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Title	Ontological support for the use of design science research results
Authors	Reiterer, Emanuel;Venable, John R.
Publication date	2016-05
Original Citation	Reiterer, E. & Venable, J. R. 2016. Ontological support for the use of design science research results. In: Parsons, J., Tuunanen, T., Venable, J. R., Helfert, M., Donnellan, B., & Kenneally, J. (eds.) Breakthroughs and Emerging Insights from Ongoing Design Science Projects: Research-in-progress papers and poster presentations from the 11th International Conference on Design Science Research in Information Systems and Technology (DESRIST) 2016. St. John, Canada, 23-25 May. pp. 75-82
Type of publication	Conference item
Link to publisher's version	https://desrist2016.wordpress.com/
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Download date	2026-11-07 10:29:48
Item downloaded from	https://hdl.handle.net/10468/2569

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Ontological Support for the Use of Design Science Research Results

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Abstract. *In applied fields of research, Design Science Research (DSR) produces practical and theoretical knowledge in the form of descriptions of new artefacts with utility for particular purpose(s). People, including researchers and practitioners, need to identify, access, comprehend, and synthesize DSR results. This paper addresses these issues by describing and demonstrating a design of a formal DSR ontology approach to represent the essential semantics of the DSR results presented in a DSR document. The proposed ontology (DSRDCO) extends the UMBEL reference ontology of over 35,000 concepts. DSRDCO can be used in the context of a digital library or of the semantic web and can support search and automatic summarisation of DSR publications. Ideally, a summary of DSR results would fulfil five Cs: comprehensive, concise, coherent, correct, and clear. Feasibility of this approach has been evaluated by demonstration, which will be followed by an expert evaluation.*

Keywords: Design Science Research, digital library, ontology, ontology population, exploratory search

1 Introduction

Researchers and practitioners need to identify, access, comprehend, integrate, and synthesise DSR results reported in documents (papers, books, websites). However, doing so presents problems in locating documents, interpreting those documents into DSR knowledge, and merging and understanding knowledge contained in publications.

Existing digital library systems' search facilities and web search engines mainly return answers to queries in the form of lists of publications. These lists sometimes contain snippets, excerpts, or definitions from trusted sources of the searched documents. However, a more useful search result would attempt to summarise the essential information of the returned documents from a perspective that is relevant to and usable for the user. A highly useful search result summary would ideally meet five desirable characteristics (the five Cs): comprehensive, concise, coherent, correct, and clear.

For example, practitioners might want to find all solutions for a specific problem or researchers might want to search for all applications of a particular artefact.

One potential approach to achieve the five Cs in summarising DSR research is to codify the DSR knowledge contained in papers according to a formal ontology of DSR.

This approach has three main components: (1) a formal ontology to represent the essential semantics of DSR results presented in a DSR document called the DSR Document Core Ontology (DSRDCO), (2) ontological representations of DSR publications and (3) cloze text patterns for presenting DSR result summaries.

DSRDCO extends the UMBEL ontology (Structured Dynamics LLC 2012), which currently contains over 35,000 concepts. The DSR content of each DSR paper is stored according to the DSRDCO, together with links to the relevant parts of the original documents. DSRDCO can be used in digital libraries or on the web to support search and automatic summarisation of DSR publications. Instances of DSRDCO for individual publications can either be stored collectively with publications in a database or could be distributed as annotations to publications across the web. The implemented reasoning strategies to create summaries use certain features of ontologies, such as UMBEL. Some features used to identify, for example, artifacts or similar artifacts, are hierarchical information and logical descriptions of classes, also called complex classes. Cloze text templates provide patterns for summaries that can be filled in with instances of concepts drawn from the DSRDCO representation of individual DSR publications.

The next section provides a literature review of DSR and formal ontologies, followed by an analysis of the requirements of the proposed approach. After that, the proposed ontology and the cloze text templates are described followed by a demonstration. Finally, the paper concludes with a discussion of the proposed approach.

2 Literature Review

This section reviews key literature on DSR and formal ontologies to provide a better understanding of the problem domain. This key literature together with a more extensive set of DSR literature has been used to identify main concepts of DSR and their relations, which was used in the top-down design process of the DSRDCO.

Venable and Baskerville (2012, 142) define DSR as "research that invents a new purposeful artefact to address a generalised type of problem and evaluates its utility for solving problems of that type." It must be a means to achieve some end or purpose.

The term Design Science Research follows from Simon's The Sciences of the Artificial (Simon 1996) and is commonly used in the field of Information Systems. The DSR research paradigm applies in any applied field, which universally develops new technological means to solve problems and make improvements (Venable 2010).

March and Smith (1995) identified four kinds of "design artefacts" produced by DSR: constructs that describe problems or solutions, models that express relationships between constructs, methods also called process artefacts, and instantiations that realize a model or method.

Many proponents of DSR see design theories as a product of DSR (Baskerville and Pries-Heje 2010, Gregor and Jones 2007, Walls, Widmeyer, and El Sawy 1992). A design theory asserts a relationship between the artefact's purpose and solution. There has been less agreement about the need for other components proposed for design theories, including kernel theories (Walls, Widmeyer, and El Sawy 1992) or justificatory knowledge (Gregor and Jones 2007), testable hypotheses (Walls, Widmeyer, and El

Sawy 1992) or testable propositions (Gregor and Jones 2007), artefact mutability (Gregor and Jones 2007), and principles of implementation (Gregor and Jones 2007).

Models for how to conduct DSR reach from simple two stage models ("build" and "evaluate" (Hevner et al. 2004, March and Smith 1995)) to more complex process models with multiple stages (Peffers et al. 2007, Vaishnavi and Kuechler 2004). However, all of these process models include a stage or activity for evaluation.

The term formal ontology used in this paper refers to an information object used as a computational artefact and is defined as an "explicit, formal specification of a shared conceptualization" (Borst 1997). This paper deals with the category of core ontologies (Breuker, Muntjewerff, and Bredeweg 1999). Core ontologies define what is relevant in a domain (Breuker, Muntjewerff, and Bredeweg 1999) (in our case DSR).

Various languages, e.g. OWL (web ontology language), are used to express ontologies. Basic elements of OWL are classes, properties, instances of classes, relationships, and axioms (W3C 2012). An ontology usually consists of Terminology boxes and Assertional boxes (Baader 2003). T-boxes define the classes, properties, relationships, and axioms, while A-Boxes provide instantiations of those definitions, similar to how objects instantiate a class. Ontologies can be stored in text files, relational databases, and triple or quad stores. A triple consists of a subject, a predicate and an object. A quad extends this triple by a graph element that can used to represent the context.

3 Requirements Analysis for DSR Search Support

A high quality DSR article representation or summary would have five qualities (the five Cs). Such a summary would be (1) *comprehensive* if it includes all the relevant concepts and knowledge conveyed in an article. Such a summary would be (2) *concise* if it does not contain irrelevant concepts and knowledge. It would be (3) *coherent* if all the concepts and knowledge are well organised and related to each other. It would be (4) *clear* if all concepts and relations can be clearly understood and (5) *correct* if it does not draw any incorrect conclusions, including inconsistencies. A summary needs to be produced automatically, which requires computer-readable and computer-processable content. The purpose of the DSRDCO is to provide a data structure that makes it possible to store essential information about DSR documents and support reasoning over instantiations of this ontology to extract information to get a summary and/or a combined search result that meets the five Cs. The five Cs are based on the semiotic metrics suite for ontology evaluation by Burton-Jones et al. (2005) to reflect syntactic, semantic, and pragmatic aspects. All these aspects relate to the informativeness and quality of summaries mentioned in (Lloret and Palomar 2012).

4 Design Science Research Document Core Ontology (DSRDCO)

The DSRDCO represents the domain of DSR in addition to argumentation in publications that follow the DSR paradigm. Figure 1 depicts core DSR concepts (which will

serve as reference concepts) that make up the DSR-specific portion of DSRDCO. Links to UMBEL supertypes as well as other aspects of DSRDCO, such as document structure, document meta-data, etc. are not shown in figure 1, but are part of DSRDCO. The OWL DL ontology language has been chosen to describe DSR publications.

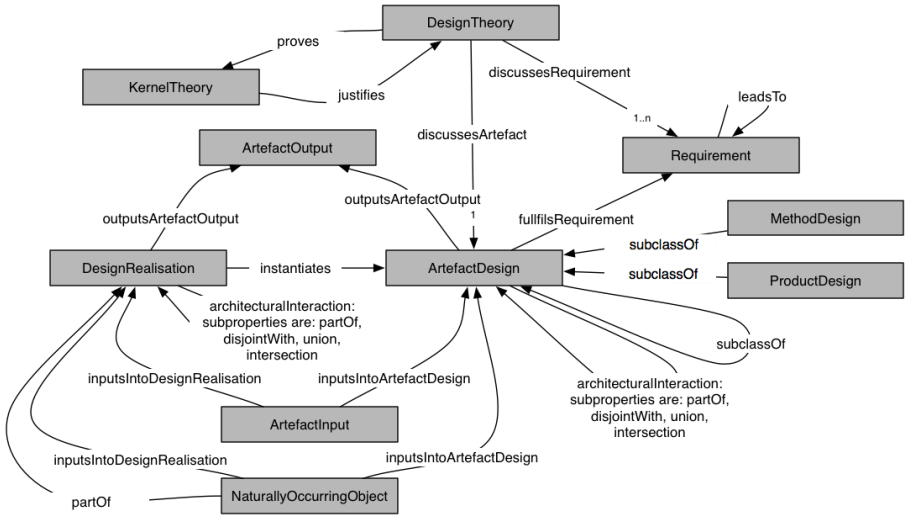


Fig. 1. Ontology Model of DSR aspects of DSR Document Core Ontology (DSRDCO)

The DSRDCO needs to fit a shared understanding of DSR. The following concepts are used by many proponents of DSR as outlined in section 2. A bottom-up approach was also used to identify concepts out of DSR articles. Firstly, in DSR, *ArtefactDesigns* are produced. These artefacts are either models (*ProductDesign*) or methods (*MethodDesign*). The concept *Requirement* together with the concept *ArtefactDesign* expresses the context of a specific piece of DSR. We chose the name *ArtefactDesign* (in comparison to *DesignArtefact*) to emphasise the design aspect of DSR. A *DesignTheory* consists of one *ArtefactDesign* that fulfils a set of *Requirements*. A *DesignRealisation* is usually used to evaluate a *DesignTheory* in providing evidence that the *ArtefactDesign* is capable of reaching the requirements. A *DesignRealisation* must also instantiate any components or other assertions that have been made concerning its corresponding *ArtefactDesign*. Interaction between *ArtefactDesigns* and *DesignRealisations* are either of functional (use of *ArtefactInput* and *ArtefactOutput*) or architectural nature. Object properties, such as *fulfilsRequirement*, are used to define associations between instances of classes and are important to express semantics to relate concepts.

A key aspect of a good DSR article is its argumentation (not included in figure 1). Two main things have to be argued about: *ArtefactDesign* and its *Requirements*. The thesis or *MainClaim* of a DSR paper is that the focal *ArtefactDesign* fulfils some *Requirement(s)*. The *MainClaim* is supported by expressing its *TheoreticalSignificanceClaim*, its *PracticalSignificanceClaim*, and by providing evidence that the *ArtefactDesign* fulfils the *Requirement(s)* through an *EvaluationArgument* or possibly a *BasisArgument*, in which an *ArtefactDesign* is based on an earlier *ArtefactDesign*.

5 Cloze Text Templates for Summaries

Below is an excerpt of a cloze text template for summarising a single article. Other templates (not included for space reasons) would be appropriate for summarising more than one article that matches a search query and require additional logical reasoning to fill the cloze text. In the template in figure 2 below, items within guillemets (e.g. "«top-level *ArtefactDesign*»") identify the blanks to be filled in and describes how they would be filled by reasoning from the reference concepts in the DSRDCO for the DSR publication being summarised.

«top-level *ArtefactDesign*»
Thesis statement
«*PublicationAuthor, PublicationYear*» describes an artefact named «top-level *ArtefactDesign*». The proposed artefact fulfils the requirements to «list of all *Requirements*».
Significance
The requirements to «list of *Requirements* with same significance» are significant to a «number of *StakeholderRole*» number of «*StakeholderRole*». In prior publications, «list of *CitedPriorArtPublications*», «*CitedPriorArtPublication's ArtefactDesign*» has been proposed using «list of *ArtefactDesigns* that are *partOf CitedPriorArtPublication's ArtefactDesign*». The novelty of the «main *ArtefactDesign*» lies in «list of *ArtefactDesigns* that (are *partOf* the main *ArtefactDesign*) and (are not *partOf* the *CitedPriorArtPublication's ArtefactDesign*)». In comparison to publications «list of *CitedPriorArtPublications*», a «*ImprovementType*» in «improved *Requirement*» of «*ImprovementAmount*» can be achieved.
Artefact description
The «top-level *ArtefactDesign*» consists of «list of second-level *ArtefactDesigns* that are *componentsOf the* top-level *ArtefactDesignn*».
[For each component with sub-components - recursively]
«component *ArtefactDesign*» consists of «list of *ArtefactDesigns* that are *componentsOf the* focal *ArtefactDesign*». …
[End For]
Evaluation
The artefact was evaluated by «EvaluationTechnique» with «Number» participants. Each participant conducted the following tasks: «list of tasks». The following aspects were evaluated: «list of evaluated *Requirements*».
[For each evaluated requirement and sub-requirements - recursively]

```
    «evaluated Requirement / sub-requirement» was evaluated by
     «EvaluationCriterion».
[End for]
```

Fig. 2. Partial Cloze Text Template for a Single DSR Publication

6 Example Demonstration

The ability of the DSR Ontology approach described in this paper has been demonstrated by (1) realizing DSRDCO representation in OWL, (2) applying DSRDCO to codify the essential DSR knowledge of sample DSR publications (i.e. creating a DSR Document Ontology instantiation), and (3) demonstrating that a cloze text summary template can be populated from the DSRDOs generated in demonstration step 2.

As a simplistic, but illustrative example of demonstration steps (1) and (2) above, figure 3 shows an OWL representation of the design realization portion of a DSRDCO.

```
<owl:Class rdf:ID="ArtefactDesign" />
<owl:Class rdf:ID="DesignRealisation" />
<owl:ObjectProperty rdf:ID="designRealisationInputsTo">
    <rdfs:domain rdf:resource="#DesignRealisation" />
    <rdfs:range  rdf:resource="#DesignRealisation" />
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="artefactDesignInputsTo">
    <rdfs:domain rdf:resource="#ArtefactDesign" />
    <rdfs:range  rdf:resource="#ArtefactDesign" />
</owl:ObjectProperty>
<ArtefactDesign rdf:ID="TextFeatureExtractionSequence">
    <artefactDesignInputsTo rdf:resource="#ClassificationStep" />
</ArtefactDesign>
<ArtefactDesign rdf:ID="ClassificationStep" />
<DesignRealisation rdf:ID="PrototypeOfTextFeatureExtractionSequence" />
    <designRealisationInputsTo rdf:resource="#PrototypeOfClassificationStep" />
</DesignRealisation>
<DesignRealisation rdf:ID="PrototypeOfClassificationStep" />
```

Fig. 3. OWL representation of a Design Realisation

Continuing the illustrative example and considering demonstration steps (2) and (3), figure 4 shows example potential output of the filled-in cloze text summary of a simplistic fictional paper using the cloze text (partial) provided earlier in figure 2. Note that the guillemets in figure 4 would not ordinarily be included in the summary.

Multi-speed bicycle architecture *a fictional example*
Thesis statement

«AuthorA, 19aa» describes an artefact named «multi-speed bicycle architecture». The proposed artefact fulfils the requirements to «commute cost effectively», and «commute with little human effort».

Significance

The requirements to «commute cost-effectively», and «commute with little effort» are significant to a «high» number of «people».

Artefact description

The «multi-speed bicycle architecture» consists of «derailleur gears». «Derailleur gears» consist of «a chain», «multiple sprockets», and «a gear shifting mechanism» that «moves the chain from one sprocket to another».

Evaluation

The artefact was evaluated by «a naturalistic human use experiment» with «30 participants». Each participant «travelled» «20 kilometres» «per day» for «3 days» «in an urban setting». The following aspects were evaluated: «commuting effort», and «commuting cost».

«Commuting effort» was evaluated by «measuring» «heart rate».

Fig. 4. Fictional example of populated single publication cloze text

Whereas researchers are naturally interested in the evaluation and significance aspect, practitioners usually use the evaluation aspect implicitly because it is part of the reasoning strategy. Significance statements are important for practitioners to see what novel concepts have been introduced or to see the benefit in using a specific approach.

7 Discussion

This paper presented parts of the design of a formal ontology to represent the domain of DSR results in DSR publications and examples of a part of its evaluation (through demonstration). This ontology is intended to be applied in ontology-enhanced digital libraries for DSR publications or across the semantic web. This approach will support the presentation of and reasoning over comprehensive, concise, coherent, correct, and clear summaries of publications that follow a DSR approach to support researchers and practitioners in their work. The problem addressed is general in nature and present in virtually all applied fields.

The evaluation has shown that the manual population of such an ontology is possible and that the proposed ontology includes all components necessary to describe a scientific article about DSR problems. Correctness and clarity of summaries will be evaluated in the follow-up expert evaluation to provide further evidence of the utility of summaries. These evaluations are currently in the process of being conducted for single document and multiple document summaries of real articles.

Evaluations conducted so far only artificially demonstrate the approach for formative (and illustrative) purposes. Further evaluations are under development to naturalistically evaluate outputs of the approach with both DSR and domain experts based on sample extant DSR publications in one or more applied domains.

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