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Study of aggregation algorithms for aggregating imprecise software requirements' priorities

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ABSTRACT

Extensive Numerical Assignment (ENA) is a novel Requirements Prioritization Technique introduced by the authors that acknowledges the uncertain and imprecise nature of human judgment. A controlled experiment is conducted during which data are collected using ENA for the requirements assessment of university website system. The objective of this paper is to study how the imprecise data obtained from ENA can be aggregated using aggregation algorithms: Multiple Attribute Utility Theory (MAUT) and Interval Evidential Reasoning (IER) to generate requirements' priorities in the presence of conflicting personal preferences among assessors. A simplified version of IER called Laplace Evidential Reasoning (LER) is introduced and the results are discussed. LER has the potential to emerge as a competent aggregation algorithm when compared to MAUT and IER, because of its reasonable processing requirements when compared to IER and its ability to produce rich set of outputs when compared to MAUT.

1. Introduction

A Requirements Prioritization Technique (RPT) facilitates to perform Requirements Prioritization (RP), which is a very important and commonly practiced activity in software development. RP provides support to identify the small set of most valuable requirements out of a large set of requirements and still produce software that satisfies its customers. An ordered set of requirements obtained through prioritization helps to plan and select requirements to be delivered in successive releases of software. RP further helps to focus the best efforts of developers on the features that make it possible to develop right product in the right time. If RP is not properly planned and executed, then developers may likely end up in a product that does not satisfy customer expectations (Karlsson & Ryan, 1996). Several RPTs based on precise assessments are available in the literature and experiments investigating the characteristics of RPTs (Karlsson, Wohlin, & Regnell, 1997; Karlsson & Ryan, 1997; Lehtola & Kauppinen, 2004; Karlsson, Berander, Regnell, & Wohlin, 2004; Ahl, 2005; Sahni, 2016) record their usefulness under various environments.

Prioritization as a decision making problem has to deal with uncertain and imprecise nature of human judgment. Uncertainty is a popular idea in the literature on decision making (Lipshitz & Strauss, 1997; Tversky & Kahneman, 1974). Assessors are humans whose judgment is based on intuition, experience, intelligence, assumptions, opinions and beliefs, which is more likely to be subjective and imprecise rather than objective and precise. Psychologists pointed out that a assessor psychologically prefers ranges for judgment rather than single points (Viswanathan, Sudman, & Johnson, 2004). Therefore, subjectivity and imprecision of human judgment have to be properly acknowledged by the prioritization problem.

Requirements' priorities are uncertain guesses of the upcoming product. Imprecision and uncertainty during RP is attributed for several reasons like imprecise nature of human judgment, deficient knowledge of requirements, vagueness of meaning about requirements etc. The requirements decisions are thought to be hard because of the uncertainty and incompleteness of the information available (Ngo-The & Ruhe, 2005). Requirements uncertainty is also characterized as information deficit with respect to the specification of requirements (Keutel & Mellis, 2011). Several researchers have acknowledged the presence of uncertainty during Requirements Prioritization and other related concepts (Voola & Vinaya Babu, 2013). Hence, a clear need to develop an RPT, which can handle this imprecision and uncertainty has come into picture. Techniques that aid in determining priorities of requirements must give space to the inclusion of uncertainty as a central aspect. With this drive, authors have introduced Extensive Numerical

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Table 1
Interpretation of grades with ENA.

Grade	Interpretation
Low	A nice requirement to have, whose presence is desirable, where as its absence does not affect the level of satisfaction.
Medium	A fundamental requirement whose presence will be a cause for greater satisfaction, where as its absence will be a cause for greater dissatisfaction.
High	A crucial requirement that must be present, where as its absence makes the product unacceptable.
Low–Medium	A requirement whose importance can be precisely assessed neither to Low nor to Medium but may lie in between Low and Medium.
Medium–High	A requirement whose importance can be precisely assessed neither to Medium nor to High but may lie in between Medium and High.
Low–High	A requirement whose importance the assessor is completely unsure of and may lie anywhere in between Low and High.

Assignment (ENA) that is a tailored version of Numerical Assignment (NA), acknowledging uncertainty (Voola & Vinaya Babu, 2013).

A controlled experiment is conducted with a closer look at the three RPTs: Numerical Assignment, Analytic Hierarchy Process (AHP) and Extensive Numerical Assignment. The aim is to understand the capability of ENA in dealing with the uncertain and attitudinal nature of human judgment by collecting some objective and subjective measures like time consumption, usability, attractiveness, reprioritizability and scalability. The experiment is conducted with students assessing the importance of requirements for our university website system. The list of requirements used for the experiment is provided in Appendix A. ENA based on interval scale emerged as an efficient RPT in modelling the imprecise and uncertain nature of human judgment very closely with reasonable effort.

ENA is modelled as a Multiple Attribute Decision Making (MADM) problem incorporating subjectivity and uncertainty, where assessments about requirements' importance are expressed using belief functions. Several conventional methods like AHP (Saaty, 2008), Simple Additive Weighting (SAW) (Hwang & Yoon, 1981) and ELECTRE (Roy, 1991) for solving an MADM problem are available in the literature, which do not incorporate uncertainty element. However, Multiple Attribute Utility Theory (MAUT) is one of the conventional methods, which is capable of solving an MADM problem with or without uncertainty (Keeney, 1972).

Solving an MADM problem incorporating uncertainty has become familiar with the introduction of Evidential Reasoning (ER) approach (Yang & Xu, 2002). This is a nonlinear aggregation algorithm where belief functions aggregation is based on combination rule of the Dempster–Shafer theory of evidence. ER is extended to incorporate interval uncertainty and thus named Interval Evidential Reasoning (IER). IER demands complex processing requirements. Laplace Evidential Reasoning (LER) is introduced by the authors, which uses Laplace Principle of Insufficient Reason to simplify the complex aggregation process of IER.

MAUT, IER and LER are compatible aggregation algorithms to work with inputs in the form of belief functions obtained using ENA. The objective of this paper is to examine how the requirements' assessments obtained using ENA can be aggregated using MAUT, IER and LER to produce rigorous and reliable results, in the presence of conflicting personal preferences among assessors. MAUT is linear whereas IER and LER are nonlinear aggregation algorithms. The algorithms are discussed in the context of the RP problem used in the experiment.

Section 2 gives a brief introduction of ENA. The description, operation and the results produced by the three aggregation algorithms: MAUT, IER and LER are discussed in Section 3. A comparison of the results obtained with the three is discussed in Section 4. Section 5 presents the conclusion and future work.

2. Description of ENA

NA is a simple, easy to understand and widely used RP technique, where requirements' priority is assigned precisely to one of the assessment grades: Low, Medium and High. But, in reality requirement's priority assessment cannot be done precisely for several reasons as discussed in Introduction. With this drive, NA is made extensive in order to incorporate the inherent imprecision of requirements' priorities. The enhanced technique is called ENA. With ENA, imprecision is expressed by means of probability, which is a measure of the degree of belief in the assessment done. ENA allows assessors to express uncertainty using probability distribution across individual and interval assessment grades. This notion of expressing imprecision is derived from the earlier studies (Hampton, Moore, & Thomas, 1973; Moisiadis, 2002; Nguyen, Kreinovich, & Zuo, 1997).

The assessment grades chosen vary from application to application and must be mutually exclusive and collectively exhaustive. Following this, the grades and their interpretations as shown in Table 1 are chosen and communicated to the assessors of requirements' priorities. The individual and interval grades shown in Table 1 along with probabilities facilitate in expressing uncertainty, ignorance and incompleteness. A requirement can now be assessed in the form of belief function

$$\{(L, l\%)\ (M, m\%)\ (H, h\%)\ (LM, lm\%)\ (MH, mh\%)\ (LH, lh\%)\} \quad (1)$$

where l, m, h are the degrees of belief associated with the individual grades: L(Low), M(Medium) and H(High) respectively and lm, mh, lh are the degrees of belief associated with interval grades: LM(Low–Medium), MH(Medium–High) and LH(Low–High), respectively. Degrees of belief l, m, h, lm, mh, lh are probability measures and their sum must be 100 for each requirement.

Suppose, a requirement R1 is assessed to the grade Low with 80% belief and the remaining 20% to the grade Medium–High, is represented as R1: {(High, 80%) (Medium–High, 20%)}.Suppose, another requirement R2 is assessed to the grade Low with 70% belief and the remaining 30% the assessor is unsure of, is represented as R2: {(Low, 70%) (Low–High, 30%)}.If the assessor is completely ignorant of the importance of a requirement, it can be assessed to the grade Low–High with 100% belief. The assessment of all requirements carried out in this manner can be arranged in the form of a matrix, whose data can be aggregated using IER (Xu, Yang, & Wang, 2006).

ENA based assessments, collected as a result of execution of the experiment are provided in Appendix B. This data is used as input for the algorithms. A total of 8 students of the second and third year Master of Computer Applications course in a 1:1 ratio were selected as representative participants of the experiment. Representative participation is opted with basis as reliance on earlier experiments of similar context (Xu et al., 2006; Berander, 2016; Chin, Wang, Yang, & Poon, 2009) and also availability of participants. The prerequisite for the aggregation algorithm $\sum_{i=1}^{N} wi = 1$, N is the number of assessors selected for assessing the relative importance of software requirements with each assessor assigned a relative weight $w_i > 0$ ($i = 1,\ldots,N$).

The second year students are assigned a relative weight of 0.4 and the third years are assigned a relative weight of 0.6 and this is done subjectively with the assumption that third year students do better than second years. Third years are better in the sense that