Context Uncertainty in Requirements Engineering: Definition of a Search Strategy for a Systematic Review and Preliminary Results

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Abstract. [Context and motivation] Cyber-physical systems (CPS) and self-adaptive systems (SAS) strongly rely on the context they are operating in and need to adapt their behavior at run-time based on contextual information. Therefore, it is challenging to completely predict the context of such systems for their entire operating time already at design time. **[Question/problem]** Since several approaches dealing with uncertainty have been proposed for different research and problem domains in recent years, some might provide valuable insights for the engineering of CPS or SAS in uncertain contexts. However, there is no study so far that provides an overview of them. **[Principle ideas/results]** Thus, we aim at conducting a systematic literature analysis to create a research landscape of approaches coping with context uncertainty. **[Contribution]** We manually searched one journal and the proceedings of two conferences in the requirements engineering field to determine and evaluate the adequateness of search strings to be used in an automated search. In doing so, we can furthermore present preliminary findings from the manual search for uncertainty in the requirements engineering field.

Keywords: Uncertainty, Context, Requirements Engineering, Cyber-Physical Systems, Self-Adaptive Systems, Systematic Review, Search Strategy, Systematic Literature Search.

1 Introduction

During requirements engineering it is important to consider the context, into which the system under development will be deployed [1]. Hence, the context of a system should be documented explicitly at design time (e.g., [2]). This, however, can be challenging for CPS and SAS, whose contexts might not be completely predictable at design time, as is, for example, the case for long-living systems such as embedded systems in aircraft, which will have to interact with newer versions of other systems in the future [3]. Therefore, the engineering process must cope with a high degree of uncertainty.

In the past couple of years, several approaches for dealing with uncertainty have been proposed for different research and problem domains. As these approaches might provide valuable insights for the engineering of CPS or SAS in uncertain contexts, it is important to provide an overview of existing research.

In this paper we present the development of a search strategy for a systematic review on uncertainty. We particular focus on the development of a search string for an automated search and present preliminary results from the field of requirements engineering. The remainder of the paper is structured as follows: Section 2 briefly discusses related work regarding the definition of systematic search strategies. In Section 3 the process of our systematic search is introduced. Section 4 presents our preliminary findings, and Section 5 concludes the paper and gives an outline of future work.

2 Related Work

Systematic reviews, such as mapping studies [4] and systematic literature reviews [5], have proven useful to review the state of the art with respect to a certain topic and to derive research landscapes, since they are less biased and result in more reliable findings than ad-hoc reviews [6]. One example for a systematic review is provided by *Yang et al*. in [7]. The authors present a systematic literature review of requirements modeling and analysis for SAS, where they also categorize papers with respect to uncertainty. While the approach of *Yang et al*. can be seen as a basis for our study, we aim at focusing on context uncertainty in a more fine-grained sense. In addition, the final study shall not only be restricted to the field of requirements engineering, as techniques from other fields might be transferable to requirements engineering as well.

One important aspect of systematic reviews is the definition of a search strategy [8], i.e. defining which approach will be used to find the relevant literature. There are three main approaches for finding relevant papers: automated search, which uses predefined search strings on selected search engines, manual search of selected proceedings and journals, and snowball search, where the references of relevant papers are searched [8]. These approaches are often combined to reduce the number of missed papers. To conduct an automated search it is necessary to define a search string that will be applied to the selected search engines. This search string should filter out as many irrelevant papers as possible without filtering out any relevant papers.

Zhang et al. [8] propose the quasi-gold standard, a set of all relevant papers for a limited time span and a limited number of publication venues, which have previously been identified by manual search. The quality of a search string can, thus, be assessed by using it for an automated search that is limited to the same time span and publication venues, and calculating the sensitivity (i.e. the ratio between the relevant papers found and the total number of relevant papers found) and the precision (i.e. the ratio between the number of relevant papers found and the total number of papers found).

3 Systematic Literature Search Strategy

Our systematic search process can be divided into four steps. First, we manually searched the proceedings of the two main requirements engineering conferences: the *International Requirements Engineering Conference* (RE) and the *International Working Conference on Requirements Engineering: Foundation for Software Quality* (REFSQ) and the *Requirements Engineering Journal* (REJ) from 2010 to 2014 for articles on uncertainty. Not only did we search for papers that deal with context uncertainty, we moreover searched for papers that deal with uncertainty in general to also find approaches that could be adaptable to deal with context uncertainty. The manual search found the 23 papers presented in **Table 1**.

Table 1. Selected Papers

Venue	Selected Papers
REFSQ	[9], [10], [11], [12], [13], [14], [15], [16]
RE	[17], [18], [19], [20], [21], [22], [23], [24], [25], [26]
REJ	[27], [28], [29], [30], [31]

In the second step, we derived search terms for an automated search by analyzing title, abstract, and keywords of the selected papers to find the most frequently used words (excluding common words such as 'a' or 'is' and unspecific terms such as system or approach). **Table 2** shows the 10 most frequently used words and their frequency.

Table 2. Most Frequent Words in Title, Abstract, and Keywords

Word	Frequency
requirement(s)	133
uncertainty	59
adaptive	47
model(s)	46
self	25
engineering	22
result(s)	20
goal	18
monitoring	18
analysis	17

Search strings were then constructed in the third step, starting with the second most frequently used word 'uncertainty' and then using the Boolean "OR" to add further terms in order of their frequency until we reached acceptable sensitivity. Subsequently, further terms where added using the Boolean "AND" in an attempt to increase the precision without sacrificing too much sensitivity (see **Table 3**). The most frequent term 'requirement(s)' was not considered for two reasons. First, because the manual

search was limited to requirements engineering publications; thus, making it obvious that the term 'requirement(s)' will appear in almost every paper, and second, because we do not want to limit future searches to the requirements engineering field, as others might provide approaches that could be transferable to requirements engineering.

In the fourth and final step the derived search strings were evaluated with respect to their adequateness for an automated search. As **Table 3** shows, the search for the term 'uncertainty' resulted in a sensitivity of 78.26% and a precision of 27.27%. According to *Zhang et al*. [8], an acceptable sensitivity is reached at 72%, and an appropriate precision is reached at 15%. Even though acceptable, this search string still missed five papers. Hence, we tried to increase the sensitivity by adding the second search term 'adaptive'. This search found all papers in the quasi-gold standard, increasing the sensitivity to 100%, while lowering the precision to 24.21%. The search term 'adaptive' alone had a sensitivity of only 60.87%, thus making it unsuitable. The sensitivity values for the second search string "uncertainty OR adaptive" are more satisfactory than the values of the first one but the precision is lower, which makes the search more time-consuming. In an effort to increase the precision we tried adding, for example, the fourth most frequently used word to the search string using the Boolean "AND". While this did increase the precision slightly it also reduced the sensitivity by 25%, which means the search missed a quarter of the relevant papers. We therefore deem the search string "uncertainty OR adaptive" the most appropriate.

Table 3. Search String Evaluation

Search String	Sensitivity	Precision
uncertainty	78.26%	27.27%
uncertainty OR adaptive	100%	24.21%
adaptive	60.87%	29.17%
(uncertainty OR adaptive) AND model	78.26%	21.95%

Fig. 1 further illustrates the ratios between the relevant papers missed (light gray), the relevant papers found (shaded), and the irrelevant papers found (dark gray) by automated search for the four search strings and also the ratios between the quasi-gold standard (all papers found by manual search) and the (relevant and irrelevant) results from the automated search.

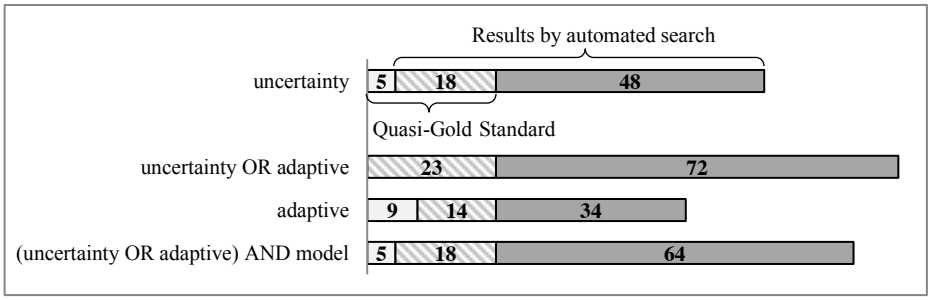

Fig. 1. Relationship between Quasi-Gold Standard and Automated Search Results

4 Preliminary Results

This section gives insight into preliminary results gained from the papers published at RE, REFSQ, and in the REJ between 2010 and 2014. **Fig. 2** depicts the annual publication volume for the years 2010 to 2014, which shows some fluctuations but no clear trend for those years.

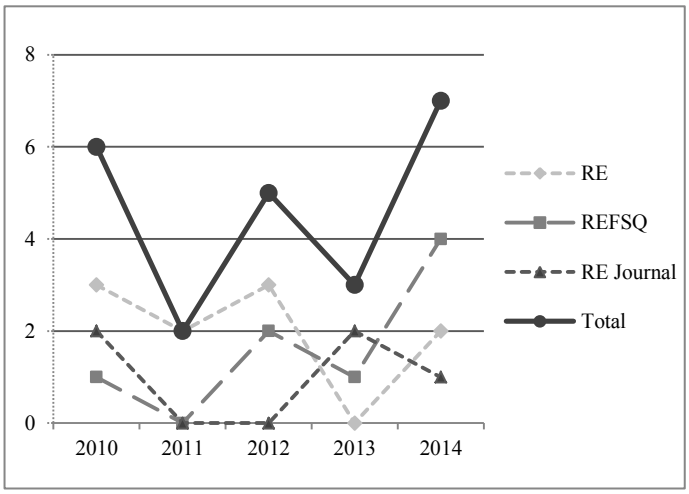

Fig. 2. Annual Publication Volume

We furthermore categorized the papers by the type of their main contribution, distinguishing between *problem statement*, *solution proposal*, *evaluation*, and *tool*. The findings show that most papers dealing with uncertainty propose solutions for current challenges (19 out of 23) or described a problem (4 out of 23). Yet, there were no papers whose main contribution was clearly an evaluation of a solution or a tool presentation, indicating that the problem of uncertainty is well understood and being solved but also showing a lack of evaluations regarding the feasibility and usefulness of the proposed solutions.

Additionally, the papers were categorized based on the life cycle phase (*run-time* or *design-time*) and the type of uncertainty the approaches deal with (*uncertain context* or *uncertainties within one context*). Note, that some papers were sorted into more than one category for each facet, while others, which did not provide the necessary information, were sorted into not specified categories. As **Fig. 3** shows most approaches deal with uncertainties within the context at design-time, very few with uncertain contexts at run-time, and none with uncertain contexts at design-time. Overall, more of the approaches are concerned with the run-time phase as opposed to the design-time phase.

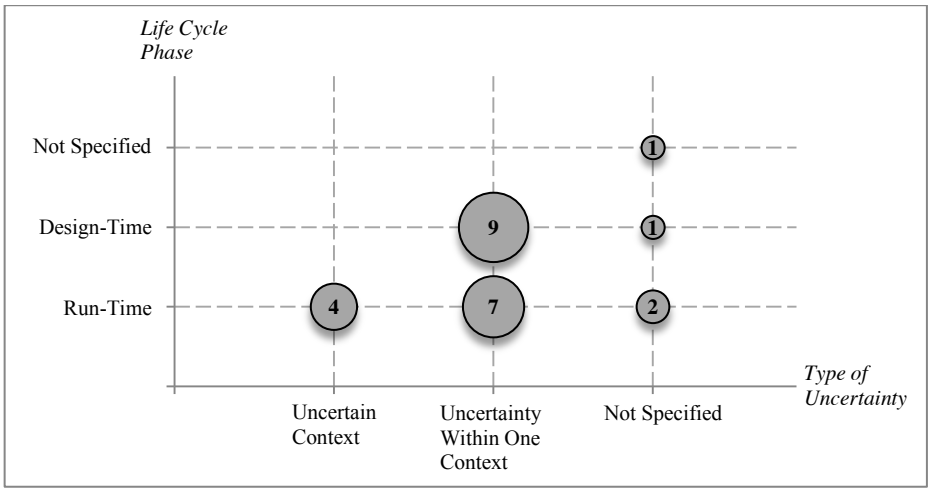

Fig. 3. Mapping Results

A frequency analysis of the keywords chosen by the papers' authors highlighted the importance of uncertainty for self-adaptive systems in particular (see **Fig. 4** for all keywords that were used in more than one paper). The frequency analysis also revealed a relatively high number of papers about goal models.

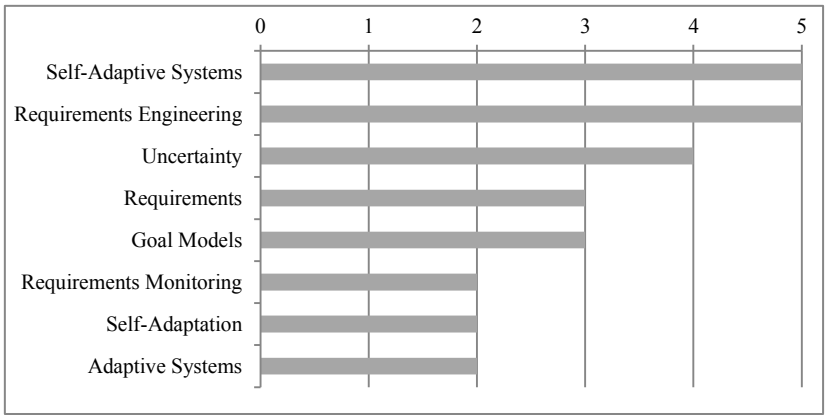

Fig. 4. Most Frequent Keywords

5 Conclusion and Future Work

In this paper, we presented preliminary results from a literature review on uncertainty in requirements engineering. The literature search was conducted manually for a limited time span and limited publication venues. Based on titles, abstracts, and keywords we derived search terms and evaluated their performance. In the future we are planning to use this for a more extended systematic review on uncertainty.

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