A Description Logic for InferenceNet.Br

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Abstract. The InferenceNet.Br is a new linguistic resource for Portuguese language knowledge bases, which follows some principles of the WordNet, ConceptNet and FrameNet. Unlike these other linguistic resources, InferenceNet.Br allows representation of more expressive relationships between concepts, permitting to characterize premises or conclusions of these relationships. However, the integration between InferenceNet.Br with other linguistic resources is not possible directly. In order to settle this problem, in this paper we present a mapping of the knowledge bases of InferenceNet.Br to the Description Logic *DL-Lite*$_{\mathcal{A}}$, which is a fragment of OWL. As we know, OWL is a standard language designed to facilitate machine interpretability of Web content, through explicitly representation of the meaning of concepts in vocabularies and relationships between them. By doing this, we provide a connection between InferenceNet.Br and resources as WordNet and ConceptNet, since there are some efforts to link them to OWL.

Key words: Linguistic Resource, InferenceNet.Br, Description Logic, OWL.

1 Introduction

Natural Language Processing (NLP) is a field of computer science and linguistics concerned with technics to construct computational systems which treat different levels of meanings and uses of natural languages. Roughly speaking, NLP systems are conceived to enable computers to manipulate linguistic signs reasonably in order to take decisions, extract and retrieve information, summarize texts, and solve other tasks involving the understanding of sentences and texts in natural language.

In Mitkov [21], it was stated that the reasoners of current NLP systems employ predominantly syntactic approaches, facing difficulties in capturing certain kind of knowledge, mainly because of the lack of linguistic resources that support a complete understanding of concepts and sentences. The usual reasoners define taxonomies or ontologies through objects of determined domain, classes of objects and relationships between objects, but do not represent their practical content. For instance, when we take into consideration the word *chair*, we can either conclude that it is made of a specific material, as wood for example, or we can conclude that it has some practical utilities, as a seat or even a weapon.

An alternative applied to improve the quality of inferences in NLP systems is to resort to lexical-semantic base systems, whose aim is to add contextual elements that enhance the ability of these systems. The three principal bases used in semantic systems and applications of NLP are the WordNet [19], the FrameNet [6] and the ConceptNet [15]. WordNet provides lexical-semantic resources for the Portuguese language;

however it expresses only basic semantic hierarchy relationships (hyperonymy and hyponymy), inclusions (holonymy and meronymy), equivalences (synonymy) or oppositions (antonymy), and it is not available for large-scale use. FrameNet is based on the theory of frames proposed by Minsky [20]. A frame is a conceptual hierarchical structure defining a situation, object or event by participants and their relationships. ConceptNet is a commonsense knowledge base in Portuguese language, which creates a net of relationships between concepts, such that these relationships may express causality, functionality, location, time, etc.

The Semantic Inferencialism Model (SIM) [22,23] is another lexical-semantic base with good results. It consists of a new model for treatment of pragmatic-semantic level of natural languages, adding new information in relationships and allowing richer inferences. SIM comprises four components: Conceptual Base, Sentence Patterns Base, Rule Base for Practical Reasoning and an algorithm to deduce information from these knowledge bases. To represent Conceptual and Sentence Patterns Bases it is used the Portuguese linguistic resource InferenceNet.Br [24] and the Rule Base for Practical Reasoning is represented as a knowledge base in logic programming [16].

ConceptNet, the InferencentNet.Br is a commonsense knowledge base which can represent many different types of knowledge, as relationships between concepts, expressed as simple phrases of natural language. This resource can be accessed by the portal www.inferencenet.org, where its Conceptual Base contains around 180.000 relationships between concepts and 700.000 relationships of pragmatical content, and the Sentence Patterns Base contains 5963 sentence patterns through 1061 relationships.

However, the InferenceNet.Br is not directly related to any other resources known, as WordNet, FrameNet and ConceptNet. Following the works [12,14], which converts WordNet and ConceptNet databases in Web Ontology Language (OWL) [18], the standard language to represent ontologies in the Semantic Web, in this paper we will translate InferenceNet.Br into a Description Logic namely $DL\text{-}Lite_{\mathcal{A}}$ [7]: a logic of the *DL-Lite* family that can be expressed in OWL-Lite [13,18] and that is expressive enough to represent InferenceNet.Br knowledge bases. By doing this translation, we can establish a connection between InferenceNet.Br with databases of WordNet and ConceptNet.

This paper is organized as follows: Section 2 describes the general aspects of InferenceNet.Br and explains the component and main characteristics of the resource. In Section 3 we describe the Description Logic $DL\text{-}Lite_{\mathcal{A}}$ and we show how to represent the content of Conceptual and Sentence Patterns Bases using this logic. Finally, we conclude the paper in Section 4.

2 InferenceNet.Br

One motivation for introducing a new linguistic resource is the lack of linguistic resources with large scale semantic knowledge for the Portuguese language. Lexical-semantic bases in Portuguese as WordNet.Pt [10], WordNet.Br [9], TeP 2.0 [17], PAPEL [11], FrameNet Brasil [25] or OMCS-Br [1] are restricted to specific domains, i.e., they depend of a text corpus, a dictionary or a thesaurus [26]. Another motivation is the non-existence of a linguistic resource with inferentialist semantic knowledge, either for Portuguese or other languages [22,23]. InferenceNet.Br contains two knowledge bases included in the SIM (Semantic Inferentialism Model): the Conceptual Base and the Sentence Patterns Base. Thus, SIM permits to realize inferences through three knowledge bases (Conceptual Base + Sentence Patterns Base + Rule Base for Practical Reasoning), an input text generated by a parser and an inference algorithm.

2.1 Conceptual Base

The Conceptual base is represented by a set of relations R_C, which is denoted by a tuple $R_C =$ (relationship, c_i, c_j, type), where the relationship denotes a relation between two concepts: c_i and c_j. A concept can represent simple or composite words from the noun, verb, adjective, or adverb classes, e.g., *crime* (crime), *morte* (death), *viver* (to live), *prova de inglês* (english test) or *anteontem* (day before yesterday). Words which belong to the preposition, pronoun or conjunction classes do not have semantic value, and therefore are not expressed by concepts. Table 1 shows the types of relationships presented in the Conceptual Base, whose relationships were inherited from the ConceptNet knowledge bases. These relationships may express physical, functional or even causal characteristics of the concepts. Each relationship defines uniquely a pre-condition or post-condition of origin of the concept. Pre-conditions or premises of use are what gives someone the right to use the concept and what could exclude such right, serving as premises for utterances and reasoning. Post-conditions or conclusions of use are what follows or what are the consequences of using the concept, which let one know what someone is committed to by using a particular concept, serving as conclusions from the utterance and as premises for future utterances and reasoning. We use type = Pre or Pos, to denote pre-condition or post-condition. For instance, a partial vision of the relations of the concept *crime* can be:

1. *(capazDe, crime, ter vítima, Pre).*
2. *(efeitoDe, crime, culpa, Pos).*
3. *(usadoPara, crime, vingança, Pre).*

1. (capableOf,crime,to have victim, Pre).
2. (effectOf, crime, guilt, Pos).
3. (usedFor, crime, vengeance, Pre).

Category	**Type of relationship (ConceptNet)**	**Type of inferential relation (InferenceNet.Br)**
Things	PropertyOf, PartOf, MadeOf, IsA, DefinedAs	Pre-condition
Events	LastSubEventOf, PreRequirementEventOf, FirstSubEventOf, SubEventOf	Post-condition
Causal	EffectOf, DesirousEffectOf	Post-condition
Affective	DesireOf, MotivationOf	Pre-condition
Functional	UsedFor, CapableOfReceivingAction	Post-condition
Agents	CapableOf	Pre-condition
Spatial	LocationOf	Pre-condition

Table 1. Types of relationships expressed by ConceptNet.

2.2 Sentence Patterns Base

The Sentence Patterns base is represented by a set of relations R_P, which is denoted by a tuple $R_P =$ (isA, t_p, c_i, type), where t_p can be a noun phrase (NP) or a prepositional phrase (PP) of a sentence, c_i is a concept and type = Pre or Pos. Note that in the Sentence

Patterns Base, there are only relationships of the kind *isA* (in Portuguese: *éUm*). For instance, a partial vision of the relations of sentence $p =$ *X ser assassinado por Y* (*X* to be killed by *Y*) can be (where sn(p) and sp(p) are respectively a noun phrase (NP) and prepositional phrase (PP) of p, i.e., sn(p) = *X* and sp(p) = *Y*):

1. *(éUm, sn(p), pessoa, Pre).*
2. *(éUm, sn(p), vítima, Pos).*
3. *(éUm, sp(p), assassino, Pos).*

1. (isA, sn(p), person, Pre).
2. (isA, sn(p), victim, Pos).
3. (isA, sp(p), assassin, Pos).

Unlike the Conceptual Base, the inferential content of the relationship *isA* is not defined only as a pre-condition. The sentence patterns permit either create pre-conditions (generated from the the Conceptual Base), as well post-conditions, generated according to the circumstance expressed by the adverbial complement of main verbs and auxiliary verbs of a phrase [24].

3 The *DL-Lite*$_{\mathcal{A}}$ Logic

3.1 Syntax and Semantics

The Semantic Web [2,5] aims for machine-understandable Web resources, whose information can be shared and processed both by automated tools, such as search engines, and by human users. To make sure that the resources will be understandable, one needs ontologies in which the knowledge is described. Basically, an ontology is a collection of definitions of concepts.

Description Logics (DLs) [4] are a family of knowledge representation languages that can be used to represent ontologies of an application domain in a structured and formally well-understood way. Besides, these logics are more expressive than propositional logic and have a decision problem more efficient than first order logic. In general, they have a good relation between expressivity and complexity (most of them are decidable).

In this section we describe *DL-Lite*$_{\mathcal{A}}$ [7], a logic of the family of Description Logics *DL-Lite* [3], which will represent the content of the knowledge bases in InferenceNet.Br. *DL-Lite* are logics with low expressivity and good results of complexity. In general, these logics have a polynomial-time algorithm for its satisfiability problem [3]. This DL was chosen as the base of our work because its expressivity is sufficient to represent knowledge bases of InferenceNet.Br. Indeed, *DL-Lite*$_{\mathcal{A}}$ is more expressive than InferenceNet.Br, but a good result obtained is that this logic maintains the polynomial-time algorithm for its satisfiability problem [8].

The logic *DL-Lite*$_{\mathcal{A}}$ works with three components: individuals, concepts and roles. An individual represents an element of the universe of discourse (domain). Concept represent unary predicates related to individuals. For instance, let *john* be an individual and *Person* be a concept name; we can say that *john* is an instance of *Person*, denoting that John is a person. In this work, we will employ concept names to express words of the noun, adjective, article or adverb classes. Roles represent binary predicates between individuals. If *john* and *mary* are individuals and *IsMarried* is a role name, by *IsMarried(john, mary)*, we mean that the individual *john* is married to the individual *mary*. Elementary descriptions as *Person* and *IsMarried* are called, respectively, *atomic concepts* and *atomic roles*. In *DL-Lite*$_{\mathcal{A}}$, general descriptions can be inductively built from them with concept constructors as follows, where B (basic concept) and L (light concept) are concepts, A is an atomic concept, R is an atomic role and R^- is inverse of an atomic role:

$$B \longrightarrow A \mid \bot \mid \exists R \mid \exists R^-$$
$$L \longrightarrow B \mid \neg B \mid \exists R.L \mid \exists R^-.L$$

The basic concept B may denote an atomic concept (A), which can be a noun, adjective, article or adverb, e.g., *Crime, Person, Death, Assassin*; or a bottom concept ($\bot$) which denotes the empty set; or an unqualified existential concept ($\exists R$). Indeed, this last concept can be used to represent the noun phrases of a sentence pattern with a verbal phrase (R), e.g., the concept $\exists$*KilledBy*, denoting someone that was killed by something/someone. The inverse unqualified existential concept ($\exists R^-$) represents the prepositional phrase of a sentence pattern, e.g., the concept $\exists$*KilledBy*$^-$, which denotes someone that killed someone. The light concept L may denote a basic concept B or a complement of basic a concept ($\neg B$), as example $\neg$*Man*, which denotes the concept *Woman*; or a qualified existential concept ($\exists R.L$), which can be used to represent the noun phrase of a sentence pattern with a verbal phrase + prepositional phrase of a sentence. For example, $\exists$*Kill.Man* denotes someone that killed a man. Finally, for the inverse qualified existential concept ($\exists R^-.L$), we can have the concept $\exists$*Kill*$^-$*.Man* as a example, which denotes someone that was killed by man.

The semantics of *DL-Lite*$_{\mathcal{A}}$ concepts is given by an interpretation I = ($\Delta^I, \cdot^I$), where the domain Δ^I is a non-empty set of elements and $\cdot^I$ is a mapping function defined by: each individual a is mapped to $a \in \Delta^I$; each atomic concept A is mapped to $A^I \subseteq \Delta^I$; each atomic role R is mapped to $R^I \subseteq \Delta^I \times \Delta^I$. Complex concepts can be inductively interpreted as follows: $\bot^I = \emptyset$; $\neg B^I = \Delta^I \backslash B^I$; $(\exists R)^I = \{a \in \Delta^I \mid \exists b \in \Delta^I, (a,b) \in R^I\}$; $(\exists R^-)^I = \{a \in \Delta^I \mid \exists b \in \Delta^I, (b,a) \in R^I\}$; $(\exists R.L)^I = \{a \in \Delta^I \mid \exists b \in \Delta^I, (a,b) \in R^I \wedge b \in L^I\}$; $(\exists R^-.L)^I = \{a \in \Delta^I \mid \exists b \in \Delta^I, (b,a) \in R^I \wedge b \in L^I\}$.

The knowledge representation on Description Logics can be divided into two components: the TBox and the ABox. TBox introduces the *terminology*, i.e., the vocabulary of an application domain, while the ABox contains assertions about individuals in terms of this vocabulary. The vocabulary consists of concepts and roles. The TBox can be used to assign names to complex concept and role descriptions. Syntactically, the terminology is represented by a finite set of *terminological axioms*, which have the form $B \sqsubseteq L$. Axioms of these kinds are called inclusions. The inclusion axiom $B \sqsubseteq L$ means that each individual of B is an individual of L. For instance, we can define *Crime* $\sqsubseteq$ *ViolaçãoDeLei* (*Crime* $\sqsubseteq$ *LawViolation*), denoting that every crime is a law violation; or we can define *Crime* $\sqsubseteq$ $\exists$*motivaçãoDe.Vingança* (*Crime* $\sqsubseteq$ $\exists$*motivationOf.Vengeance*), to denote that every crime is a motivation of vengeance; or *Assassino* $\sqsubseteq$ $\exists$*AssassinadoPor*$^-$ (*Assassin* $\sqsubseteq$ $\exists$*KilledBy*$^-$), denoting that every assassin is an individual that killed someone.

An ABox (Assertional Box) consists of a finite set of *assertion axioms* of the form $L(a)$, $R(a,b)$ and $R^-(a,b)$, where a and b are individuals. These assertions denote that an individual a is an instance of the concept L and that the pair of individuals (a,b) is an instance of R or R^-, respectively. For instance, the assertions *Assassino(john), AssassinadoPor(mary, john)* (*Assassin(john), KilledBy(mary, john)*) denotes that John is an assassin, that he killed Mary. The semantics of inclusion and assertion axioms is given by: $B \sqsubseteq L$ iff $B^I \subseteq L^I$; $L(a)$ iff $a \in L^I$; $R(a,b)$ iff $(a,b) \in R^I$; $R^-(a,b)$ iff $(b,a) \in R^I$.

3.2 Mapping InferenceNet.Br to *DL-Lite*$_{\mathcal{A}}$

In this section, we will show that we can convert any knowledge base in InferenceNet.Br into *DL-Lite*$_{\mathcal{A}}$, and consequently we can reason about InferenceNet.Br using some Semantic Web tools, specifically those one using the OWL-Lite language. We will show how the tuples of InferenceNet.Br can be translated into inclusion axioms in *DL-Lite*$_{\mathcal{A}}$. We regard that we are only considering knowledge bases in *DL-Lite*$_{\mathcal{A}}$ with an empty ABox, since the InferenceNet.Br represents only terminologies. First we will show that all tuples of the Sentence Patterns Base correspond to inclusion axioms in the TBox:

- For all tuple of the form (*éUm*, sn(p), c, type) in the Sentence Patterns Base, we can transform it in an axiom inclusion in which
  - If type = Pos, then the axiom inclusion will be of the form $\exists$sv(p) $\sqsubseteq A$, where sv denotes the verbal phrase (VP) of a sentence in Portuguese and A is the atomic concept created from the concept c;
  - If type = Pre, then the axiom inclusion will be of the form $A \sqsubseteq \exists$sv(p).

Suppose the following tuple *(éUm, sn(X ser assassinar por Y), vítima, Pos)* in the Sentence Patterns Base . The translated axiom inclusion will be of the form $\exists$sv(*X* ser assassinar por *Y*) $\sqsubseteq$ *Vítima* which is equivalent to the axiom $\exists$*serAssassinarPor* $\sqsubseteq$ *Vítima*.

- For all tuple of the form (éUm, sp(p), c, type) in the Sentence Patterns Base
  - If type = Pos, then the axiom inclusion will be of the form $\exists\text{sv}(p)^- \sqsubseteq A$;
  - If type = Pre, then the axiom inclusion will be of the form $A \sqsubseteq \exists\text{sv}(p)^-$.

Let *(éUm, sp(X ser assassinar por Y), assassino, Pos)* be a tuple in the sentence Patterns Base. The translated axiom will be $\exists$*serAssassinarPor*$^-$ $\sqsubseteq$ *Assassino*. Finally, we will show the mapping from the tuples of Conceptual Base to inclusion axioms in *DL-Lite*$_{\mathcal{A}}$.

- For all tuples of the form (r, c_1, c_2, type) of the Conceptual Base, we can transform them into inclusions in $\mathcal{T}$ of the form $A_1 \sqsubseteq \exists r.A_2$, where r is a relationship name and A_1 and A_2 are atomic concepts created from the concepts c_1 and c_2, respectively.

Suppose that we have the tuple *(usadoPara, crime, vingança, Pre)* in the Conceptual Base; thus the axiom inclusion in $\mathcal{T}$ will be *Crime* $\sqsubseteq$ $\exists$*usadoPara.Vingança*.

4 Conclusion

In this paper, we used the Description Logic *DL-Lite*$_{\mathcal{A}}$ to represent the knowledge bases of the web resource InferenceNet.Br. We showed a mapping of InferenceNet.Br to *DL-Lite*$_{\mathcal{A}}$, which enables the integration of InferenceNet.Br with Semantic Web tools, in special, tools based on the OWL-Lite language. Consequently we can make inferences using some related Description Logics reasoners.

As a future work, we can consider to investigate a mapping for the case in which the ABox is non-empty. In this case, we are treating not only with the InferenceNet.Br resource, but with the whole SIM (Semantic Inferentialism Model), where the ABox can be generated by an input text and a morphosyntactical parser. Another line of research is to extend the expressivity of InferenceNet.Br or SIM and consequently extend the logic introduced in this paper in order to represent more expressive concepts and relationships between concepts. This extension will enable us to express more complex concepts rather than only the atomic ones or even to represent other kinds of relationships, e.g., similarities between concepts.

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