Semantic Matchmaking for Argumentative Intelligence in Ubiquitous Computing

Corrado Fasciano[1,2][0000−0001−7813−5915], Michele Ruta[1][0000−0003−2125−327X],
and Floriano Scioscia[1][0000−0002−7859−9602]*

[1] Polytechnic University of Bari - via E. Orabona 4, Bari (I-70125), Italy
{corrado.fasciano, michele.ruta, floriano.scioscia}@poliba.it
[2] Exprivia S.p.A. - via A. Olivetti 11, Molfetta (I-70056), Italy
{corrado.fasciano}@exprivia.com

Abstract. The Semantic Web of Things enables the exchange of knowledge fragments through machine-to-machine interactions, supporting collaborative decision-making among ubiquitous smart objects. Available methodologies, however, have often limited generality of applications and interpretability of results. This paper introduces early work on a novel structured argumentation approach, integrating Dung-style abstract argumentation with Description Logics reasoning. A semantic matchmaking scheme, exploiting non-standard, non-monotonic inferences, allows the appraisal of argument relations. This enables graded acceptability ranking of arguments with a formal explanation, while enabling the automatic evaluation of an argumentative graph to draw conclusions. The proposal is general-purpose, but oriented toward SWoT multi-agent systems, as illustrated in a vehicular network case study.

Keywords: Bipolar Weighted Argumentation · Description Logics · Semantic Matchmaking · Web Ontology Language (OWL).

1 Introduction

The Semantic Web of Things (SWoT) [23] integrates Semantic Web technologies into Internet of Things contexts. In SWoT environments, individual knowledge fragments are disseminated by heterogeneous connected smart objects. Knowledge exchange occurs via machine-to-machine interactions, which can be considered as an ongoing *dialogue* among objects, which behave as autonomous agents. This vision fits classical *argumentation* paradigms [13]: *Abstract Argumentation* (AA) [8] is a simple but powerful formalism to reason over conflicting knowledge. It studies the acceptability of arguments based purely on their relationshipships and abstracted from their content. Basically, an argument is a set of assumptions (*i.e.*, information), together with a conclusion that can be drawn by one or more reasoning steps.

Nevertheless, proper integration of principled argumentation frameworks in SWoT contexts is still an open problem. The majority of available approaches

---

* Corresponding author Tel.: +39-080-596-3515; fax: +39-080-596-3410

belongs to AA, thus they overlook the *structure* of arguments: this is, however, a fundamental aspect for the appraisal of relationships between arguments which are obtained from information generated by devices. Furthermore, AA frameworks can explain outcomes about the acceptability of arguments only in a shallow way, based on information about the direction and possibly type (attack or support) and/or numerical weight assigned to each relationship between a pair of arguments. This is a barrier for more meaningful interpretability of models and results, which would increase users' confidence in automatic argumentation facilities.

This paper introduces early work on a general-purpose but SWoT-oriented approach for integrating argumentation frameworks with Knowledge Representation and Reasoning (KRR). Information generated and shared by a device (or, generalizing, an agent) is represented as an annotation in standard Semantic Web languages, based on reference ontologies. Each annotation takes the role of an argument. Referring to the Bipolar Weighted Argumentation Framework (BWAF) family –which include both attack and support relationships, with an assigned weight to represent connection type and strength– type and weight are assessed exploiting non-standard, non-monotonic inference services for semantic matchmaking [20]. This enables (i) a more meaningful appraisal of individual relationships, (ii) assessment of the accuracy and reliability of collected information in SWoT device networks and (iii) interpretability of results, by virtue of logic-based explanation capabilities of the adopted inferences. The approach aims to deal with key open challenges for the realization of fully automatic argumentation, as discussed *e.g.*, in [2]: how arguments are constructed (*structural layer*), what are the relationshipships between arguments (*relational layer*), and how a constellation of interacting arguments can be evaluated and conclusions can be drawn (*assessment layer*).

The remainder of the paper is organized as follows. Section 2 recalls useful background on argumentation –and particularly BWAF– as well as on reasoning in the SWoT. Section 3 describes an early approach integrating KRR and argumentation, while Section 4 outlines an illustrative case study regarding a vehicular ad-hoc network (VANET) comprising vehicles and roadside units, with the goal of dynamic collaborative management of the traffic flow around a road interruption point. Related work discussion is in Section 5, before conclusion.

2 Background

In what follows, preliminary notions regarding the Bipolar Weighted Argumentation and the Semantic Web of Things are recalled to make the paper self-contained.

2.1 Bipolar Weighted Argumentation

The *Argumentation Framework* (AF), introduced by Dung [8], is a graph-based formalism to reason over conflicting knowledge without considering the internal structure of the arguments, but only their relationhipss of *attack* –denoting

Fig. 1. BWAF legend: S_1 attacks R_1, S_2 supports R_2

conflicts between pairs of arguments– and the *semantics* for evaluating them. *Extension semantics* divide all subsets of arguments according to some acceptability criteria, *e.g.*, *conflict-freeness*, *defense*, *admissibility* [4]. An argument is *accepted* if it belongs to an extension (*i.e.*, an acceptable subset of arguments), and *rejected* otherwise. Another family of semantics proposed in the literature, called *gradual semantics*, focuses on individual arguments, and assigns them a numerical weight –typically called *overall strength*– to explicitly rank them according to their degree of acceptability [1].

Dung's original formalism for abstract argumentation has been extended along many lines, giving rise to a large and thriving literature [24,5]. Bipolar Weighted AF (BWAF) [18] incorporates two of the most important generalizations of Dung-style AFs: the bipolar AF (BAF), and weighted AF (WAF). In a BAF [7] two kinds of interactions between arguments are possible: the *attack* and the *support* relationships. Differently, in a WAF [9], a numerical weight is associated with all attack relationships between arguments, representing the relative strength of the attack. The main novelty of the BWAF is to allow not only weighted attack relationships between arguments, but also weighted support relationships. This is achieved by assigning a positive or negative weight to each relationship.

Definition 1. *A BWAF is a triple* $\mathcal{G} = \langle \mathcal{A}, \hat{\mathcal{R}}, w_{\hat{\mathcal{R}}} \rangle$*, where* $\mathcal{A}$ *is a finite set of arguments,* $\hat{\mathcal{R}} \subseteq \mathcal{A} \times \mathcal{A}$ *is a set of relationships and* $w_{\hat{\mathcal{R}}} \colon \hat{\mathcal{R}} \mapsto [-1, 0[\cup]0, 1]$ *a weighing function. Attack relationships are defined as* $\hat{\mathcal{R}}_{att} = \{\langle a, b\rangle \in \hat{\mathcal{R}} \mid w_{\hat{\mathcal{R}}}(\langle a, b\rangle) \in [-1, 0[\ \}$ *and support relationships as* $\hat{\mathcal{R}}_{sup} = \{\langle a, b\rangle \in \hat{\mathcal{R}} \mid w_{\hat{\mathcal{R}}}(\langle a, b\rangle) \in]0, 1]\ \}$*. Given two arguments* $a, b \in \mathcal{A}$ *and a path* $\langle a, x_1, x_2, \ldots, x_n, b\rangle$ *from* a *towards* b*, then:*

- a bw-attacks b *if the product of weights* $w_{\hat{\mathcal{R}}}(\langle a, x_1\rangle) \cdot w_{\hat{\mathcal{R}}}(\langle x_1, x_2\rangle) \cdot \ldots \cdot w_{\hat{\mathcal{R}}}(\langle x_n, b\rangle)$ *is negative.*
- a bw-defends b *if the product of weights* $w_{\hat{\mathcal{R}}}(\langle a, x_1\rangle) \cdot w_{\hat{\mathcal{R}}}(\langle x_1, x_2\rangle) \cdot \ldots \cdot w_{\hat{\mathcal{R}}}(\langle x_n, b\rangle)$ *is positive.*

A BWAF can be represented as a directed graph whose nodes represent arguments, relations represent attacks (with solid edges from the attacker to the attacked node) and supports (with dashed edges), and weights represent the relative strength of relationships, as depicted in Figure 1.

2.2 The Semantic Web of Things

The Semantic Web of Things (SWoT) [23] consolidates the Semantic Web and the Internet of Things (IoT). Its goal is to support user activities and provide general-purpose innovative services by improving intelligence of embedded objects and autonomic information management in pervasive contexts. In order to facilitate sharing and understanding of unambiguous knowledge across heterogeneous ubiquitous micro-devices, Semantic Web languages and technologies grounded on Description Logics (DLs) [3] are used, including the *Resource Description Framework* (RDF) 1.1 [15] and the *Web Ontology Language* (OWL) 2 [17]. Specifically, this work adopts an OWL 2 subset corresponding to the *Attributive Language with unqualified Number restrictions* ($\mathcal{ALN}$) DL. It provides moderate expressiveness, while granting polynomial complexity to both standard and non-standard inference tasks.

Semantic matchmaking techniques [20] are useful in SWoT contexts, as they compare ontology-based annotations to retrieve the most relevant *resources* for a given *request*. Unfortunately, *Subsumption* and *Satisfiability* standard inference services on concept expressions only manage full matches, which are quite rare in practical scenarios. Furthermore, in both cases the output is Boolean, hence these services can only provide "yes/no" answers without an explanation of the outcome. The following non-standard, non-monotonic inference services [20], implemented in *Tiny-ME (the Tiny Matchmaking Engine)* [21], support gradual approximate matches and logic-based explanation:

- *Concept Contraction*: if a *request* R and a *resource* S are not compatible with each other, Contraction determines which part of R is conflicting with S. By retracting only conflicting requirements G (for *Give-up*) in R, an expression K (for *Keep*) remains, which is a contracted version of the original request. The solution G to Contraction explains "why" the conjunction of R and S is not satisfiable;
- *Concept Abduction*: if request and resource are compatible, but S does not subsume R, Abduction determines what should be hypothesized in S in order to obtain a full match, *i.e.*, to make the subsumption relation true. The solution H (for *Hypothesis*) to Abduction can be interpreted as what is requested in R and not specified in S, thus providing an explanation for missed Subsumption;
- *Concept Bonus*: a resource S could contain features not requested in R -–possibly because the requester did not know or consider them-– which could be useful in a query refinement process to improve matchmaking outcome. For this purpose, this service extracts a Bonus concept B from S which denotes what the resource provides even though the request did not ask for it.

Moreover, adopting a *normal form* for concept expressions can allow defining a metric space with a *norm* operator $||\cdot||$. This work focuses on $\mathcal{ALN}$ concept expressions in Conjunctive Normal Form (CNF): the CNF norm of G and H can then represent a semantic distance *penalty* for Concept Contraction and Abduction, respectively, which can be used to compare results of matchmaking and rank resources w.r.t. a given request; similarly, $||B||$ provides a measure of the relevance of the Bonus [20].

3 Knowledge representation, reasoning and argumentation

This section describes how knowledge representation and automatic reasoning could be exploited for the evaluation and explanation of a bipolar weighted argumentative graph.

3.1 Interpretable BWAF

Starting from an argumentative graph obtained from semantically annotated messages exchanged in a network of smart devices in SWoT contexts, this work explores the argumentation process composed of: (i) argument relationship appraisal, (ii) argument acceptability assessment, (iii) explanation of outcomes. In this perspective, each device is associated with a semantic-based annotation representing its shared knowledge in the field. Annotations are expressed as (unfolded and CNF-normalized) concept descriptions w.r.t. a common domain ontology $\mathcal{T}$, and they are shared following the network topology. Given two generic smart devices D_R and D_S in a SWoT network, their annotations –denoted as R and S respectively– are treated as arguments, since they state knowledge owned by the devices. The set of exchanged annotations thus takes the role of $\mathcal{A}$ in the BWAF $\mathcal{G}$, and the set of pairwise device interactions coincides with the set of relations $\hat{\mathcal{R}}$ between the corresponding arguments. If D_S communicates with D_R ($D_S \rightsquigarrow D_R$), in order to evaluate the acceptability of R and S, according to a matchmaking-based perspective [21] R and S can be considered respectively as request and resource, since in SWoT scenarios S can be used to "respond to needs" expressed in R. This peculiarity shows a possible argumentative relation can exist with edge orientation from S to R.

Once the relation orientation is defined, a knowledge-driven process can be devised to appraise its type, discriminating whether S attacks or supports R. Particularly, a semantic consistency check could be suitable for this activity: if $R \sqcap S$ is consistent, the relation that links S to R is a support, otherwise it is an attack. Following this preliminary check, a non-standard inference services-based strategy could be devised to appropriately weight each edge connecting two nodes. This process is iterated for each pair of arguments interacting in the graph.

3.2 Weighting of relations

In order to establish a strategy assigning the correct weight to each edge between two nodes of a BWAF, it is crucial to identify which informative contributors take part respectively in the attack and support relationships.

In an attack, as the one shown in Figure 1, the following four informative contributions should be taken into account to compute its weight:

A. the amount of conflicting information between the two arguments;
B. the amount of information confirmed by both arguments;

C. the amount of information in the attacked argument which is not confirmed nor rebutted by the attacker;
D. any amount of additional information in the attacker which is not present in the attacked argument.

Term A is the cause of semantic inconsistency, and thus of the attack relationship. Since the weight of an attack is a real negative number, the maximum emphasis should be given to term A. At the same time, the remaining three contributions are useful to mitigate the strength of the attack, since they express either agreement (term B) or non-disagreement (terms C and D). Considering the non-standard inference services recalled in Section 2.2 on R (the attacked argument) and S (the attacker), term A will depend on $||G||$ as determined by Concept Contraction; then, taking the compatible part K obtained from Concept Contraction, term B can be computed via two nested Concept Bonus inferences, as the inner Bonus yields the additional information in S w.r.t. K and the outer Bonus identifies what is "not additional", *i.e.*, common to both K and S; term C corresponds to $||H||$ induced from Concept Abduction between K and S; finally, term D can be computed via a (single) Concept Bonus between R and S.

Conversely, in case an argument S supports another argument R, two informative contributions should be identified and quantified. They respectively are: (i) the amount of information S is lacking to reach a full match with R; (ii) the amount of information S has in addition w.r.t. R. The former is directly determined via Concept Abduction, while the latter via Concept Bonus in classical semantic matchmaking settings, as per definitions recalled in Section 2.2.

4 When smart objects argue in the street: a case study

In order to clarify peculiarities of the proposal, a case study has been carried out taking as reference SWoT contexts based on VANETs. *One of the two lanes of a two-way road has an interruption due to maintenance work. For this reason, on each lane there is a temporary traffic light, which allows vehicles coming from both directions to cross the part of the lane adjacent to the interruption alternately.* Figure 2 depicts the situation.

The purpose of this scenario is collaborative argumentation in a network of intelligent devices for an efficient management of the occupation of the single lane used for temporary transit, estimating the traffic density in the proximity of traffic lights and the characteristics of incoming vehicles. *Each vehicle is able to describe itself by means of a semantic-based annotation, which provides information about the type of vehicle, traveling speed, size, etc. VANET roadside units include: two cameras, monitoring the traffic density and vehicle position w.r.t. the interruption in both lanes; the two traffic lights, managing the traffic in the conflict area by acquiring information from incoming vehicles and from the cameras themselves.* Two *Controllers* work as actuators in the scenario, maintaining the information to be considered winning at the end of the argumentation process and setting the two traffic lights accordingly.

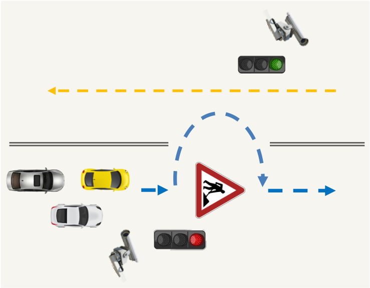

Fig. 2. Case study: first situation

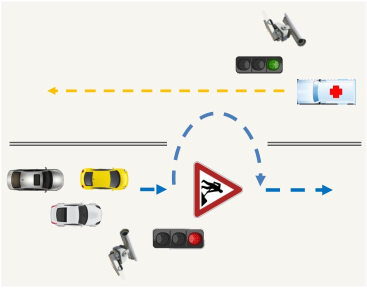

Fig. 3. Case study: second situation

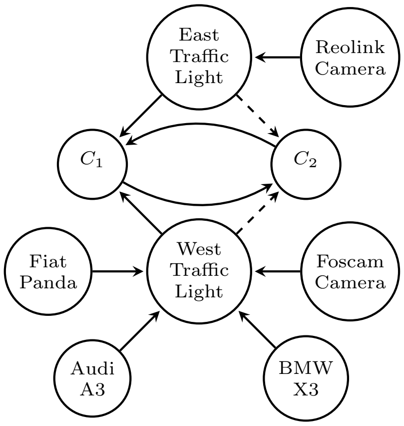

Fig. 4. $\mathcal{G}_1$: BWAF of first situation

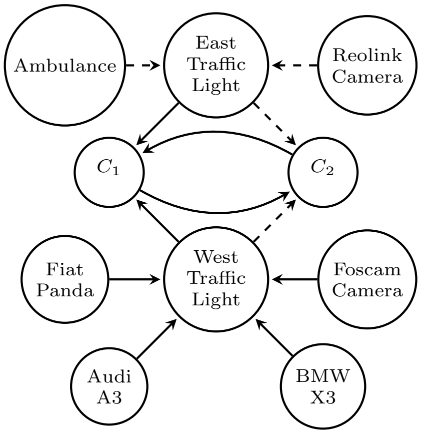

Fig. 5. $\mathcal{G}_2$: BWAF of second situation

Two different situations are assessed in the case study. Figure 2 depicts the former, assuming an initial configuration with green East Traffic Light and red West Traffic Light for the next 30 seconds, no vehicle coming from the East and three cars coming from the West having low priority and expected time of arrival of 5, 10, and 15 seconds respectively. The roadside cameras detect no traffic on the East side and a presence of cars on the West side. It is correct to expect that, after collecting the information from the devices and executing the argumentation process, the configurations of the Traffic Lights will be promptly reversed to let the three cars pass. Figure 3, depicting the second situation, has the same starting configuration as the former, but in addition it sees the arrival of an ambulance in 5 seconds from the East. Due to the higher priority of the ambulance w.r.t. the three cars, Controllers should set the Traffic Lights to keep their current configuration to allow the ambulance to quickly cross the road interruption point.

The case study uses a KB (not reported here due to lack of space) modeled in $\mathcal{ALN}$ DL. The Terminological Box (*TBox*) $\mathcal{T}$ contains all the classes used to describe the devices in the scenario: Vehicles, Traffic Lights, Cameras and

Deciders. Each device is modeled as an individual of the Assertion Box ($ABox$) and its class expression is used as a single argument in the BWAF.

The BWAF $\mathcal{G}_1$ –without weights on the edges– in Figure 4, which reflects the situation in Figure 2, shows how the node that describes the green *East Traffic Light* (ETL) suffers an attack by the roadside *Reolink Camera* (RC), which detects no vehicles in the vicinity and therefore believes the light should not stay green. Similarly, in the bottom half of the graph, the red *West Traffic Light* (WTL) is attacked by the three cars (*Fiat Panda*, *Audi A3*, *BMW X3*), which are approaching the traffic light and need to pass, and also by the *Foscam Camera*, which detects the presence of vehicles in the proximity. In addition, both the Traffic Light nodes are related to Controllers C_1 and C_2, which provide opposite arguments; $C1$ represents red ETL and green WTL, while $C2$ represents green ETL and red WTL.

As an illustrative example, the appraisal of the relationship of RC w.r.t. ETL is analyzed hereafter. Arguments are reported in OWL 2 *Manchester Syntax* [11]. `RC: Camera and (hasTrafficDensity some owl:Thing) and (hasTrafficDensity only NoTraffic) and (requiredTrafficLight some owl:Thing) and (requiredTrafficLight only RedEastTrafficLight)`
`ETL: TrafficLight and (requiredTrafficLight some owl:Thing) and (requiredTrafficLight only GreenEastTrafficLight) and (hasTrafficDensity some owl:Thing) and (hasTrafficDensity only LowTraffic) and (hasDurationSec min 30 owl:Thing) and (hasDurationSec max 30 owl:Thing)`

The preliminary consistency check between ETL and RC fails, as the conjunction of the two expressions is unsatifiable due to the clash of mutually disjoint classes `RedEastTrafficLight` and `GreenEastTrafficLight`. The relationship is thus recognized as an attack and its weight must be computed by identifying the four information contributions as explained in Section 3.2. The strength of the attack, characterized essentially by the contrasting part between the two semantic annotations, is equal to the Give-up of Concept Contraction:
`A := (requiredTrafficLight some owl:Thing) and (requiredTrafficLight only GreenEastTrafficLight)`
The remaining three terms mitigate the attack. The second term, quantifying the common elements between the two arguments, is :
`B := (hasTrafficDensity some owl:Thing) and (hasTrafficDensity only LowTraffic)`
This outcome is due to the semantic compatibility of classes `LowTraffic` and `NoTraffic` in the reference ontology. The third term of the formula quantifies the information in the attacked argument ETL that is absent from the attacking one RC:
`C := TrafficLight and (hasDurationSec min 30 owl:Thing) and (hasDurationSec max 30 owl:Thing)`
Finally, the information that RC has in addition to ETL is:
`D := Camera and (hasTrafficDensity only NoTraffic)`
Class expressions in A, B, C and D provide the formal explanation which makes the relationship interpretable.

The situation depicted in Figure 3 is instead represented by the BWAF $\mathcal{G}_2$ in Figure 5. In this case, the green ETL receives a support from both the *Ambulance* and the RC: the former describes itself as a special high priority vehicle, ready to overcome the road interruption in a time of 5 seconds; the latter detects the presence of vehicles in proximity and states the ETL should stay green. The bottom half of the graph, on the other hand, remains completely unchanged w.r.t. the previous situation. Although seemingly small, the differences of $\mathcal{G}_2$ w.r.t. $\mathcal{G}_1$ have a significant impact on the overall acceptability of arguments.

A preliminary assessment of the acceptability of the arguments has been conducted by exploiting the *ARGUER* (*ARGuing Using Enhanced Reasoning*) argumentation reasoner [18]. It was used on the BWAFs in both scenarios, evaluating the extensions by means of the (a) preferred and (b) stable semantics.

The preferred semantics for $\mathcal{G}_1$ produces the following extensions:
{`Reolink`, `Controller` $\texttt{C}_1$, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`},
{`Reolink`, `West Traffic Light`},
{`East Traffic Light`, `Controller` $\texttt{C}_2$, `West Traffic Light`},
{`East Traffic Light`, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`}.

Conversely, the stable semantics for $\mathcal{G}_1$ produces a single extension:
{`Reolink`, `Controller` $\texttt{C}_1$, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`}.

This happens because the stable semantics is more "skeptical" as, by definition, it requires the satisfaction of stricter constraints. The solutions produced by stable semantics, if they exist, are therefore considered more reliable than those produced by the preferred semantics. The expected result from the argumentation process on $\mathcal{G}_1$ is confirmed by the stable extension, which includes the "Controller $\texttt{C}_1$" argument, whose semantic description specifies red East Traffic Light and green West Traffic Light. Consequently, the system must reverse the configuration of the two traffic lights.

The preferred semantics for $\mathcal{G}_2$ produces the following extensions:
{`Reolink`, `Ambulance`, `East Traffic Light`, `Controller` $\texttt{C}_2$, `West Traffic Light`},
{`Reolink`, `Ambulance`, `East Traffic Light`, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`},
{`Controller` $\texttt{C}_1$, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`}.

The stable semantics for $\mathcal{G}_2$ produces a single extension:
{`Reolink`, `Ambulance`, `East Traffic Light`, `Foscam`, `Fiat Panda`, `Audi A3`, `BMW X3`}.

In this case the stable semantics does not include the argument "Controller $\texttt{C}_2$" as expected, but the presence of the ETL argument in the extension allows to consider that it is correctly set to green. In both argumentative graphs, the adoption of extension-based semantics does not appear completely satisfactory since (i) the arguments expected as "winning" are often not contained in the extensions (ii) in SWoT scenarios a finer evaluation of the decisions to be enacted is fundamental. A ranking semantics that fully exploits the weights of the relationships of a BWAF, calculated by arranging the informative contributions identified in this proposal, could solve the issues detected with extension-based semantics.

5 Related work

In recent times, the argumentation theory originally promoted by Dung [8] is increasingly exploited within IoT contexts to model interactions among smart devices and to enable autonomous argumentation-based coordination. In [14], argumentation theory is employed to coordinate smart vehicles on a congested road. Arguments represent both data collected through vehicle sensors and possible actions. By processing the argumentative graph, each vehicle agent is able to solve conflicts, identify winning arguments (*i.e.*, suggested actions) and change appropriately the road line according to the current road configuration. Also in [13], the argumentation graph models object interactions concretizing a sequence of dialogues in natural language. The main goal is to define an argumentation-based decision-making system, overcoming the limitations of traditional rule-based approaches. The vision was exemplified in two real-world scenarios regarding traffic management and ambient-assisted living.

Despite both works showing the feasibility and usefulness of argumentation in IoT, adoption of formal argument models and automatic relation appraisal is still an open challenge. Combining knowledge representation and non-monotonic reasoning with argumentation frameworks can lead to significant improvements, allowing to handle issues such as defeasibility and inconsistency in ways that traditional logics are not able to support [19]. Along this vision, early proposals exploited abstract argumentation for reasoning over inconsistent knowledge bases (KBs). The Generalized Argumentation Framework (GenAF) [16] has been defined to model an argumentative graph upon an underlying KB: each argumental atom represents a formula in the KB and every attack relation between two arguments models inconsistency or incoherence between conflicting sources of information. While it provides a general extension to AA, adaptable to different logics for representing knowledge inside arguments, conflict recognition is based only on consistency check. A deductive argumentation framework is presented also in [6] to reason with conflicting and uncertain ontologies. It models two different relations based on the argument structures. Differently from the previous work, each argument is also associated with a weight representing the information certainty degree. In both cases, the final argumentation graph was used to study acceptability of arguments, but implementations in concrete scenarios were not proposed and the reference logical formalisms are not related to standard Semantic Web languages (*e.g.*, RDF and OWL).

As explained in [10,12], a knowledge-based approach can be exploited to: (i) annotate arguments w.r.t. a reference ontology providing the conceptualization and vocabulary for the particular knowledge domain; (ii) simplify graph sharing among different agents; (iii) autonomously identify support and attack relations among argument descriptions. A related approach for knowledge fusion was introduced in [22] for SWoT VANETs: although providing acceptability evaluation and reconciliation of inconsistencies, it lacks the larger flexibility of Dung-style abstract argumentation. Starting from the positive outcomes presented above, the adoption of knowledge representation was preliminarily investigated not only to model information but also to introduce a matchmaking process to recognize and weight relations through non-standard inferences.

6 Conclusion and perspective

This paper has introduced a novel approach for integrating DL-based semantic matchmaking into argumentation frameworks. Non-standard, non-monotonic inferences, endowed with formal justification of results, allow a structured appraisal of relationships between pairs of arguments. The approach also provides a direct mapping from structured to abstract argumentation evaluation, specifically in BWAF. The conclusions on the overall acceptability of arguments become not only more fine-grained, but also more interpretable through meaningful explanations. The proposal is theoretically general-purpose, but motivated by collaborative autonomous decision-making and information reliability evaluation in SWoT networks of smart objects.

Notwithstanding, this work should be considered only as an early effort. While non-standard inferences analyze relationships between pairs of arguments structurally, further investigation is needed on the usage of induced CNF penalties for weighing them. A *score combination function* (a.k.a. *utility function*) is a possible approach to combine logical and extra-logical considerations in the appraisal. Furthermore, semantic explanations of relationships could be embedded into the argumentative graph itself. This would further improve transparency of the approach, making it immediate to interpret the model and its results.

References

1. Amgoud, L., Ben-Naim, J.: Ranking-based semantics for argumentation frameworks. In: International Conference on Scalable Uncertainty Management. pp. 134–147. Springer (2013)
2. Atkinson, K., Baroni, P., Giacomin, M., Hunter, A., Prakken, H., Reed, C., Simari, G., Thimm, M., Villata, S.: Towards artificial argumentation. AI magazine **38**(3), 25–36 (2017)
3. Baader, F., Calvanese, D., McGuinness, D.L., Nardi, D., Patel-Schneider, P.: The Description Logic Handbook. Cambridge University Press (2002)
4. Baroni, P., Caminada, M., Giacomin, M.: An introduction to argumentation semantics. The Knowledge Engineering Review **26**(4), 365–410 (2011)
5. Baroni, P., Gabbay, D., Giacomin, M., van der Torre, L.: Handbook of Formal Argumentation, vol. 1. College Publications (2018)
6. Bouzeghoub, A., Jabbour, S., Ma, Y., Raddaoui, B.: Handling conflicts in uncertain ontologies using deductive argumentation. In: International Conference on Web Intelligence. pp. 65–72. ACM (2017)
7. Cayrol, C., Lagasquie-Schiex, M.C.: On the acceptability of arguments in bipolar argumentation frameworks. In: European Conference on Symbolic and Quantitative Approaches to Reasoning and Uncertainty, ECSQARU. Lecture Notes in Computer Science, vol. 3571, pp. 378–389. Springer (2005)

8. Dung, P.M.: On the Acceptability of Arguments and its Fundamental Role in Nonmonotonic Reasoning, Logic Programming and N-Person Games. Artificial intelligence **77**(2), 321–357 (1995)
9. Dunne, P.E., Hunter, A., McBurney, P., Parsons, S., Wooldridge, M.: Weighted argument systems: Basic definitions, algorithms, and complexity results. Artificial Intelligence **175**(2), 457 – 486 (2011)
10. Heras, S., Botti, V., Julián, V.: An Ontological-based Knowledge-representation Formalism for Case-based Argumentation. Information Systems Frontiers **17**(4), 779–798 (Aug 2015)
11. Horridge, M., Patel-Schneider, P.: OWL 2 Web Ontology Language Manchester Syntax (Second Edition). W3C note, W3C (Dec 2012), http://www.w3.org/TR/owl2-manchester-syntax/
12. Kökciyan, N., Yaglikci, N., Yolum, P.: An argumentation approach for resolving privacy disputes in online social networks. ACM Transactions on Internet Technology (TOIT) **17**(3), 27 (2017)
13. Lippi, M., Mamei, M., Mariani, S., Zambonelli, F.: An argumentation-based perspective over the social IoT. IEEE Internet of Things Journal **5**(4), 2537–2547 (2018)
14. Lovellette, E., Hexmoor, H., Rodriguez, K.: Automated argumentation for collaboration among cyber-physical system actors at the edge of the Internet of Things. Internet of Things **5**, 84–96 (2019)
15. Manola, F., Miller, E., McBride, B.: RDF 1.1 Primer. W3C Working Group Note, W3C (Jun 2014), https://www.w3.org/TR/rdf11-primer/
16. Moguillansky, M.O., Simari, G.R.: A Generalized Abstract Argumentation Framework for Inconsistency-tolerant Ontology Reasoning. Expert Syst. Appl. **64**(C), 141–168 (Dec 2016)
17. Parsia, B., Rudolph, S., Krötzsch, M., Patel-Schneider, P., Hitzler, P.: OWL 2 Web Ontology Language Primer (Second Edition). W3C Recommendation, W3C (Dec 2012), http://www.w3.org/TR/owl2-primer
18. Pazienza, A., Ferilli, S., Esposito, F.: Constructing and evaluating bipolar weighted argumentation frameworks for online debating systems. In: 1st Workshop on Advances In Argumentation In Artificial Intelligence, XVI International Conference of the Italian Association for Artificial Intelligence. pp. 111–125 (2017)
19. Reed, C., Budzynska, K., Duthie, R., Janier, M., Konat, B., Lawrence, J., Pease, A., Snaith, M.: The argument web: An online ecosystem of tools, systems and services for argumentation. Philosophy & Technology **30**(2), 137–160 (2017)
20. Ruta, M., Di Sciascio, E., Scioscia, F.: Concept Abduction and Contraction in Semantic-based P2P Environments. Web Intelligence and Agent Systems **9**(3), 179–207 (2011)
21. Ruta, M., Scioscia, F., Bilenchi, I., Gramegna, F., Loseto, G., Ieva, S., Pinto, A.: A multiplatform reasoning engine for the Semantic Web of Everything. Journal of Web Semantics **73**, 100709 (2022)
22. Ruta, M., Scioscia, F., Gramegna, F., Ieva, S., Di Sciascio, E., De Vera, R.P.: A knowledge fusion approach for context awareness in vehicular networks. IEEE Internet of Things Journal **5**(4), 2407–2419 (2018)
23. Scioscia, F., Ruta, M.: Building a Semantic Web of Things: issues and perspectives in information compression. In: Proceedings of the 3rd IEEE International Conference on Semantic Computing. pp. 589–594. IEEE Computer Society (2009)
24. Simari, G.R., Rahwan, I. (eds.): Argumentation in Artificial Intelligence. Springer (2009)