrend Semiconductor Inc, Wintek for the CPV_Codes_30231320 and Foxconn for CPV_ Codes_44322200 (see Figure 10).

As mentioned earlier, any prospective SME_Partner needs to be a member of an appropriate CPool. They can also register for additional SYNERGY services if they wish. The prospective SME_Partner would need to subscribe to the CMS and become a formal CMS_Member, who is also able to access CMS services and register their items of interest using the knowledge population classes of CMO.

A major task for the CMS is to capture the items of interest for each and every CMS_Member who are registered with CMS service. This can be done using the KP/KA rules and constraints defined using the CMO and populated in the Protégé environment in this example. The information provided by the KP/KA rules along with the information entered by the partner, contains the necessary information and knowledge of what is important to each partner and hence when an event occurs (such a business opportunity being identified, or information about the collaboration activities in the CPool or VO being changed), CMS can deduce whether this event is likely to affect any other partners (CMS members) within the collaboration. Therefore KP/KA rules are needed to support identification, acquisition, maintenance and evolution of knowledge and to support knowledge sharing through the raising of awareness of possible consequences of actions and other partner's needs during collaboration.

5. Conclusion

The semantic web is regarded as an integrator across different contexts and information applications and systems; it provides mechanisms for the realisation of integration of VE/VO information. The rapidity of the growth experienced provides the motivation for researchers to focus on the internet and semantic web application areas in the field of enterprise interoperability and enterprise collaboration, e.g. the European SYNERGY and COIN (2008–2011) project. This research has proposed a rule-based knowledge system using semantic web technologies for CMS and this is intended to support networked enterprises to successfully participate in collaborative VOs. This paper examines the potential of combining an OWL semantics-based representation of the CMS domain knowledge with the use of rules to define axioms to operate on the CMS taxonomy and also to compute the taxonomy from given concept definitions, which can function on a platform to support interoperability and collaboration activities within VOs. The main research contribution of this work lies in the development of a CMO Model and KP/KA rules for reasoning with ontologies and rules, based on the semantic web standards and tools. An advantage of this research is that the semantic tools used are readily available, e.g. the ontology model has been implemented using Protégé_OWL, SWRL and JESS inference engine. Previous implementations of moderators have primarily focused on using knowledge which has been captured using object oriented database design technology and the implementation of programming languages which demand significant control over the computer's operation. Further research work is currently being carried out on other knowledge representation technologies for CMS.

Note

1. The MSE Ontology was implemented to provide a common understanding of manufacturing related terms to enhance the semantic interoperability within globally VO team and was reported in earlier papers (Lin *et al*. 2005, Lin and Harding 2007).

References

COIN, 2008–2011. *COllaboration and INteroperability for networked enterprises* [online]. EU FP7-ICT Project No. 216256. Available from: http://www.coin-ip.eu/ [Accessed 18 November 2010].

Davis, R., Shrobe, H., and Szolovits, P., 1993. What is a knowledge representation? *AI Magazine*, 14 (1), 17–33.

Genesereth, M.R. and Fikes, R.E., 1992. *Knowledge interchange format, Version 3.0*. Technical report Logic-92-1, Stanford University: Computer Science Department.

Giarratano, J.C. and Riley, G.D., 2004. *Expert systems: Principles and programming*. 4th ed. Course Technology Publisher, ISBN-10:0534384471.

Gruber, T.R., 1993. Toward principles for the design of ontologies used for knowledge sharing. *International Journal Human-Computer Studies*, 43, 907–928.

Harding, J.A. and Popplewell, K., 1996. Driving concurrency in a distributed concurrent engineering project team: A specification for an engineering moderator. *International Journal of Production Research*, 34 (3), 841–861.

Harding, J.A., Popplewell, K., and Cook, D., 2003. A manufacturing system engineering moderator: An aid for multi-discipline project teams. *International Journal of Production Research*, 41 (9), 1973–1986.

Hangos, K.M., Lakner, R., and Gerzson, M, 2001. *Intelligent control systems. An introduction with examples*. Kluwer Academic Publishers.

Horrocks, I., *et al*., 2005. OWL rules: A proposal and prototype implementation. *Web Semantics: Science, Services and Agents on the World Wide Web*, 3 (1), 23–40.

Lassila, O., *et al*., 2000. The Semantic Web and its Languages. *Intelligent Systems*, 15 (6), 67–73.

Lin, H.K. and Harding, J.A., 2007. A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration. *Computers in Industry*, 58 (5), 428–437.

Lin, H.K., Harding, J.A., and Teoh, P.C., 2005. An inter-enterprise semantic web system to support information autonomy and conflict moderation. *Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture*, 219 (12), 903–911.

Matheus, C.J., Baclawski, K., Kokar, M.M. and Letkowski, J.J., 2005. Using SWRL and OWL to capture domain knowledge for a situation awareness application applied to a supply logistics scenario. In: *Proceedings of international conference on rules and rule markup languages for the semantic web (Rule ML-2005)*, November 2005, Galway, Ireland, 130–144.

McGuinness, D.L. and van Harmelen, F., 2004. *OWL web ontology language overview* [online]. Available from: http://www.w3.org/TR/owl-features [Accessed 18 November 2010].

MISSION, 1998–2001. Modelling and simulation environments for design, planning and operation of globally distributed enterprises. (MISSION). Project No. ESPRIT IMS 29656.2.

MOSES, 1992–1995. *Model oriented simultaneous engineering systems* [online]. EPSRC GR/H24273. Available from: http://leva.leeds.ac.uk/www_moses/moses.html [Accessed 18 November 2010].

O'Connor, M., *et al*., 2005a. Supporting rule system interoperability on the semantic web with SWRL. Paper presented at the 4th International Semantic Web Conference (ISWC 2005), Galway, Ireland, 974–986.

O'Connor, M., *et al*., 2005b. Writing rules for the semantic web using SWRL and JESS. *8th international protégé conference*, 18–21 July, Madrid, Spain.

Popplewell, K., *et al*., 2008. Supporting adaptive enterprise collaboration through semantic knowledge services. *In*: K. Mertins, R. Ruggaber, K. Popplewell and X. Xu, eds. *Enterprise interoperability III: New challenges and industrial approaches*. New York: Springer, 381–393.

Swartout, B., *et al*., 1997. *Toward distributed use of large-scale ontologies . Workshop on ontological engineering. AAAI spring symposium series, USA,* 138–148.

Swarnkar, R., Choudhary, A.K., Das, B.P. and Harding, J.A., 2010. A framework for collaboration moderator services to support knowledge based collaboration. Research Paper. Loughborough University, UK.

SYNERGY, 2008–2011. *Supporting highly adaptive Network enterprise collaboration through semantically enabled knowledge services* [online]. EU FP7-ICT No. 216089. Available from: http://www.synergy-ist.eu/ [Accessed 18 November 2010].

Walker, A., *et al*., 1987. *Knowledge systems and prolog: A logical approach to expert systems and natural language processing*. Addison-Wesley.