Institution: Durham University

Unit of Assessment: Philosophy (32)

Title of case study: The Influence of Formal Ontology on Information Systems (CS1)

1. Summary of the impact

Research on the four-category ontology by Professor E.J. Lowe (appointed at Durham in 1980) has had the following impacts upon the work of applied ontologists developing information systems.

1. It has had an important influence on the developers and users of the Domain Ontology for Linguistic and Cognitive Engineering (DOLCE) and the Basic Formal Ontology (BFO). These are top-level category systems used to organise data in computationally efficient and user-friendly ways, used by information systems designers.

2. It features significantly in the education and training of applied ontologists and information systems designers.

2. Underpinning research

The research was carried out by Professor E.J. Lowe at Durham University. An ontology is a system of categories, which identifies the kinds of beings that can exist and co-exist, along with their interrelations. Lowe argues in favour of a four-category ontology. This was first set out in his 1998 book *The Possibility of Metaphysics,* and further developed in a succession of other books and articles. The four-category ontology assigns all actual and possible entities to one of four fundamental ontological categories: *object* (or *individual substance*), *kind*, *attribute*, and *mode* (or *individual accident*). Lowe argues that the four-category ontology possesses a classificatory and explanatory power unrivalled by more ontologically parsimonious systems employing fewer or no categories. He demonstrates this by providing a unified account of identity and individuation, causation, dispositions and tendencies, natural laws, necessity and possibility, and truth-making (that is, how true propositions are 'ontologically grounded' by entities whose existence explains their truth).

The four-category ontology is distinctive in mirroring the natural or intuitive classificatory practices of human beings and belongs to a 'common-sense' tradition in metaphysics that can be traced back to Aristotle. Furthermore, it also reflects the syntactic structures of natural language much more closely than do its chief rivals, giving it greater human user-friendliness. It consequently possesses an intelligibility and robustness that many other current ontologies of philosophical origin do not. Lowe has further developed these claims concerning human cognition, natural language, and the four-category ontology in his two most recent books, *Forms of Thought* and *More Kinds of Being*.

3. References to the research

Outputs: Publications on the four-category ontology include:

- Lowe, E.J. 2013. *Forms of Thought: A Study in Philosophical Logic* (Cambridge: Cambridge University Press).
- Lowe, E. J. 2009. *More Kinds of Being: A Further Study of Individuation, Identity, and the Logic of Sortal Term*s (Malden, MA and Oxford: Wiley-Blackwell).
- Lowe, E.J. 2008. *Personal Agency: The Metaphysics of Mind and Action* (Oxford: Oxford University Press).
- Lowe, E.J. 2006. *The Four-Category Ontology: A Metaphysical Foundation for Natural Science* (Oxford: Oxford University Press).
- Lowe, E.J. 2002. *A Survey of Metaphysics* (Oxford: Oxford University Press).
- Lowe, E.J. 1998. *The Possibility of Metaphysics: Substance, Identity, and Time* (Oxford: Oxford University Press).

Research Quality: This is demonstrated by its inclusion in several peer-reviewed monographs (four with Oxford University Press, one with Cambridge University Press, one with Wiley-Blackwell), all of which received very positive reviews. Lowe's ontology has been the subject of five conferences/workshops (2006-2012). That Lowe was President of the Mind Association (2011-12) further exemplifies the high regard in which his work is held.

Research Grants: The research has been supported by two grants:

- AHRC research grant of £165,974 (awarded February 2008) for a major two-year project entitled 'The New Ontology of the Mental Causation Debate', which ran from 1 October 2008 until 30 September 2010. Dr. Sophie Gibb (Durham) was the Principal Investigator and Professor Lowe was Co-investigator.
- British Academy/Leverhulme Trust Senior Research Fellowship award of £28,342 to Professor Lowe (awarded March 2003) for 'The Four-Category Ontology: A Metaphysical Foundation for Natural Science', from October 2003 to September 2004.

4. Details of the impact

Lowe has a well-established reputation in the applied ontology community, owing to his wide-ranging work in the 'commonsense' tradition in metaphysics. His research on the four-category ontology is promoted by several world-leading figures in applied ontology. The four-category ontology is especially attractive to information systems designers for two main reasons. First it renders explicit — while also refining and formalising — our intuitive classificatory distinctions, making it a 'human-friendly' formal system, which enables human users to cope more easily and effectively with the human/machine interface in complex information processing tasks. This quality is vital for modern information systems, which include vast amounts of information, of many different kinds, from a great diversity of sources. Second, it is a 'top-level' and 'domain-neutral' ontology, which gives it enormous scope. (It is 'top-level' in that it focuses on the most general and basic ontological categories, to one or other of which all entities belong; it is 'domain-neutral' in that it can be applied in any field of inquiry.) Many existing information systems utilise only lower-level and domain-specific ontologies, encompassing only entities involved in a relatively limited range of data (for example, biochemical or neurological data). However, with the information-processing power of modern computers increasing exponentially, with a corresponding increase in the quantity and complexity of information, there is a growing desire and need to systematise and collate information across many different domains. This demands a 'top-level' and 'domain-neutral' ontology which can, in principle, accommodate any sort of entity whatever, thereby providing a framework for organising information from any possible source and domain.

Lowe's four-category ontology has fulfilled these requirements, providing a robust ontology that can classify information from all domains and sources according to principles which are cognitively intuitive and human-friendly. As a result, his research has had a significant influence upon a diverse range of applied ontologists and information systems designers. Because of this, Lowe was invited to present the opening keynote address at a premier conference in the field, the International Conference on Formal Ontology in Information Systems (FOIS) in Ogunquit, Maine, 2001. Subsequent interaction between Lowe and applied ontologists culminated in a two-day workshop in May 2013, which focused on 'Information Systems and the Four-Category Ontology'. Lowe has thus been in direct dialogue with world-leading applied ontologists representing the three main international centres for applied ontology: the Director of the National Center for Ontological Research (NCOR, Buffalo, New York), the Director of the Laboratory for Applied Ontology (LAO, Trento, Italy), and a leading researcher at the Institute for Formal Ontology and Medical Information Science (IFOMIS, Saarland University, Germany). All three were present at the 2013 workshop, where Lowe presented recent developments in the four-category ontology and discussed potential practical applications to the current projects at NCOR, LAO, and IFOMIS.

The research has proved indispensable to the applied ontology community in two principal ways:

(i) Development of Ontologies:

The four-category ontology has been fundamental to the work of the most influential applied ontologists. It is extensively cited in the biannual proceedings of the Formal Ontology in Information Systems conference (2004, 2006, 2010) and in all of the major articles by the NCOR and LAO directors, themselves amongst the most cited figures in applied ontology and information systems theory (with over 30,000 citations between them). The applied ontology and information systems community spans not only academic but also important industrial, commercial, medical and governmental organisations, and influences the design and/or use of information systems in a very diverse range of contexts. For instance, non-academic partners of the main centres at NCOR, LAO, and IFOMIS include IBM, the US National Institute of Standards and Technology, and the US Department of Defense. Without Lowe's research, key developments in applied ontology would not have happened, developments that have been put into practice in both academic and non-academic contexts. The NCOR director writes of Lowe's 'foundational role' in describing the 'basic ontological categories' upon which the NCOR relies, while the LAO director explains that it was through studying Lowe's work that he 'realised that formal ontology can capture the fundamental categories and relations' needed for the design of effective information systems. A researcher at IFOMIS describes Lowe as 'one of the analytical philosophers who have had the greatest impact on applied ontology research and development,' and comments that 'Professor Lowe's work on ontology has been and still is indispensable for establishing applied ontology as a field of its own in the area of computing science in general and of information systems in particular.'

To be more specific, Lowe's four-category ontology has contributed fundamentally and directly to the development of two of the most important formal ontologies currently used in information systems theory – namely, Domain Ontology for Linguistic and Cognitive Engineering (DOLCE), developed by researchers at the LAO, and Basic Formal Ontology (BFO), developed by the research groups at IFOMIS and, later, NCOR, which hosted a 2006 conference in Lowe's honour, at which he gave the keynote address. Hence the principal beneficiaries of this research are the developers and users of these ontologies.

DOLCE and BFO were both launched in 2002 and have been continually used and updated ever since – for instance, BFO version 2 was launched in July 2012 - and provide domain ontologies that enable information retrieval, analysis, and integration in scientific, medical, and other domains. Those two ontologies between them form the basis of over one hundred applied projects in areas ranging from biomedical classification, cancer research, pharmacology, earth sciences, epidemiology and workflow management systems, all of which require DOLCE and BFO to organise and process vast amounts of data from diverse sources and formalise it in human-friendly information systems. A total of 67 major organisations are listed on the DOLCE and BFO websites as users of these ontologies. They include AstraZeneca, IBM, the UN Food and Agriculture Organisation, the Bulgarian Academy of Science, and the New York State Center of Excellence in Bioinformatics & Life Sciences.

Furthermore, Lowe's metaphysics is also playing a central role in the development of particular domain ontologies, of which two examples are given here. (i) Biomedical ontologies that build upon BFO have been influenced not just by Lowe's four-category ontology, but also by his closely connected work on individuation, identity, dispositions and tendencies. These ontologies are of special interest to biologists and epidemiologists, for instance when attempting to model the spread of infectious diseases. A leading biomedical ontologist describes Lowe as 'one of my main points of reference' and confirms that that his research is 'very much esteemed in the bio-ontological community'. In particular, Lowe's account of probabilistic dispositions (roughly, 'tendencies') has initiated new avenues of research into biomedical ontology, especially in relation to the development of disease ontologies. (ii) Lowe's work is also applied in the Library of Congress Functional Requirements for Bibliographic Records (FRBR) Ontology, which is a general conceptual model for bibliographic records (and relationships between them), developed by the International Federation of Library Associations and Institutions. The model is designed to govern the development of cataloguing rules within particular systems.

(ii) Education and training:

Lowe's research also has a wider influence on the fields of applied ontology and information-systems design, by featuring prominently in educational documents and training courses. His distinctive conception of metaphysics and ontology is adopted by leading state-of-the-art texts in applied ontology, such as the IFOMIS training document 'Ontology for the Twenty First Century: An Introduction with Recommendations' (a freely-available key training resource for the applied ontology community, hosted by organisations including the Neuroinformatics Center at the University of Oregon and the School of Information Science at the Federal University of Minas Gerais, Brazil) and Katherine Munn and Barry Smith's *Applied Ontology: An Introduction*. Both of these explicitly acknowledge the fundamental influence of Lowe's work upon applied ontology and information systems; for instance, the former lists Lowe alongside Aristotle, Kant, and Quine as a major figure in the history of ontology, while the latter describes him as 'one of the most important contemporary representatives' of categorial ontology that is of special value to the applied ontology community. The importance of Lowe's four-category ontology was also recognized by its incorporation into the training session 'Ontological Analysis: The Philosophical Perspective' at the First International Summer School in Ontological Analysis held in July 2012 at Trento, Italy (attended by 80 students, researchers, and practitioners of applied ontology and computer science).

5. Sources to corroborate the impact

1. The Director of the National Center for Ontological Research (US) reports on Lowe's foundational contributions to applied ontology, information systems, and biomedical ontology.
2. The Head of the Laboratory for Applied Ontology (Trento), who is Editor-in-Chief of *Applied Ontology* and President of the International Association for Ontology and its Applications (IAOA), testifies to Lowe's foundational importance to the discipline of applied ontology.
3. A researcher at the Institute for Formal Ontology and Medical Information Science (Saarbrücken, Germany) testifies to Lowe's impact on applied ontology research and development.
4. The Principal Investigator of the 'Good Ontology Design' project (Rostock, Germany) reports on Lowe's contributions to biomedical ontology and his wider reception within the biomedical ontology community.
5. The website of BFO lists and details the ninety-five ontologies and thirty-nine institutions which use it, including a wide range of medical, scientific, agricultural, pharmaceutical and information systems development organisations and companies: http://www.ifomis.org/bfo/users
6. The website of DOLCE lists the twenty-eight institutions and corporations who use it, including the IBM Software Group and the IBM Watson Research Centre: http://www.loa.istc.cnr.it/dolcus.html
7. The website of the National Center for Ontological Research at Buffalo includes a searchable electronic database indicating Lowe's substantial influence on applied ontology. http://ncor.us