Institution: University of the West of England, Bristol

Unit of Assessment: 11 - Computer Science and Informatics

Title of case study: More efficient and effective requirements engineering in the aerospace industry using the newly developed ontology-driven methodology, OntoREM

1. Summary of the impact

The Airbus company has used OntoREM, a semi-automated methodology developed at UWE Bristol, for developing systems' requirements specifications and improving the quality of such specifications. This has saved Airbus [text removed for publication] cost and time to develop aircraft operability requirements for wing design and industrialisation in two different aircraft programmes - with a significant increase in requirements reusability. It has enabled improved assessment of risk in advance of a project's start through prior estimation of the cost and time of developing requirements. This has allowed reliable forecasts and scheduling, and better management of the expectations of a project's key stakeholders.

2. Underpinning research

Dr Mohammed Odeh (Senior Lecture at UWE 1999-2011, Associate Professor 2011-present) has led requirements engineering research at UWE Bristol (from 2006-2010) into bridging the gap between sets of needs (the "problem domain") and the specification of systems that can meet them (the "solution space"). The challenge has been whether it is feasible to make a productive and intelligible bridge between a model of a business process and a model of a computer-based system in some form so as to mirror, support and potentially automate the business process.

The research in [1] resulted in methods for modelling business processes on the one hand and computer-based systems on the other, between which a form of regular translation or conversion was found to be possible. Furthermore, *re-modelling* of business processes to achieve better representation [5] and realisation of quality aspects was demonstrated. This was achieved by adapting a software engineering approach to linking non-functional requirements (NFR) to conceptual models [4]. This demonstrated that NFR graphing, including operationalisation, interaction analysis and evaluation of goals could produce an NFR model of a business process.

An *ontology* is an explicit specification of a conceptualisation – it captures the agents and processes involved and relationships between them. Odeh researched: (i) the differences and similarities between *domain* ontologies and *generic/transferable* conceptual models; and (ii) the role that ontologies can play in establishing *usable* conceptual models during the process of developing information system requirements. This revealed that the generated conceptual models *based on* ontologies provided a high degree of accuracy in identifying the substantial domain entities and their relationships derived from the consensual semantics of domain knowledge [3]. In addition, the research in [2] revealed the significance of requirement reusability: on average 43% of typical computer-based systems functionality is domain independent leaving 57% as domain dependent.

Collectively, the above findings resulted in the development of knowledge-driven semi-automated methods and processes to capture end-user needs, goals and requirements, and analyse and validate them. The resulting systems' requirements specifications are rigorously representative of the underlying business processes and are highly reusable, correct, complete and consistent. A distinctive approach to requirements engineering (RE) has therefore been identified that is *knowledge driven* rather than only *process driven*. Thus, the RE process: (i) becomes proactively driven by domain specific ontologies that can be utilised to generate system models including conceptual data models such as ER (Entity-Relationship) models; and (ii) connects the overarching non-functional requirements, and natural, traditional and organisational divides (including roles and interactions undertaken in specific business processes) among all stakeholders involved. Consequently, the outcomes will include an agreed body of domain knowledge that is not only specified in an unambiguous way but which also reflects all stakeholders and system requirements

with high completeness, consistency, and correctness in a form that is machine interpretable.

The research work of Odeh came to the attention of Dr Mario Kossmann of Airbus resulting in joint development of a new semi-automated requirements engineering methodology and software tool called **Onto**logy-driven **R**equirements **E**ngineering **M**ethodology (**OntoREM**). OntoREM is *knowledge centric*: the representations of the requirements allow the knowledge to be re-used in further applications of the OntoREM process in new contexts within the same domain – in this case the aerospace industry.

OntoREM is based on the triangulation of three key components, namely the OntoREM metamodel, the OntoREM process and OntoREM specific tooling support. OntoREM's RE process is distinctive in being a generic process and is represented using the Ontology Web Language – Description Logic (OWL-DL) and thus is fully machine interpreted. Generic workflows, roles, activities and other elements of this process can be instantiated for particular applications in specific organisations and fields of interest. The domain ontology metamodel, another key component, is also represented using OWL-DL. As well as capturing information that becomes the content of the domain ontology, it acts as a blueprint not only to maintain existing domain ontologies, but also to instantiate and develop new ones.

3. References to the research

[1] Odeh, M. and Kamm, R. (2003). Bridging the Gap between Business Processes and System Models. *Information and Software Technology*, 45 (15), pp. 1053-1060. http://dx.doi.org/10.1016/S0950-5849(03)00133-2

[2] Issa, A., Odeh, M. and Coward, D. (2006). Using Use-Case Patterns to Estimate Reusability in Software Systems. *Information and Software Technology*, 48 (19), pp. 836-845. http://dx.doi.org/10.1016/j.infsof.2005.10.005

[3] El-Ghalayini, H., Odeh, M. and McClatchey, R. (2007). Engineering Conceptual Data Models from Domain Ontology: A Critical Evaluation. *International Journal of Information Technology and Web Engineering*, 2 (1), pp. 57-70. http://www.igi-global.com/article/engineering-conceptual-data-models-domain/2624 or http://dx.doi.org/10.4018/jitwe.2007010105

[4] AbuelRub, F., Odeh, M. and Beeson, I. (2007). Modelling Non-Functional Requirements of Business Processes. *Information and Software Technology*, 49 (11-12), pp. 1162–1171. http://dx.doi.org/10.1016/j.infsof.2006.12.002

[5] AbuelRub, F., Odeh, M., Beeson, I., Pheby, D. and Codling, B. (2008). Modelling Healthcare Processes Using Role Activity Diagramming. *International Journal of Modelling and Simulation*, 28 (2). http://dx.doi.org/10.2316/Journal.205.2008.2.205-4546

4. Details of the impact

OntoREM has been applied in the aerospace company Airbus. One key application to date has been in the development of aircraft operability requirements for the wing design. This has entailed instantiating the OntoREM approach using its RE process and domain metamodels and the development of domain ontologies specific to Airbus' aircraft operability and wing domains. This resulted in the generation of requirements specifications for Airbus that embodied both existing and newly identified requirements. These are concerned with ensuring effective and efficient full life cycle support of aircraft regarding maintenance, repair and other operational airline aspects, as well as health and safety.

OntoREM was initially developed and implemented as a prototype, together with its supporting tools: **Onto**logy-driven **R**equirements **A**nalysis **T**ool (OntoRAT) and **O**ntoREM **M**ind**M**apper (OMM) both funded by Airbus and researched and developed by UWE in collaboration with Airbus.

A number of different case studies were pursued following that in the aircraft operability domain, in particular in the domain of aircraft industrialisation. Here the industrialisation requirements for a

major aircraft program were specified using OntoREM.

A direct *comparison* of data from these case studies using OntoREM was made with two other cases for which Airbus's traditional RE approach had been applied. Underlining the advantages of an ontology-based approach to RE, the comparison revealed significant RE process improvements concerning: cost savings; enhanced quality of the resulting requirement specifications; and reduced time taken to generate them.

Airbus has reported the following specific impacts during its application of OntoREM to date.

Improved quality of the final requirement specifications

Three quality indicators were compared: (i) overall completeness of the individual requirements statements; (ii) their completeness in terms of mandatory attributes and link information; and (iii) their structure. On these measures, the ones generated using OntoREM were significantly better than those developed using the traditional approach. This is largely because the OntoREM RE process and domain ontology metamodels enforced the population of all mandatory attributes, ensured integrity with the relevant domain ontologies and automatically compiled requirements in a predefined structure.

Time and cost savings

The development of new AO requirements using OntoREM took less time than using the traditional Airbus approach [text removed for publication]. Cost savings from using OntoREM in the above mentioned case studies also resulted [text removed for publication]. This does not take into account further savings resulting from the higher quality of the requirement specifications, such as the reduced corrective reworking later in the development lifecycle, or from re-use of the specified domain ontologies for new aircraft programmes [S1].

Reusable domain knowledge

An additional advantage of the OntoREM process has been the development of domain ontologies that serve as a formal repository of validated domain knowledge that can therefore be re-used in new projects once they have been validated by experts, with minimal need for further validation apart from periodic/cyclic verifications of the integrity of the domain ontology. This has therefore demonstrated scalability of using OntoREM for aircraft programmes within Airbus, with further cost and time savings. "*The saving potential in case of a larger scale application of OntoREM and even more so considering the re-use of domain ontology once it has been specified for the first time, is of course of a very different order of magnitude.* [text removed for publication]" [S1].

Improved advanced estimation of the cost of requirements development

OntoREM has made it possible to forewarn programme managers of the likely percentage of re-usable requirements and the proportion of new requirements. This in turn enables more accurate estimates of the time and costs of developing projects' requirements, and informs the level of associated risk, e.g. a high proportion of new requirements implies higher associated risks for the programme.

OntoREM has delivered these benefits in a real industrial environment, with substantial, measurable cost savings to Airbus.

A joint IPR document between UWE and Airbus has been formally signed. Airbus fully funded the cost of filing a US patent concerning OntoREM in February 2012 [S2] reflecting OntoREM's significance and its expected contribution to next generation requirements engineering at Airbus. Airbus has subsequently invested [text removed for publication] to apply a new derivative of OntoREM to a further area, its Photonics research project with development cost savings already identified [S1].

Airbus and UWE have been working on developing OntoREM into a full industrial platform to include: (i) transnational use of OntoREM by many concurrent users and integration with organisations' IT systems; and (ii) linking the OntoREM process and its metamodel with configuration and quality management processes generically and thus instantiating these into

particular organisation-specific implementations.

OntoREM has also been the driver for collaboration with Airbus, SogeClair France and P3 Germany to develop the business case for establishing the *European Institute for Configuration Management* (EICM). This is intended to be the European focal entity for configuration management research/development, training and certification with UWE Bristol nominated as its EU-headquarters [S3]. EICM objectives include: (i) advancing the state of the art (research and development) in configuration management including processes, tooling and integration with the other stages of the systems development life cycle; and (ii) aspiring to achieve and sustain world-wide recognition as a leader in developing standards and processes for "best practices" in configuration management.

5. Sources to corroborate the impact

All of the documents listed below are available from UWE, Bristol.

S1. **Testimonial** [1 on REF system] from Systems Engineering Specialist and Engineering Directives Manager and also from Configuration Management Process Architect, **Airbus** (21 October 2013) – corroborates the benefits and cost savings resulting from the implementation of OntoREM at Airbus and also the Photonics Project.

S2. Document corroborating filing of US patent.

S3. **Testimonial** [2 on REF system] from Configuration Management Process Architect, **Airbus** (16 October 2013) – corroborates that OntoREM stimulated the development of the new European Institute for Configuration Management.