An Argumentation Based Approach for Design Change Management in Aerospace Projects

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Abstract. Understanding and managing information contained within large, complex interrelated documents in Aerospace Projects is problematic. Such documents contain vital information regarding business and manufacturing processes. However, some of this information may be incomplete or inconsistent which can have detrimental impacts upon large-scale Aerospace Projects in terms of time and cost. To address such issues this research proposes an argumentation based approach to handle design change management, in which large amounts of information need be effectively and efficiently processed. A use case based within the Aerospace domain has been developed. Furthermore, the areas of argumentation mining, computational semantics and reasoning with uncertainty are explored. The project aims to illustrate the possibility of reducing cognitive and duration effort people are required to exert in order to understand, navigate, search, compare, update, and deliberate on large, complex interrelated documents.

Keywords: argumentation, reasoning, logic, probabilistic, information retrieval, natural language processing, computational semantics

1 Problem Domain

The volume of information available to and stored by large-scale engineering companies (e.g. Aerospace) is expanding exponentially. It has been estimated that 80% of information in enterprise companies is stored within unstructured text [1]. The unstructured nature, coupled with the huge volume of information, makes it inherently difficult for users to search and identify relevant information. In particular, it is critically important to know and understand the impact of low-level design change on engineering functions, business domains and support stages. Many Product Lifecycle Management (PLM) systems do not offer automatic support for such impact analysis in documents and interrelated collections of documents. Usually, information relating decisions and change must manually be given a structure using a homogeneous set of tools which cannot include implicit design decisions captured in unstructured text documents. This is not a trivial problem, as many documents crucial to product development have heterogeneous origins e.g. existing/legacy projects, specialized third party tools or external partners, each of which may not be tied into using a unified PLM solution. Consequently, change management relies heavily upon human experts to decide antecedent and subsequent activities.

Within the Aerospace domain the sophistication, complexity and volume of information contained in these documents is formidable. Frequently such documents are interdependent, making the task of understanding them, comparing them, tracking design changes and propagating impact through them a resource intensive activity. Current information management applications in the Aerospace, Defense and Automotive industries use extrinsic document meta-data and often include advanced versioning to support change management. However, the complexity, size and interrelatedness of many technical documents ensures that even simple change management can be difficult.

Clearly, supporting the capture of design decisions, rationale and supporting arguments from unstructured documents would greatly enhance and benefit PLM in the engineering domain. The field of Argumentation provides several methods to enable partial automation of the task and provide decision support to PLM users.

2 Argumentation

Argumentation is an interdisciplinary field applied in various areas such as philosophy, linguistics, communication, law and sociology [9]. Besnard and Hunter [3] describe argumentation as an important cognitive process which can handle information that may be in conflict by generating and/or comparing arguments. Computational Argumentation involves the detection of various elements of an argument such as the claim, facts, rebuttals, warrants, backing and qualifiers as outlined in Toulmin's influential model of argumentation [13]. In the argumentation process, relationships between these elements are built by leveraging natural language processing and computational reasoning. In sections 2.1 to 2.3 a number of important approaches that have been applied within the field to formalize argumentation are summarized.

2.1 Argumentation Based on Classical Logic

In Classical Logic, arguments are represented as a set of facts and conclusion(s) that follows from the given facts [2]. As there is no variation in the weight an individual fact can have, uncertainty can be represented as disjunctions. Classical Logic is a well-established formalism which allows the use of tools such as highly mature and efficient theorem provers. Once a knowledge base has been created, a range of operations can be performed. For each argument, counterarguments can be found. By repeating this process, one can derive an argument tree that represents all possible arguments and counterarguments that support or attack a certain claim [4]. Other operations measure the degree of inconsistency that a knowledge base has. For example, Hunter and Konieczny [11] take into account the responsibility of each individual formula for the overall inconsistency of the knowledge base.

2.2 Argumentation Based on Defeasible Logic

Argumentation schemes can also be modeled using Defeasible Logics. These logics include a defeasible implication in addition to the classical implication. A defeasible implication represents the notion that a claim is believed to be true, unless further evidence is found that indicates the contrary [7]. It thus expresses the limitations that partial views of a system have, as opposed to universal, all-encompassing representations. Dung [7] proposed that logic programming and non-monotonic reasoning are types of argumentation which can be formalized in an abstract way via notions of argument and attack. Furthermore, Dung [7] proposed a method for generating meta-interpreters for argumentation systems, showing also that argumentation can be seen as logic programming.
Research by Garcia *et al.* [8] introduced the concept of Defeasible Logic Programming (DeLP) which combines the results of logic programming and defeasible argumentation. Weak rules are used to represent information in a declarative manner. These rules represent a relation between items of knowledge that can be defeated after all has been considered. The defeasible argumentation inference mechanism is applied to warrant the entailed conclusions. This work was extended by Chesñevar *et al.* [5] where DeLP was expanded by incorporating possibilistic uncertainty and fuzzy knowledge (P-DeLP). Fuzzy propositional variables and arguments had an attached necessity measure associated with the supported conclusion. These features were formalized using PGL, a possibilistic logic based on Gödel fuzzy logic. Arguments were modeled as sets of uncertainty weighted formulas that support a goal, and support weights were used to resolve conflicts among contradictory goals [5].

2.3 Probabilistic Argumentation

Both the Classical and Defeasible approaches defined above rely on logic in one form or another to analyze the validity of arguments, resulting in a qualitative assessment (yes or no). Haenni *et al.* [9] has performed research in the area of Probabilistic Argumentation. This approach is based on logic and probability theory. The credibility (or the weight) of logical arguments is measured by probabilities. Uncertainty of the premises for defeasible arguments is represented by a joint probability function. In the approach by Haenni *et al.* [9] an argumentation system consists of a set of assumptions A which represent uncertain events. Each possible combination of truth values that can be assigned to the assumptions

stands for an interpretation $S \in N_A = \{0,1\}^{|A|}$ relative to A. Using a function $p : N_A \rightarrow [0 \ldots 1]$ that maps interpretations to probabilities, one can calculate the probability of a claim.
Zukerman *et al.* [15] applied a probabilistic approach incorporating user beliefs and inferences as a means to interpret user arguments. A web based argumentation system entitled BIAS was constructed which translates user arguments into interpretations in the form of Bayesian subnets, these subnets were then used for reasoning about the arguments.

3 Use Case

Since discrete manufacturing and process manufacturing can be supported by PLM, Aerospace for discrete manufacturing has been chosen as the use case application area for this research.
PLM for Aerospace needs to handle large volumes of unstructured text. The impact of change within aerospace projects is critical. For example, initial requirement specifications and tender documents within the Aerospace industry can consist of hundreds of pages of text. Typical problems encountered in the Aerospace industry include the inability to cross-compare specifications on the same subsystem or between subsystems, as well as differing terminology across areas of expertise, technical granularity and time (end-to-end Aerospace projects can span decades and workforces).

3.1 Aerospace Use Case: Thermoplastics vs. Thermosets?

Alan is an experienced Aeronautical Engineer who has been tasked with designing the wing for a new mid-size passenger aircraft. An initial design decision Alan must make is which material to use for constituting the wing. In previous projects, Alan has used thermoset composites for this purpose. Thermosets are a mature technology in use since the 1960's, and Alan has developed substantial design and processing knowledge to exploit the material. His company has made major investments in a material property database for thermoset composite aerospace applications. Furthermore, capital equipment and support services, such as tooling and semi-automation methodologies, are well established in his company. Since Alan is familiar and comfortable with the material, he sets out drafting a design document describing the new wing and its properties using thermosets as the material.
In the background, Alan's PLM system analyses his draft and captures the design decision he has made. It makes a request to Alan to justify his decision with supporting argumentation. The system has previously analysed and indexed argumentation from state-of-the-art literature on composites from external publications e.g. journal articles and industry magazines, including a recent innovation resulting in a superior thermoplastic composite which has been proposed for use in wing construction. With no apparent justification to support his decision to use thermosets, the system recommends that Alan considers thermoplastics as

an alternate material. Curious, Alan is able to browse a summary of supporting and countering argumentation for both materials to compare and contrast them. The argumentation shows Alan that compared to thermosets, thermoplastic material makes considerable saving opportunities in manufacturing costs possible through low cycle times and a high degree of automation. Thermoplastics also provide Alan with a more tailor-able and forgiving manufacturing process. Furthermore, Alan realises that there is a strong current trend towards a greater use of thermoplastics in high performance composite structures, driven by considerations of mass reduction as well as sustainability and recyclability issues which have become increasingly important for his company to comply with regulations. Alan decides to change the material in his design to thermoplastics based on this information. The PLM system enables him to justify the cost with supporting argumentation showing that in the long term this will be worthwhile, as well as keeping his company one step ahead of their competitors.

4 Proposed Solutions

An argumentation-based approach has been proposed to manage design and process change decisions within Aerospace Projects. Input to the argumentation model will be derived from Aeronautical Engineering documents including requirement specifications, test analysis and design reviews. This complex information is large in volume and often stored as unstructured text. Furthermore, these documents often contain inconsistencies and counter claims which can have a critical impact upon a project. An overview of the proposed methodology to address these issues is presented below.

4.1 Argument Extraction

Argumentation Mining in text or during dialogue has received research attention from areas such as enterprise research for making decisions and legal negotiation. Argumentation mining is the extraction of argumentative information from documents. Automatic Argumentation Mining is not a trivial task as computers still lack the capability to capturing meaning of the human language [12]. The detection and extraction of arguments within unstructured text can be viewed as a data mining problem and can draw on data mining techniques to identify and extract arguments from text [12]. Classification methods can be applied to classify the element extracted from text into a specific category. For example the extracted text could be classified as a claim, a premise that supports an argument or a counter argument. A difficult task in the identification of premises is identifying those premises which are inferred from text (enthymemes). For example from the statement *"thermoplastics can be fully recycled with little to no volatile organic compounds released during processing whereas thermosets cannot"* one could infer that thermoplastics are more environmentally friendly compared to thermosets, based on the implicit assumption that *"if something can be fully recycled then it is good for the environment"*.

4.2 Reasoning

Computational Semantics The process by which the meaning of a natural language sentence can be constructed is based on the principle of compositionality. This states that the meaning of the sentence is determined by the meanings of its parts and the way in which they are combined. A parse tree produced by a context free grammar syntactic analysis through the use of taggers/parsers provides one level of meaning. However, to provide a mechanism for logical reasoning and inference requires a rule-to-rule translation. This is where syntactic production rules from the parse tree are annotated or augmented with semantic attachments. These attachments are specified using first order logic and lambda calculus to determine the meaning representation of a construction. Toolkits such as NLTK provide mechanisms to be able to provide syntactic and semantic analysis as one complete step either through the use of feature based context free grammars or advanced mechanisms such as glue semantics [6]. The latter is able to handle semantic ambiguity of natural language sentences through the use of different quantifications or readings e.g. the sentence *"Every company manufactures an air wing"* leaves it unclear whether or not all companies manufacture the same air wing. Such semantic representations allow for inference mechanisms such as textual entailment or syntactic consequence to be carried out.

Reasoning with Uncertainty Important information is contained within complex requirements specifications for an Aerospace project, however, these specifications may contain data which is unreliable, incomplete, or even contradictory. Critical design information such as setting the weight of an aircraft wing could be specified within early design documents. However, a change to this weight may not be propagated through to reliant technical design documents. To address these issues, a flexible argumentation system has been proposed that aims to improve the comprehensibility and transparency of concepts, decisions and feedback in complex knowledge-intensive and cross-functional environments which are found within Aerospace projects. The proposed argumentation system will reason with data that contains inconsistencies, assumptions, uncertain premises and with the aim of constructing arguments and resolutions. A number of approaches could be applied including Probabilistic Argumentation whereby probabilities assigned to premises are combined to determine a probable conclusion. Another approach is the application of the Dempster–Shafer theory [14]. This theory models belief and plausibility combining evidence from various sources to calculate a degree of belief taking into account all available evidence for a particular argument/conflict. A key advantage of the Dempster–Shafer theory over a probabilistic approach is the ability to take into consideration ignorance and inconsistency [10].

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