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Relevance of Buddhist Philosophy to Ontological Modelling in Information Systems and Computer Science

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Abstract

This paper underlines the importance of insights gained from philosophical studies of ontology for research in certain areas of information systems and computer science. It shows how the understanding of ancient views on ontology may help to resolve some current issues in disciplines such as Multi-Agent Systems, Semantic Web and Web Services. In particular, we single out natural language processing and semantic translation as two areas of ontological modelling with great research importance where Sri Lankan researchers could make significant contributions

1. Introduction

Distributed problem solving is a trend in modern computing, as exemplified by Multi-Agent Systems (Rzevski, 2002), Semantic Web (Tim Berners-Lee *et al.,* 2001) and Web Services (Korhenon *et al.,* 2002). A common thread in all these areas of computing is the ontological modelling. Ontology is most commonly defined as "an explicit specification of a conceptualisation" (Gruber, 1995). However, there are more than 7 different definitions for the term ontology in computer science literature (Guarino, 1997). Although most ontological approaches have the same grounding of object-orientation, frames, logics and XML based web technologies, there are too many ontology languages and environments differing from each other only slightly, thus creating overlaps in technologies rather than a new coherent paradigm. In spite of numerous tools for ontological modelling, issues such as merging and translation of ontology across domains have not been solved. As a result the intended goal of

semantic manipulation by machines of huge repository of world knowledge on the World Wide Web has not been achieved. We argue that one of the major reasons for such state of affairs is the lack of understanding of philosophical foundations of ontology. We point out that computer scientists cannot solely rely on simulation power of computers, without seeking important insights for new directions. This paper reports some results of our research into philosophical studies of ontology.

The rest of the paper is organised as follows. Section 2 explains why insight from philosophy is important for scientific developments. Section 3 reports on various philosophical viewpoints on ontology. Section 4 describes current approaches to ontological modelling in computer science. Section 5 suggests how we can contribute to further development of ontological modelling in computer science and Section 6 concludes the paper.

2. Why is Insight Important?

Too many computer professionals appear to be satisfied just to master the art of programming of modern computers. This attitude is hardly conducive to creating radically new paradigms. It is essential not to neglect ideas, analogies and philosophical insights. The modern computer itself was developed on the basis of Charles Babbage's idea of *mill and store,* as inspired by manufacturing environment in Europe after the industrial revolution. Mill-store concept has contributed to thinking of a machine, with a store attached to it, as an effective processor of materials and, by analogy, of a computer with an integral memory, as an effective processor of information. Artificial Neural Networks are inspired by ideas borrowed from physiology of brain as modelled by neurons and connections. Here neurons are defined, as distributed processors while connections are a distributed memory. Genetic Algorithms (GA) is yet another example, which is inspired by DNA and Darwin's theory of evolution. Using GA technology, evolutionary nature of biological systems has been exploited to postulate the idea of evolutionary computing. It could be argued that the currently popular Agent Technology has been inspired by human agents who work on behalf of their clients, attempting to meet their requirements. Further more, a Multi-Agent System (MAS) is a software implementation of the idea of the team spirit as well as the embodiment of the idea of *intelligence* emerging from interaction of a large number of elements each one with rather limited smart capabilities (Rzevski, 2002).

Let us consider a succession of steps in the development of computer programming. In the early days, computers were instructed in terms of *how to do* things. This was the basis of procedural programming and we have worked following this philosophy for many years. With the emergence of Artificial Intelligence it was discovered that computers could be instructed in terms of *what to do*, resulting in the development of declarative programming languages such as Prolog. Subsequently, the thinking in terms of processes, or declarations, was replaced by thinking in terms of objects and operations that can be performed on these objects, and thus the concept of object-oriented programming was born. There has been an obvious rapid development in the field of computer science driven by the concept of object-oriented programming. It is interesting to note that thinking in terms of objects dates back to views of Plato and Aristotle. Plato's view of *forms* (Silverman, 2003) and Aristotle's view of *genus* and *differentia* (Sowa, 2000) can be closely matched with the concepts such as objects, classes and inheritance. Philosophical considerations are always at the roots of new trends.

Ontology is emerging now as one of the key research areas in computer science. It is an important building block for new applications such as Semantic Web and Multi-Agent Systems. However, present approaches to developing computer-readable ontologies are rather intuitive and the progress is somewhat patchy. A clearer understanding of philosophical basis for ontological thinking is required.

3. Philosophical Foundations of Ontology

Philosophy is a vast subject area. Two branches of philosophy of special interest to information systems scientists and practitioners are epistemology and metaphysics (Donald, 2001). Epistemology, the study of the nature of knowledge has already been exploited by branches of Artificial Intelligence (AI) such as knowledge modelling and knowledge representation. In his classical paper, Newell has pointed out that the development of intelligent systems in AI must be driven by concerns at the *knowledge level* (Newell, 1982).

In contrast, metaphysics is concerned with what is *being* or *existence* and ontology can be viewed as a synonym of metaphysics (Donald, 2001). The study of *being* is as old as early Indian philosophies notably Hinduism, Jainism and Buddhism (McEvilley, 2002; Robert & Kathleen, 1996; Jayatilleka, 1963). Classical philosophers Aristotle and Plato, and Modern philosophers Descartes, Leibniz, Brentano, Kant, Sanders Peirce and Alfred North Whitehead have also made significant contributions to the understanding of ontology (Sowa, 1995).

3.1 Aristotle's Ontology

Aristotle (384-322BC) defined ontology as, *science of being with regard to the aspects of being.* In a practical sense, ontology is concerned with determining what *categories of being* are fundamental. Yet Aristotle never defined the concept of *being* exactly and we are indebted to the Viennese philosopher Franz Brentano for identifying some categories of *being* based on his studies of Aristotle's metaphysics (Sowa, 1995), which are illustrated in Figure 1.

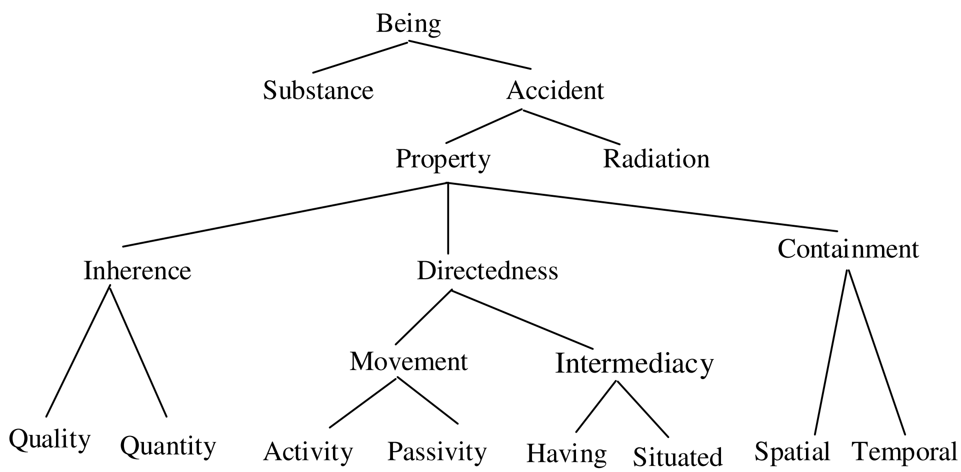

Figure 1: Aristotle's categories of *being*

Later on, in the 3rd century AD, Greek philosopher Porphyry expanded on *substance* (Figure 1) and identified its two constituent categories as *material* and *immaterial* things. Material thing was label as body and further classified. Immaterial thing was label as spirit without any further classifications. Aristotle has also introduced a way to expand on categories in terms of the concepts called *genus* and *differentia*. The term *differentia* refers to properties that distinguish different subtypes of the same genus or supertype. For example, *substance* as a genus has differentia - *material* and *immaterial*. It should be noted that *genus* and *differentia* are fundamental to the concept of inheritance and also provide a basis for artificial intelligence, object-oriented systems and semantic web.

3.2 Plato's Ontology

In contrast to Aristotle, Plato (427-347 BC) was interested in mental categories such as perception (Cornford, 1970). One of the key points in Plato's thinking was that reality was wholly within a person and not in the world outside. Further, Plato maintained that our perception is subjective and reality (being) is eternal. Plato strongly contended that person is not merely a body (matter), but a combination of mind and matter (Richard, (1978). Plato defines ontology by means of the concept of *frames*, ie, *what many things have in common*. The concept of *forms* matches the concept of classes in object-oriented thinking. Plato claimed that *forms* were eternal, the notion that is directly contradicted by the mounting evidence of evolving nature of knowledge. According to Cornford (1970) Plato never answered the question of what was the extent of the world of forms. However, Plato's idea of subjectivity of nature of our perception is useful as it leads to the notion of *ontology of individuals*.

3.3 Ontology in Buddhism

According to Buddhist thinking (563BC) ontology of *being* consists of *rupa,* ie, physical phenomena or matter, and *nama*, that is, mental phenomena or mind/soul (Nayanatiloka, 1983). Inanimate entities consist of physical phenomena only, while animate entities consist of both physical and mental phenomena. Twenty-eight categories of physical properties are identified in Buddhist writings (Nina 2004). Further, mental phenomena are classified into *citta* (consciousness) and *cetasika* (mental factors). Eighty-nine (or hundred and twenty-one according to another classification) different *cittas* and fifty-two different *cetasikas* such as perception, cognition, feeling, etc. are also identified (Nayanatiloka, 1983). The conventional term "mind" belongs only to *citta* or consciousness. Therefore *nama,* which is both *citta* and *cetasika*, is more than mind. It follows that Buddhist definition for *being*, which is *nama-rupa* is not the same as *mind-matter*. The notion is far more complex as *being* is a conditional flow of *nama* and *rupa,* but none of the two separately. The duality, and at the same time, inseparability of *nama* and *rupa* is a key distinction of Buddhist view on ontology. There are several different ontologies (descriptions of *being*) in Buddhist literature (Kalupahana, 1987). For example, *punchaskandha* or five aggregates, proposes five categories of *being*: *rupa* (physical phenomena), *vedana* (feelings), *sanna* (perception), *sankara* (cognitive activity, disposition) and *vinnana* (consciousness). The fundamental ontology and the *pancahskandha* ontology are nevertheless comparable. Figure 2 shows a mapping between the two worldviews.

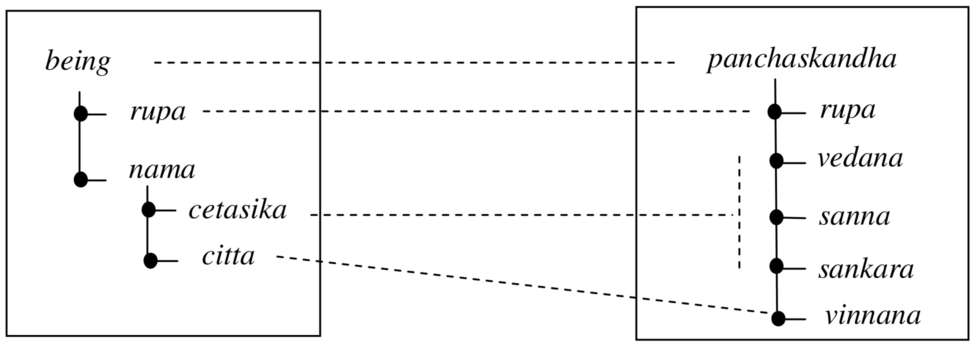

Figure 2: Mapping between two Buddhist ontologies

As shown in Figure 2, a mapping between two different ontologies requires a translation among some terms, for instance, *citta* as *vinnana* and *cetasika* as *vedana*, *sanna* and *sankara*. The concept of comparable ontologies found in Buddhism can be used to develop an insight into modern computing issues such as *ontology merging* (Dou et al., 2002,) *ontology translation* and the notion of a *middle agent* (Payne *et. al*., 2002). Ontology merging is a very common need in MAS and Semantic Web applications when different terms are used in different ontologies to refer to the same or similar concept.

One of the key assertions of Buddhist discourses is that Buddha could explain the same material with the use of different ontologies to suite different individuals. All such ontologies were comparable and lead to the ultimate goal of Buddhism. Buddhist concept of ontology supports the evolution of knowledge through the comparable ontologies without being restricted to a single ontology.

3.4 Modern Philosophical views on Ontology

Descartes, Leibniz, Brentano and many other Western philosophers have also worked on defining ontology. Most of their work emphasised the importance of physical phenomena, with the exception of Brentano who held the view that the most important mental phenomenon is intention, which, as it happened, is one of the 52 mental factors defined in Buddhism. Charles Sanders Peirce, Alfred North Whitehead and Marin Heidegger have also done significant work in this area and the interested reader may refer to Sowa (1995) for a comprehensive coverage of their views. In general these works have attempted to identify a top-level global ontology, which is rather ambitious.

Our intention is not to identify a top-level global ontology but to reveal the nature of ontology from various viewpoints. At this point we also wish to highlight the relevance of views of philosophy of science as proposed by Popper (1979) and Kuhn (1996) for understanding the nature of ontologies. Since our research falls under computer science in general, and also Popper & Kuhn are considered as the champions of modern philosophy of science, we thought that it is appropriate to relate their views in this context. Popper presents the idea of *falsification*, while Kuhn presents his idea of *paradigm shift* as the means for evolution of scientific knowledge. Though falsification is radically different from paradigm shift, both viewpoints lead to a common implication that evolution of science is governed by the perception of the world through different ontologies. Stated another way, Newton and Einstein had two different ontologies about the physical world. It is not important whether we say that Einstein falsified certain assertions of Newtonian physics or that he created a paradigm shift with regard to these assertions. What is important is to understand that Newton and

Einstein had different ontologies. If everybody had the same ontology, sciences would never evolve and there would be neither falsification nor paradigm shift. Therefore, a notion of subjective ontology is an essential prerequisite for understanding the evolution of knowledge. We argue that ontological modelling in computer science and information systems must be powered by the notion of the subjective nature of ontology. In this sense, ontology should not be treated as a static piece of software such as an object or a procedure, but a "gene like software" with its ability to evolve and work with other genes cooperatively.

4. Ontology in Information Systems and Computer Science

At present, Multi-Agent Systems, Semantic Web and Web services can be considered as three major areas of ontology applications. All these areas include communication in a heterogeneous environment, in which ontology plays the key role of mediating between various knowledge representations. In such environments, we expect machine to communicate with each other without human intervention. To achieve this goal we must develop methods for semantics processing of the huge repository of information and knowledge on globally distributed environments. Although semantic description is relatively straightforward to achieve through definition of languages such as XML and its extensions, a machine implementation of the semantic translation is an inherently challenging task.

As we progress further into Knowledge Society and Global Knowledge Economy we shall no doubt build *all* information systems supporting this society, including its business activities, as knowledge-based. Therefore the importance of ontology as the key element of knowledge-based information systems cannot be exaggerated.

4.1 Current Ontology Development Environments

Most of the ontology description languages have been developed as extensions of XML such as RDF and RDFS. RDF (Frank & Eric, 2004) is fundamental to Semantic Web and provides a means for adding semantics to documents without making any assumptions on the structure of the document. RDFS (Brickley & Guha, 2004) provides basic type schema such as objects, classes and properties for RDF thereby making RDF more descriptive. Further, DAML (Hendler & McGuinness, 2000) and OIL (Horrocks et al., 2000) are again very similar languages for semantic descriptions and both have the same grounding. Emerging standard language for semantic description, which is DAML-S (Ankolekar *et al.*, 2002) is based on DAML+OIL (McGuinness, 2002) and both of these languages DAML and OIL have very similar features and the same fundamentals.

Although DAML-S was originally developed for ontology description for Semantic Web and Multi-Agent System, it is now being used in Web Service applications as well. It appears that the usual semantic description languages for Web Service, namely, UDDI and WSDL are inadequate for complex applications. A very good comparison of capabilities of UDDI and WSDL (Christensen *et. al.*, 2001) with DAML-S can be founded in Ankolekar *et al.* (2002). There are also specific toolkits for the development of MAS, including LARKS (Sycara *et al*., 1999), ZEUS (Nwana *et. al.,* 1999) and Magenta Multi-Agent Platform (Rzevski, 2002), which also include means for developing and managing ontologies.

4.2 The Use of Ontologies in Software Applications

There are a large number of ontologies developed and used in computer applications. Here we review a selection of five ontologies with a view to show their basic nature and applications potentials. These five systems include Chat-80, Cyc, WordNet, EDR and Ontolingua.

Chat-80, a question-answering system, is one of the first major Prolog-based systems to demonstrate natural language processing on a geographical database (Warren & Pereira, 1982). It deals with the domain of geography. The ontology of Chat-80 comprises categories, such as, *area, point* and *line*. These categories are further divided and the entire ontology consists of about 20 categories. Chat-80 ontology is relatively small and domain specific.

Cyc is the well-known system with quite comprehensive ontology available today (Lenat, 1995). Cyc is an acronym derived from the word encyclopaedia. It is an Artificial Intelligence project attempting to assemble comprehensive ontology for enabling a variety of knowledge-intensive products and services to work together. Cyc can be considered as a huge expert system with a domain that spans all everyday objects and actions. The most general category of the Cyc is *thing*, which has three sub categories, namely, *individual objects*, *intangibles*, and *represented things* followed by various sub categories. With reference to those categories Cyc has defined over one million commonsense axioms to operate on the ontology.

WordNet is lexical ontology available online for natural language processing pertaining to English language (Miller, 1995). The ontology in WordNet includes most general concepts in English language; *nouns, verbs, adjectives* and *adverbs* together with set of synonyms related to each. In WordNet, the vocabulary of language has been defined as a set of pairs comprising word *form* and *sense*. More than 166,000 word form-sense pairs are included. Ontology of WordNet also comprises semantic relationships such as synonym, antonym, hyponym, meronym, holonym and proponym. As Lenat *et al* (1995) point out, WordNet offers just six types of semantic relations, whereas Cyc has thousands. However, WordNet is the most widely used ontology for natural language processing in the world.

EDR is an electronic directory containing meaning of words from both Japanese and English languages (Yokoi, 1995). It has over 400,000 concepts, with their mapping to both English and Japanese words. As compared with WordNet, EDR is a bilingual system. Although EDR ontology is bigger than that of Cyc, EDR does not provide much detail for each concept. Nevertheless, the EDR project has addressed a very important branch in ontological modelling since world knowledge is available not only in English but also in many other natural languages. As such, EDR is an initiative for machine processable knowledge sharing across various nations regardless of mother tongues.

Ontolingua (Gruber, 1993) is a tool for translating a given ontology to a variety of other ontologies. It enables a chosen ontology to be translated to different ontology environments, including KIF (Genesereth & Fikes, 1992), Loom (MacGregor, 1991), Epikit (Genesereth, 1990) and EXPRESS (Spiby, 1991). Therefore, with the help of Ontolingua the same ontology can be used for different purposes. For example, Loom can be used for conceptual design of ontology and managing the knowledge base; using Epikit, explanatory reasoning can be obtained; Express can be used for the design of logical databases for sharing data. An Ontolingua server is now available for the web access to the Ontolingua system (Farquhar *et al*., 1997). Ontolingua is a good example of the use of ontologies among a pre-identified set of systems. However, according to Semantic Web concept, we need ontologies to be shared among any application.

4.3 The Concept of Middle Agents

The concept of Middle Agents is a basis for a major approach to matching different ontologies in heterogeneous distributed environments. The role of Middle Agents is to find agents who might have information or capability required by a particular agent (Genesereth & Ketchpel, 1994). Middle Agents work as matchmakers or brokers between the request agent and service provider agents. For this purpose, the middle agent should be able to understand ontologies of request agents and the service provider agents. The difficulty is that often in different ontologies different words may be used to refer to the same concept. For example, an agent searching for a *telephone* may need to understand the term *item*, which appears in the ontology of an agent handling shopping basket applications. In such a situation a middle agent should be able to translate one term to another. Mapping between ontologies leading to effective communication is the key role of middle agents. At present most middle agents are capable of only the syntactic translation between ontologies; a human intervention is expected for semantic translation (Dou *et al*, 2002; Payne *et. al,* 2002). Until the problem of the machine implementation of semantic processing is solved the primary goals of Semantic Web cannot be achieved.

5. Lessons from the Current State of Ontological Modelling

Issues with the current ontological modelling can be discussed from various points of view. Here we look at the issues that can be addressed through the insights gained from philosophical studies of ontology. We argue that further ad-hoc development of systems for ontological modelling would lead to an even worst duplication of tools and environments. We highlight ontological concern related to natural language processing and semantic translations, since both have very high relevance to Sri Lanka.

5.1 Natural Language Processing

Natural language processing should be a trust area of research if we expect Semantic Web to enable the global access to the Web regardless of languages used. EDR is a commendable initiative in this line of research. There is something definitely missing when people say that machines can comprehend each other with a view to sharing knowledge on the Semantic Web, while human being cannot communicate with each other due to the language barrier. Therefore, bilingual translation between English and other languages must be promoted as a major part of Semantic Web research. Obviously such bilingual systems must be powered by ontology of respective languages. We must understand that one of the reasons for the current lack of progress in natural language processing is mainly due to inadequate attention given to ontological modelling of natural languages.

In Sri Lanka, we are working on a project called BEES, an attempt to develop an expert system to run on standard web browsers to translate downloaded web pages into Sinhala language. BEES is expected to work as a bilingual translator, without achieving a hundred percent translations of the web pages in English. The philosophy behind this approach is to slowly build up the English vocabulary while the understanding is powered by mother tongue. Due to this approach, BEES can work even when corresponding meaningful Sinhala translations are not available for some English words. This will also make the machine implementation of ontology mapping between two languages easier. The ontologies of two languages are fundamentally based on their grammatical structures followed by exceptions in two languages. As such these ontologies are more than dictionary of words. Two parsers to work on ontologies of English and Sinhala languages have already been developed and BEES is capable of translating simple web pages giving Sinhala-English bilingual display. Formal evaluation of BEES is due. As further work we would be interested to study to what extend the English language ontology developed for EDR can be used for BEES. However we expect that EDR ontology may not be immediately applicable for BEES since Sinhala and Japanese languages are quite different. It should be noted that ontologies are more than parsers of languages.

5.2 Semantic Translations – A Research challenge!

We pointed out that machine implementation of semantic translation between ontologies is a crucial issue in ontological modelling. Although this also applies to the filed of natural language processing, we identify semantic translation as the key issue. Although various languages have been developed for semantic descriptions of ontologies, very little has been achieved in semantic translations. At presents the process of semantic translation relies on human intervention in critical areas of translation. As we pointed out earlier, Buddhism encourages the use of different ontologies and communication through comparable ontologies. In such a scenario, we need to map between ontologies and apply corresponding translations for ontological terms. One reason for difficulties in translation is the lack of knowledge about the contextual meaning of the terms in ontologies. In other words, intended meaning of the terms should be associated with the context as a part of the ontology. Although this happens to some extend at the moment, no one has addressed many different dimension of association. Merging of ontologies with associated semantics also leads to evolution of ontologies, which is a bonus for MAS. Buddhist literature describes 52 mental categories with various degree of emphasis on the context. For example, perception, intension, attention and desire are some mental categories, which have context related meanings. It is quite likely that research into mental phenomenon described in Buddhist literature can reveal some factors relevant to expressing context-dependent semantics in a more comprehensive manner. We could be using those mental factors to define "tags" for describing the semantics of terms in ontologies from a broader viewpoint. This may lead to a possibility for implementation of machine-driven translation of semantics between ontologies.

It should be noted that though Sri Lanka has immediate access to literature on Buddhism, very little research have been done for exploiting Buddhism for the benefit of Computer Science. Among others, Karunananda (1993) has developed a computer model of Buddhist theory of mind. In this project, a computer model of mind has been proposed in terms of three major mental factors, namely, *attachment, aversion* and *equanimity*. Further, Karunaratne (2001) has exploited Buddhist theory of mental factors for developing an approach to response-driven conflict resolution for reasoning in expert systems. This project relates Genetic Algorithms, Expert Systems and Buddhist theory of mental factors. A theoretical foundation for some of the heuristics used in Artificial Neural Networks has also been provided with the help of Buddhist theory of mind (Karunananda, 2002). We believe that ontological modelling will be a major area in computer science, which can be improved by Buddhist theory of mental categories.

It is perhaps one of the biggest mistakes in ontological modelling in computer science that mental categories have been neglected. We believe that a reappraisal of ontology as a composition of mental and physical phenomena would solve most of issues associated with semantic handling of ontologies. We are currently involved in a research into philosophical issues in ontological modelling as a part of MADIRA project at Brunel University in the UK. Based on the finding of that project we have presented more detailed study of philosophical viewpoints of ontology elsewhere (Karunananda & Rzevski, 2004).

6. Conclusions

This paper summarises our research into philosophical foundations of ontology, specifically related to ontological modelling in information systems and computer science. We suggest that some of the unresolved issues in ontological modelling stem from inadequate attention given to mental phenomena, which are an integral part of describing *being*. We highlighted the value of insights gained from philosophical studies of ontology, especially for semantic translations across different ontologies. Finally we pointed out the importance of ontology for the natural language processing with the aim of making the Semantic Web really useful for mankind regardless of the mother tongues used. We feel that research into mental phenomena described in Buddhist philosophy should be encouraged as a means of addressing semantic translation issues in ontological modelling.

7. References

[1] Ankolekar A., Burstein M., Hobbs J. R., Lassaila O., Martin D. L., McIlraith S. A., Narayanan S., Paolucci M., Payne T., Sycara K. and Zeng H. (2002), *DAML-S: Semantic Markup for Web Services,* International Semantic Web Working Symposium

[2] Brickley D., Guha R. V., (2004), *RDF Vocabulary Description Language 1.0: RDF Schema, W3C Recommendation 10 February 2004* http://www.w3.org/TR/2004/RCE-rdf-schema-20040210

[3] Cornford F. M. (1970), *Plato's Theory of Knowledge*, Routledge, London

[4] Christensen E., Curbera F., Meredith G. and Weerawarana S. (2001), Web Service Description Language (WSDL) 1.1, http://www.w3.org/TR/2001/NOTE-wsdl-200110315

[5] Donald Palmer (2001), *Looking at Philosophy: The Unbearable Heaviness of Philosophy Made Lighter*, McGraw-Hill

[6] Dou D., McDermott and Peishen Qi (2002), Ontology translation by ontology merging and Automated reasoning, In the Proceedings of EKAW workshop on Ontologies for Multi-Agent Systems, 2002

[7] Frank Manola & Eric Miller (2004), *REF Primer,* W3C Recommendation, 10th February 2004, http://www.w3.org/TR/2004/REC-rdf-primer-20040210/

[8] Genesereth, M. R. (1990), The Epikit Manual, Epistemic, Inc. Palo Alto, CA

[9] Genesereth, M. R. & & Fikes, R. E. (1992), Knowledge Interchange Format, Version 3.0 Reference Manual, Technical Report Logic-92-1, Computer Science Department, Stanford University

[10] Gruber, T. A. (1995), *Towards principles for the design of ontologies used for knowledge sharing,* International Journal of Human-Computer Studies (1995) 43, 907-928

[11] Gruber, T. A. (1993), *A Translation Approach to portable Ontology Specification*, Knowledge Acquisition, 5(2) 199-220

[12] Guarino N. (1997), *Understanding, building and using ontologies*, International Journal of Human Computer Studies, (1997), 46, 293-310

[13] Hendler J. & McGuinness. D. L. (2000), *The DARPA Agent Markup Language*. IEEE Intelligent Systems, Vol. 15, No. 6, November/December 2000, pages 67-73.

[14] Horrocks, D D. Fensel, J. Broekatra, S. Decker, M. Erdmann, C. Goble, F. Van Hermelen, M.Klein, S. Staab, R. Studer and E. Motta (2000), *The Ontology Inference layer OIL*, Technical Report, http://www.ontoknowledge.org./oil/TR/oil-long.html

[15] Jayatilleke K. N. (1963), *Early Buddhist Theory of Knowledge*, George Allen & Unwin Ltd, 1963

[16] Korhonen J., Pajunen L. and Puustijarvi (2002), Using Web Service and Workflow

Ontology in Multi-Agent Systems, EKAW'02, Workshop on Ontological Modelling for Multi-Agent Systems, 3oth September 2002, Siguenza, Spain

[17] Kalupahana David J. (1987), *The Principles of Buddhist Psychology*, State university of New York Press

[18] Karunananda, A.S. (1993), *Computer modelling of the thought process*, International Journal of Computer Applications in Technology 6(2/3), 135-140.

[19] Karunananda A. S. (2002), *Using an Eastern Philosophy for providing a theoretical basis for some heuristics used in Artificial Neural Networks*, Malaysian Journal of Computer Science, Vol 15 No. 2, December 2002, pp 28-33.

[20] Karunaratne T.M. (2001), An Approach to response-driven conflict resolution for expert systems, MPhil Thesis, Open University of Sri Lanka

[21] Karunananda A. S. and Rzevski G. (2004), *Philosophical Basis of Ontology,* MADIRA Project Brunel University

[22] Kuhn T. S. (1996), *The Structure of Scientific Revolution,* 3rd Edition, University of Chicago Press

[23] Lenat Douglas B. (1995), *Cyc: A large-scale investment in knowledge infrastructure,* Communications of the ACM, 38(11), 31-40

[24] Lenat, Douglas, Miller George, Yokoi, Toshio (1995), *Cyc, WordNet, and EDR,* Communications of the ACM, 38(11), 45-49

[25] MacGregor R. (1991), *The Evolving Technology of Classification-based Knowledge Representation Systems*, In J. Sowa (Eds), Principles of Semantic Networks: Explorations in the Representation of Knowledge, San Mateo, CA: Morgan Kaufmann

[26] McEvilley T. (2002), *The Shape of Ancient Thoughts: Comparative Studies in Greek and Indian Philosophies*, Allworth Press, New York

[27] McGuinness, D. L., Fikes R., Hendler J. and Stein L. A. (2002), *DAML+OIL: An Ontology Language for the Semantic Web,* IEEE Intelligent Systems, 17(5), 72-80

[28] Miller George (1995), *WordNet: A Lexical database for English*, Communication of the ACM, 38 (11), 39-41

[29] Nayanatiloka (1983), *Guide Through the Abhidhamma-Pitaka*, Buddhist Publication Society, Sri Lanka, 1983.

[30] Nwana H. S., Ndumu, D. T., Lee, L. C. and Collis, J. C. (1999), ZEUS: A Toolkit for building distributed Multi-Agent Systems, Applied Artificial Intelligence Journal 13(1/2), 129-185

[31] Payne, T. R., Paolucci, M., Singh, R. and Sycara, K. (2002), *Communication Agents in Open Multi-Agent Systems,* In proceedings of First GSFC/JPL Workshop on Radical Agent Concepts (WRAC), pp 365-371, McLean, VA, USA

[32] Popper K. R. (1979), *Objective Knowledge: an Evolutionary Approach*, Oxford University Press

[33] Rzevski, G (2002), *On Multi-Agent Systems and Distributed Intelligence*, MADIRA Paper 021, Version 1.0, published on MADIRA website www.brunel.ac.uk/research/madira, 24 November 2002.

[34] Richard Taylor (1978), *introductory readings in Metaphysics*, Prentice-Hall, Inc., Englewood Cliffs

[35] Robert C. S. and Kathleen M. H. (1996), A Short History of Philosophy, Oxford University Press, 1996

[36] Silverman Allan (2003), *Plato's Middle period metaphysics and Epistemology*, The Stanford Encyclopedia of Philosophy (Summer 2003 Edition), Edward N. Zalta (ed.), http://plato.stanford.edu./archives/sum2003/entries/plato-metaphysics/

[37] Sowa John F. (2000), *Knowledge Representation: Logical, Philosophical, and Computational Foundation*, Brooks Cole Publishing Co., Pacific Grove, CA

[38] Sowa John F. (1995), *Top-Level Ontological categories*, International Journal of Computer Studies (1995) 43, 669-685

[39] Spiby, P. (1991), EXPRESS Language Reference Manual, International Standard ISO 10303-11, Project Three ("Express Language") Working Group Five ("STEP Development Methods") of Subcommittee Four ("Manufacturing languages and Data") of ISO Technical Committee 184 ("Industrial Automated Systems and Integration"); International Standards Organization.

[40] Sycara K., Klusch M., Widoff S. and Lu J. (1999), Dynamic Service Matchmaking

Among Agents in Open Information Environments, SIGMOD Record (ACM Special Interest Group on Management of Data), 28(1): 47-53, march 1999

[41] Tim Berners-Lee, James Hendler, Ora Lassila (2001), *The Semantic Web*, Scientific American

[42] UDDI, The UDDI Technical White Paper, http://www.uddi.org, 2002

[43] Warren, D. H. D. & Pereira, F. C. N., (1982), *An efficient easily adaptable system for interpreting natural language queries,* Computational Linguistics (1982) 8(3-4), 110-122

[44] Yokoi Toshio (1995), *The EDR electronics dictionary,* Communications of the ACM, 38(11), 42-44