Combining Relaxation and Argumentation in Ontology Matching Negotiation

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Abstract. Communication between agents adopting different ontologies and with no prior knowledge of the other relies on agents' ability to match (or align) their ontologies in run-time. Because agents pursue different goals, they might also have different perspectives and preferences regarding the ontology matching process. To address conflicts arising from the matching process, agents engage in negotiation processes that lead them to a common and acceptable agreement. In literature, two kinds of ontology matching negotiation approaches can be found: (i) relaxation-based approaches and (ii) argument-based approaches. In this paper we survey these approaches in order to further analyze and suggest their combination based on three identified dimensions.

Keywords: Ontology Matching; Negotiation; Argumentation; Relaxation;

1 Introduction

Different organizations have different interests and habits, use different tools and have different knowledge. Frequently this knowledge has varying levels of detail. Due to these differences, organizations adopt different ontologies. When such organizations need to interoperate with each other, they need to overcome the heterogeneity problem raised by the adoption of different ontologies. According to [1], Ontology Matching is perceived as the appropriate approach to address such heterogeneity in order to enable interoperability between such organizations. Most commonly, the ontology matching process consists of establishing a set of correspondences (referred to as alignment) between the organizations' ontologies, which are further exploited to interpret or translate the exchanged messages and their content.

In applications scenarios where organizations are represented by means of agents with the ability to cooperate, coordinate and negotiate with each other in the same way people/organizations do in their everyday lives, the ontology matching process often occurs either (i) in design-time if agents are running in controlled environments where agents know *a priori* the other agents with whom they will interact or (ii) in run-time if agents are embedded in open, dynamic, ill-specified and decentralized environments with no prior knowledge of the agents with whom they will interact.

With respect to the latter case, the ontology matching process is commonly available as a service provided by the multi-agent system to all agents running on it. As such, when two agents need to interact the ontology matching service is firstly requested to generate an alignment between the agents' ontologies. This alignment is further mutually accepted and exploited during the agents' interactions. However, agents pursuing their own goals might have different matching preferences and interests due to the subjective nature of ontologies, for instance, or the context and the matching requirements. Therefore, agents need to autonomously decide on each and all correspondences between the ontologies they adopt in a conversation. In that sense, each agent might be able to exploit the ontology matching service(s) that are more suitable from its point of view [1]. However, different ontology matching service(s) have contradictory and inconsistent perspectives about (candidate) correspondences. Consequently, conflicts arise between agents about which are the best correspondences. To address such conflicts, agents may engage in any kind of negotiation process that is able to lead them to a common and acceptable agreement. This problem is often referred to as ontology matching negotiation (OMN). In literature, there are two distinct categories of OMN' approaches: (i) those based on relaxation mechanisms (e.g. [2]) and (ii) argument-based approaches (e.g. [3–6]).

In this paper, we first provide a brief overview of the ontology matching process and adopted terminology (cf. section 2). Next, we will survey the two categories of OMN' approaches (cf. section 3). Then, assuming that both categories of approaches: (i) have distinct, but complementary, advantages and limitations and (ii) they share the fact that at the end of the negotiation process only part of the initial conflicts are resolved, we analyze and suggest possible methods for the combination of these two approaches into a single approach (cf. section 4). To the best of our knowledge this is the first piece of work in which the combination of these approaches is analyzed and proposed. Finally, in section 5, we draw conclusions and comment on future work.

2 Ontology Matching Overview

Ontology Matching is seen as the process of discovering, (semi-) automatically, the correspondences between semantically related entities of two different but overlapping ontologies. Thus, as stated in [1], the matching process is formally defined as a function $f: (O_1, O_2, p, res, A) \rightarrow A'$ which, from a pair of ontologies to match O_1 and O_2, a set of parameters p, a set of oracles and resources res and an input alignment A, it returns an alignment A' between the matched ontologies. Ontologies O_1 and O_2 are often denominated as source and target ontologies respectively. An alignment is a set of correspondences expressed according to:

- Two entity languages Q_{L_1} and Q_{L_2} associated with the ontologies languages L_1 and L_2 of matching ontologies (respectively) defining the matchable entities (e.g. classes, object properties, data properties, individuals);
- A set of relations R that is used to express the relation held between the entities (e.g. equivalence, subsumption, disjoint, concatenation, split);
- A confidence structure φ that is used to assign a degree of confidence in a correspondence. It has a greatest element $\top$ and a smallest element $\bot$. The most

common structure are the real numbers in the interval $[0,1]$, where 0 represents the lowest confidence and 1 represents the highest confidence.

Hence, a correspondence (or a match) is a 4-tuple $c = (e, e', r, n)$ where $e \in Q_{L_1}(O_1)$ and $e' \in Q_{L_2}(O_1)$ are the entities between which a relation $r \in R$ is asserted and $n \in \varphi$ is the degree of confidence in the correspondence.

Over recent years, research initiatives in ontology matching have developed many systems (e.g. [7]) that rely on the combination of several basic algorithms yielding different and complementary competencies, to achieve better results. A basic algorithm generates correspondences based on a single matching criterion [8]. These algorithms can be multiple classified as proposed in [1, 9] (e.g. terminological, structural, semantic). Yet, systems make use of a variety of functions such as:

- Aggregation functions whose purpose is to aggregate two or more sets of correspondences into a single one (e.g. min, max, linear average);
- Alignment Extraction functions whose purpose is to select from a set of correspondences those that will be part of the resulting alignment. The selection method may rely on the simplest methods such as the ones based on threshold-values (summarized in [1]) or more complex methods based on, for example, local and global optimizations (e.g. [10, 11]).

The selection of the most suitable algorithms/system is still an open issue as they should not be chosen exclusively with respect to the given data but also adapted to the problem that is to be solved [1]. However, this question has already been dealt with in [12–14]. Despite all the existing (conceptual and practical) differences between matching systems and algorithms, we will refer to both as matchers as all of them have a set of (candidate) correspondences as output.

3 Ontology Matching Negotiation Approaches

This section presents general assumptions common to relaxation-based and argument-based OMN approaches. In addition, each approach is briefly described.

3.1 General Assumptions

Generically, OMN approaches take into consideration that negotiation occurs between two honest and co-operative agents. Moreover, it is assumed that each agent is capable of devising an alignment by itself or, alternatively, in collaboration with other agents not participating in negotiation. The object of negotiation is that the content of alignment is established between agents' ontologies. Therefore, agents negotiate about the inclusion or exclusion of each correspondence suggested by one of them into the agreed alignment. The value that each agent associates to correspondences is highly subjective and depends on several factors such as (i) the pertinence of the correspondence with respect to the business interoperability and (ii) dependencies between other correspondences (e.g. some correspondences may imply or depend on other correspondences in a valid alignment). Fig. 1 graphically depicts an overview of the ontology matching negotiation process.

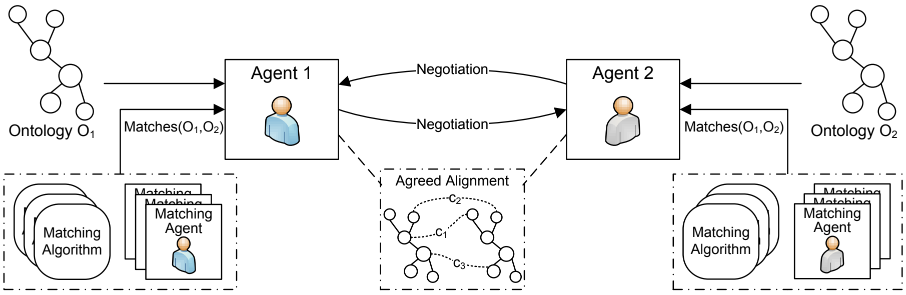

Fig. 1. An overview of the ontology matching negotiation process.

In the following description of each OMN approach it is considered that the negotiation process is completely automatic, i.e. there is no user intervention.

3.2 Relaxation-based Approaches

Only one relaxation-based OMN approach has been presented in literature [2]. In this work, it is assumed that the correspondences' confidence value is generated by means of a utility function (u) based on a set of parameters ($p_1, p_2, \dots, p_n$). Moreover, for each adopted utility function an agent must have two distinct mechanisms:

- A Correspondences Classification Mechanism, which is based on three threshold values named as (i) mandatory threshold (t_m), (ii) proposition threshold (t_p) and rejection threshold (t_r) such that $0 \leq t_r \leq t_p \leq t_m \leq 1$ is satisfied. Thus, correspondences are classified based on their confidence value (n_c) as follows:
  - Eliminated (C^e set) if $n_c < t_r$ holds. These correspondences are automatically and definitely discarded from the alignment;
  - Negotiable (C^n set) if $t_n \leq n_c < t_p$ holds. It means that the agent confidence in these correspondences is not enough to propose them to the opponent agent, but it is sufficient to consider the possibility of revising (and relaxing) its confidence in those correspondences;
  - Proposed (C^p set) if $t_p \leq n_c < t_m$ holds. It means that the agent is confident enough of the correspondences so it proposes them to the opponent agent;
  - Mandatory (C^m set) if $t_m \leq n_c$ holds. It means that the agent is so confident of the pertinence and correctness of these correspondences, that these correspondences cannot be rejected by the opponent agent.
- A Meta-Utility function (U) whose purpose is to compute an updated confidence value (n_c^u) that allows the re-categorization of correspondences from one category (e.g. negotiable) to another category (e.g. proposed or mandatory). Thus, it is responsible for (i) the identification of the parameter variation possibilities, (ii) the priorities over parameter variation and (iii) the conditions under which the variation may take place. In exploiting these elements, it might be necessary to iterate across different variations in order to find one variation that achieves the intended re-categorization. However, it might be the case that none of the possible iterations achieve the intended re-categorization.

The negotiation process exploits these mechanisms iteratively along two main phases: (i) Correspondences Exchange phase and (ii) Definitive Agreement phase.

In the former phase, each agent informs the opponent agent of its mandatory and proposed correspondences ($\forall c: c \in (C^m \cup C^p)$). At the end of this phase, the agents share three sets of correspondences: (i) the accepted (C^a), (ii) the non-accepted ($C^{\neg a}$) and (iii) the tentatively accepted (C^t). These are correspondences that one of the agents made in a convergence effort to re-categorize the correspondence from negotiable to proposed/mandatory.

In the latter phase, the tentatively accepted correspondences (C^t) are subject to a definitive decision in order to ensure that the attempted agreement ($C^a \cup C^t$) is advantageous to both agents. Thus, this phase consists of deciding if the attempted agreement is globally advantageous (i.e. at the alignment granularity) and not only locally advantageous (i.e. at the correspondences' granularity). For that, the convergent efforts (e_c) are considered undesirable and, therefore, treated as a loss. On the other hand, the agreement upon re-categorized correspondences provides some profit (p_c). In that sense, the balance between profits and losses is a function such that $balance = \sum p_c - \sum e_c : c \in C^t$. Depending on the balance value of each agent, the agents jointly decide either:

- To agree upon the attempted agreement so that it becomes definitive. In this case, the negotiation process ends successfully;
- To propose a revision of the attempted agreement so that the negotiation process proceeds again to the Correspondences Exchange phase;
- To end the negotiation process without success, i.e. without an agreement upon the alignment.

This approach is relatively simple and easy to understand since it is based on the agents' ability to (i) categorize and re-categorize correspondences and (ii) measure the profit and/or loss caused by the inclusion/exclusion of correspondences in the final agreement. Its major drawback is the enormous effort required (in terms of parameter identification, configuration and customization) to specify most of the required functions, namely meta-utility function, convergence effort and profit.

3.3 Argument-based Approaches

Regarding the use of argumentation in ontology matching domains, it is useful to distinguish between two kinds of work.

Firstly, work proposed by Trojahn *et. al.* [15] and that of Isaac *et. al.* [16] addressing the ontology matching composition problem [1] through argumentation. This work is related to the setup phase of the matching process, where different matching algorithms are selected and combined into a larger and more complex matcher. Thus, this work has different purposes/goals than those we are interested in within this paper. Therefore, this work will no longer be addressed.

Secondly, there is work which looks at the same problem that is addressed in this paper. In this respect, it is important to make a distinction between two different lines of research:

- The work proposed by Laera *et. al.* [3] and further improved by Doran *et. al.* [4] which instantiate the Value-based Argumentation Framework (VAF) [17]. A VAF captures existing arguments and attack relations between arguments. Each argument promotes a value that is further used to determine if an attack succeeds or not, based on a preferred, ordered list of values. Because arguments are generated from correspondences provided by matchers, possible argument values have been restricted to the five categories of matchers proposed in [7]: Terminological, Internal Structure, External Structural, Semantic and Extensional;
- The work proposed in [5, 6] which applies the general argument-based negotiation process (ANP) described in [18] and the generic Three-Layer Argumentation Framework (TLAF) [19] to the OMN problem.

In the remainder of this section, we will focus only on the work of [5, 6] because it allows a replication/simulation of the process and the outcome of work [3, 4], and it also overcomes several limitations.

The work presented in [5, 6] mainly relies on the notion of an argumentation model. In this context, an argumentation model is seen as an artifact (e.g. an ontology) that defines the vocabulary used to form arguments, the arguments' structure and even the way arguments affect (i.e. attack and support) each other. Thus, it captures the perception and rationality that one has about a specific domain (e.g. OMN) regarding the argumentation process.

The approach assumes that the negotiation process occurs in the scope of a given community of agents that defines a shared argumentation model such that all agents of that community are able to understand and reason on it. It is assumed that each agent might privately extend the shared argumentation model so it better fits its own needs and knowledge.

Contrary to [3, 4] where VAF is adopted, this approach adopts TLAF as the underlying argumentation framework. TLAF comprehends:

- A Meta-Model Layer that:
  - Defines an argument as being made of three parts: (i) a set of premise-statements (or grounds), (ii) a conclusion-statement (or claim) and (iii) an inference from premises to the conclusion, enabled by a reasoning mechanism;
  - Distinguishes between intentional and non-intentional arguments. The former arguments represent the correspondences that an agent wants to include/exclude from the alignment while the latter ones provide reasons for or against such correspondences;
  - Introduces the affect relationship between arguments as a generalization of the attack and support relationship to be used at the modelling level;
- A Model Layer that satisfies the notion of argumentation model;
- An Instance Layer that captures an instantiation of a given model layer for any particular argumentation process between agents.

The agent's internal phases and its external interactions follow the iterative and incremental ANP illustrated in Fig. 2. Next, each phase is briefly described.

In the Setup phase, agents participating in negotiation define the negotiation context and its parameters. In contrast to other phases, this phase occurs only once.

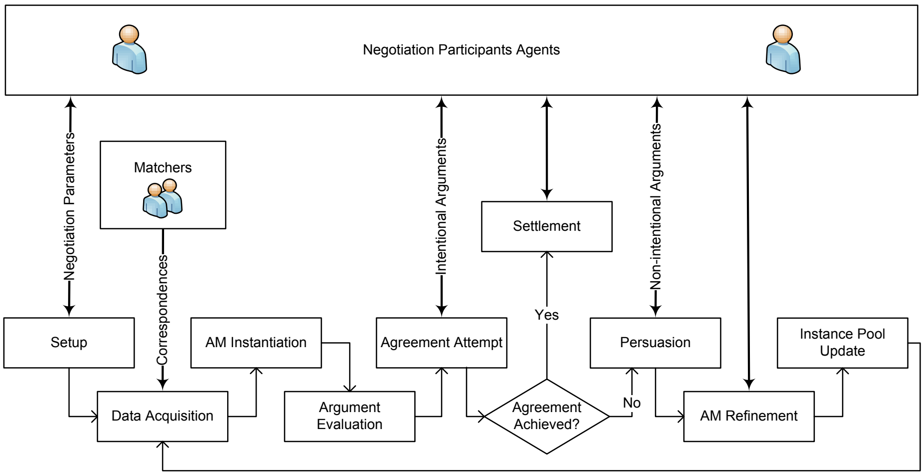

Fig. 2. The argument-based negotiation process.

In the Data Acquisition phase, each agent collects data that constitutes the grounds to generate arguments. It is the responsibility of each agent to select the data sources (e.g. matchers) that can provide the most relevant and significant information needed to instantiate its private argumentation model. Also, as a result of upcoming phases, correspondences that are temporarily agreed (but not settled as definitive) may be used to feed data-collecting mechanisms. Next, in the Argumentation Model Instantiation phase, agents make use of one or more data transformation processes (e.g. [5]) over the collected data to generate a set of arguments.

During the Argument Evaluation phase, previously generated arguments are evaluated by the agent in order to extract a preferred extension. A preferred extension is a set of arguments representing a consistent position, which is defensible against all attacks and cannot be further extended without introducing a conflict.

The Agreement Attempt phase consists of two steps. Firstly, agents exchange their proposals (intentional arguments) in order to identify (i) a candidate agreement (alignment) and (ii) their divergences. Secondly, according to the content of the candidate alignment and the identified divergences, agents decide whether to:

- Settle the candidate alignment as definitive and, therefore, proceed to the Settlement phase. This phase is seen as the initiator of a set of tasks where the agreed alignment is used to develop the business interaction process;
- Continue the negotiation, and therefore proceed to the Persuasion phase in order to try to resolve their conflicts. In the Persuasion phase, agents exchange arguments to persuade their opponent to accept or to give up disagreed correspondences.
- Conclude the negotiation without an agreement.

The Argumentation Model Refinement phase is an optional phase concerned with the refinement of the community's argumentation model according to exchanged arguments and agents' private argumentation models. It requires agents' ability to learn from agent interactions and from other agents' knowledge.

In the Instance Pool Update phase, agents analyze arguments received during the Persuasion Phase in light of their private argumentation model. As a result, the agent adds new arguments and/or updates existing arguments. Therefore, the previous preferred extension becomes invalid and is discarded. The added/updated arguments are taken into consideration by agents in the next iteration. The negotiation process proceeds (again) to the Data Acquisition phase.

A strong point of this approach relies on its ability to cope (through the argumentation model) with more, or less, argument-types as long as they are needed. As a drawback, agents lack other mechanisms than arguments to relax their demands in favor of a greater good as, for example, business interoperability.

4 Combining Relaxation and Argument-based Approaches

To combine relaxation and argument-based ontology matching negotiation approaches, three main dimensions have to be considered:

- Composition, which refers to the way both approaches are combined. Three possibilities were identified:
  - Sequential, which means that the outcome of one negotiation approach is used as input for the next negotiation approach. Thus, since the order of the approaches is relevant, two options exist: (i) the argument-based approach followed by the relaxation-based approach and (ii) vice-versa;
  - Parallel, which means both negotiation approaches run in parallel and are isolated from each other. As a result, one has two negotiation outcomes (one from each negotiation approach), which are then aggregated into a single one;
  - Merged, in which one of the negotiation approaches is seamlessly diluted into the other. Therefore, two possibilities arise:
    - Argumentation-driven, such that the relaxation-based approach is diluted into the argument-based approach;
    - Relaxation-driven, such that the argument-based approach is diluted into the relaxation-based approach;
- Process Granularity, which refers to the stage in the negotiation process at which control is passed from one approach to the other approach:
  - At the end of the negotiation. The outcome at the end of this stage is an agreement together with the remaining conflicts (i.e. the correspondences that remain in conflict after the negotiation ends);
  - At the end of each iteration. At this stage, the outcome is an intermediary result which comprehends at least (i) the accepted correspondences, (ii) the tentatively accepted correspondences and (iii) the current conflicts;
- Object of Negotiation, which refers to the type of the negotiated object on which each approach acts on. There are three possibilities:
  - Correspondence;
  - Alignment;
  - Both, i.e. correspondences and alignment.

Fig. 3 graphically illustrates the possible combinations between these dimensions.

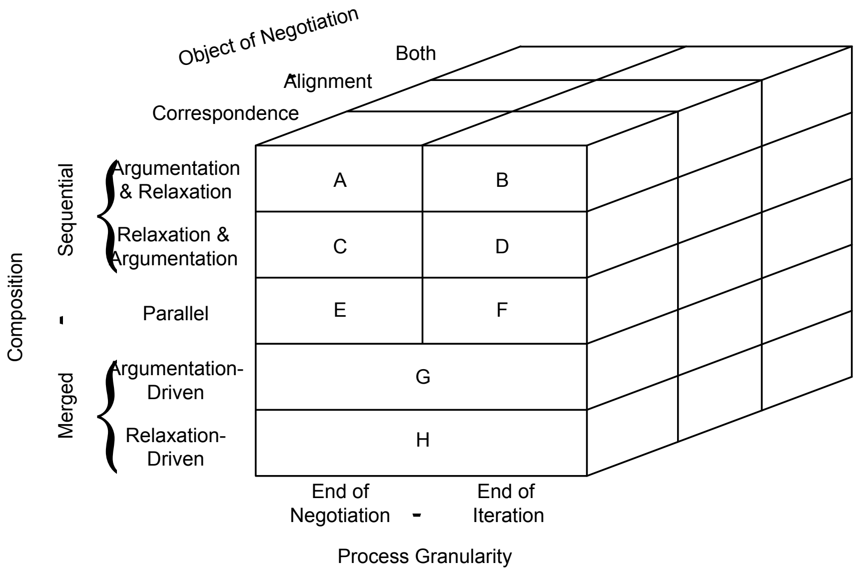

Fig. 3. The three combinatorial dimensions identified.

In the following, we address composition and process granularity dimensions only, in order to present and discuss eight plausible combination scenarios. Fig. 3 identifies each scenario by means of letters (A to H). Moreover, Fig. 4 graphically depicts an architectural overview of each scenario.

In scenarios A and C, the relaxation and argumentation are combined sequentially at the end of the negotiation process. Thus, the outcome of the first approach is used as input information for the next approach, which in turn has the responsibility of generating a new and hopefully improved outcome. The fundamentals of each basic approach are preserved so long as the later approach is able to freely manipulate the input information.

Contrary to scenarios A and C, in B and D the basic approaches are sequentially combined at the iteration level. This implies the integration of both approaches such that throughout an iteration the argumentation and the relaxation features are exploited. In this case, both basic approaches need to consider as input the outcome of other approach. Since basic approaches are combined sequentially, the later approach is responsible in deciding if the combination process runs for another iteration or, instead, it ends successfully (i.e. generating an agreement) or unsuccessfully (i.e. without an agreement).

In scenario E, the basic approaches are combined in parallel at the end of the negotiation process. In this scenario, none of the basic approaches need to consider information provided by the other approach and, therefore, they remain unchanged. In fact, in this scenario the combination relies on an external process (or function) that aggregates the two outcomes (agreements) into a single one. In scenario F relaxation and argumentation are combined in parallel at the iteration level. Similarly to scenario E, the combination relies on an external process, but here the aggregation process has two main responsibilities:

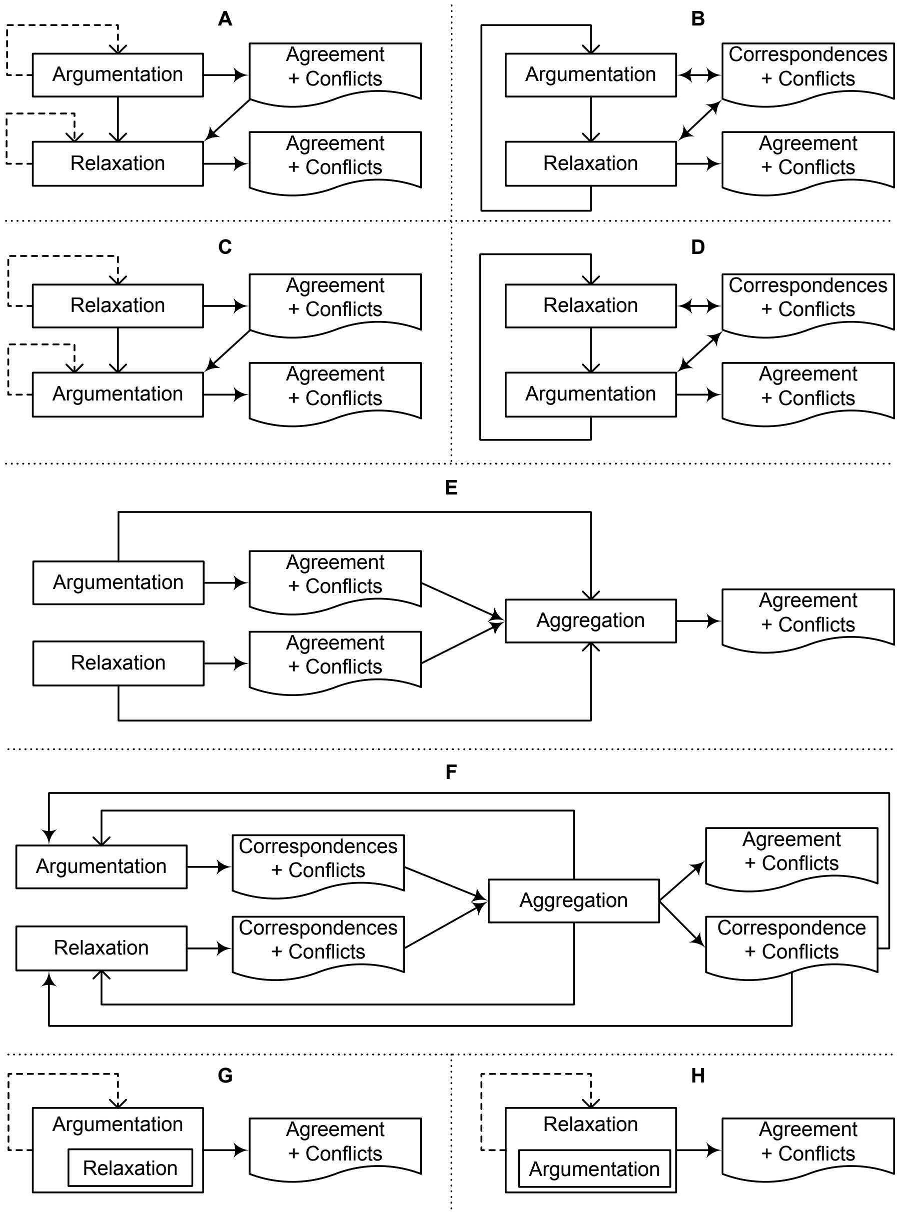

Fig. 4. Eight scenarios combining relaxation and argument-based ontology matching negotiation approaches considering composition and process granularity dimensions only.

- To aggregate the iteration outcome of each basic approach into a single one, which further serves as input information for the next iteration;
- To generate the negotiation outcome (agreement) and, therefore, ending the negotiation process.

At the end of each iteration, the aggregation process is also responsible for deciding either to continue the negotiation (next iteration) or, alternatively, to conclude the negotiation.

In scenarios G and H, the combination is driven by argument-based and relaxation-based approaches respectively. Thus, relaxation (argumentation) features are deeply intrinsic and somehow merged/embedded into the argumentation (relaxation) process so that one cannot distinguish the two basic approaches. In this respect, it is foreseen that in scenario G the relaxation features can be merged (i) at the argumentation model layer by introducing new kinds of arguments and (ii) at the argument evaluation phase. Concerning scenario H, argumentation features can be added as parameters of utility and meta-utility functions.

5 Conclusions and Future Work

Experiments developed by the team and reported in [20] and, more recently in [6], regarding relaxation-based and argument-based approaches respectively, demonstrate that, at the end of the negotiation process, a noteworthy set of conflicts remain to be solved. Furthermore, it has been noted that if those conflicts are correctly solved it would significantly improve the quality of the agreed alignment. Hence, assuming that the core principles, advantages and disadvantages of both approaches are complementary to each other, the team focused on combining both approaches into a unified negotiation process. Consequently, three main dimensions were identified (composition, process granularity and object of negotiation) and need to be taken into consideration in the combination process.

By exploring the composition and process granularity dimensions only, eight different scenarios combining the relaxation and argument-based approaches have been conceptually drawn and discussed.

Furthermore, it is worth noting that this is the first work proposing and studying the combination of relaxation and argument-based approaches in the OMN context. As such, the team did not make a comparative evaluation of this work. Nevertheless, the team is prototyping each proposed scenario in order to compare (qualitatively and quantitatively) the outcome of each scenario to (i) the outcome of original approaches (i.e. relaxation and argument-based) and to (ii) the outcome of other combination scenarios.

From the eight proposed scenarios, the team has particularly focused on scenario G. In respect to this scenario, the team is interested in capturing at the argumentation model level (i) the arguments for and against relaxation in a given correspondence and (ii) how those arguments affect (positively or negatively) other arguments. As a result of this effort, the team is also investigating methodologies capable of guiding the argumentation modelling efforts for a diversity of stakeholders. Finally, the object of negotiation dimension should be analyzed within the scope of identified combinations.

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