Description Logic Based Formal Representation of Adjectives

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Abstract

The paper introduces a system of rules for description logic based formal representation of adjectives used in both attributive and predicative functions and involved in a variety of syntactic relations. The system was developed to convey the semantics of adjectives by virtue of concept and role constructors implemented in description logic formalisms known as SHOIN(D) and SROIQ(D). The system is intended to be integrated into a large-scale system of formalization rules devised for the development of description logic based definitions of domain terms. The proposed system of rules was tested and evaluated on two sets of syntactic units that contain attributive and predicative adjectives represented in English and Russian languages.

Keywords: formal representation of semantics, attributive adjective, predicative adjective, formal definition, description logics

1. Introduction

The application of description logics (DL) for formal representation of semantics conveyed by units of various lexical categories is motivated by the extensive implementation of ontologies for natural language processing within the framework of Semantic Web development initiative (Horrocks, 2008; Ding, 2010; Yu, 2014). In order to provide for Question Answering over Linked Data, each query has to obtain a formal representation of its semantics that could be mapped to a network of classes, properties, data values, and individuals that constitute an ontology as a knowledge base (Fazzinga and Lukasiewicz, 2010; Mehta et al. 2015). For this reason, ontology-based question answering systems, instantiated with ORAKEL (Cimiano et al., 2008), Pythia (Unger and Cimiano, 2011), and AMUSE (Hakimov et al., 2018), require a solid set of rules to formalize meanings of lexical units of a natural language query.

With the view to facilitating the process of formalization, software developers compile a comprehensive ontology and augment it with an extensible lexicon. Lexicon units have their meanings defined through mappings to units of the ontology, the mappings are provided by virtue of lexicon models, instantiated with LexInfo (Cimiano et al., 2011), LexOnto (Cimiano et al., 2007), and OntoLex-Lemon (Cimiano et al., 2016; McCrae et al., 2017). If lexicon models were enhanced with formal definitions of lexicon units' semantics, a lexicon unit's semantics could be specified by virtue of interrelated ontology units rather than through a single ontology unit (Gritz, 2018a). This accurate specification of lexicon units' meanings could enhance formal representations of the semantics of queries and, therefore, contribute to the development of ontology-based semantic search technology. Furthermore, units introduced within formal definitions are supposed to bridge gaps within class and property taxonomies of an underlying domain ontology.

Even though several sets of formalization rules were designed to convert dictionary-based definitions of lexicon units' semantics into description logic based formal definitions (DL-definitions) (Völker et al., 2007; Azevedo et al., 2014), a comprehensive system of formalization rules is still required to obtain DL-definitions on a regular basis in an automatic or a semi-automatic fashion. The current research aims to contribute to the development of a system of formalization rules by devising a set of rules used for DL-based formal representation of semantics conveyed by attributive and predicative adjectives, the formal representations are intended to be applicable in the process of DL-definitions formation. For the purpose of formal representation, we implement the concept and role constructors that are applied in SHOIN(D) and SROIQ(D) description logics, which are compatible with Web Ontology Language (OWL) standards (Horrocks and Patel-Schneider, 2004; Horrocks et al., 2006).

The rest of the paper is divided into four sections. Section 2 provides a critical review of the current practice of DL-based adjective formal representation. Section 3 introduces the rules for the DL-based formal representation of adjectives and exemplifies their application. Section 4 summarizes the results of the rules testing, instantiates the successful implementation of the rules, and analyses the failures. Section 5 outlines the conclusions and objectives for future work.

2. Related research work

Traditionally an adjective is supposed to act as a modifier of a noun, which is syntactically related to the adjective, and to be used in a sentence either in the predicative or in the attributive function (Kennedy, 2012). Within the framework of formal semantics, adjectives undergo an entailment-based classification stemming from the assumption that an entity denoted by an adjective-noun compound might be independently referred to by one or both units of the compound. The entailment-based adjective typology, discussed by Kamp and Partee (1995), Bouillon and Viegas (1999), and McNally (2016), distinguishes three classes: intersective, subsective, and non-subsective adjectives. As the current formalization practice suggests, an adjective of any class should acquire a DL-based representation, with semantic and derivational properties of the adjective being considered, class and property taxonomies of an underlying ontology being utilized.

2.1. Intersective adjectives in description logic notation

An entity denoted by an adjective-noun compound containing an intersective adjective might be independently referred to by the adjective and by a modified noun: $\forall x(AN(x) \rightarrow A(x))$; $\forall x(AN(x) \rightarrow N(x))$. Within the framework of the current DL-based formalization practice, an intersective adjective is formalized through an existential restriction imposed on a certain property. Restriction specifying classes are nominated by the lexemes that are derivationally or semantically related to the intersective adjective.

For instance, Amoia and Gardent (2006) exploit an existential restriction to describe an adjective as a lexeme undertaking a theta role of a derivationally related verb: $Afloat \equiv \exists Theme^{-1}.Float$. McCrae et al. (2014) and Walter et al. (2017) define an intersective adjective by virtue of an existential restriction imposed via a class nominated by a derivationally associated noun: $Belgian \equiv \exists nationality.Belgium$. Ding et al. (2019) augmented this approach, using singleton sets to impose existential restrictions: $American \equiv \exists nationality.\{United\_States\}$, and implementing negation: $Alive \equiv \neg\exists deathDate.\top$. Gangemi et al. (2016) formalize an adjective-noun compound through an intersection of a modified noun represented class and a class described through an existential restriction imposed on the *hasQuality* property by virtue of an adjective nominated class: $CanadianSurgeon \equiv Surgeon \sqcap \exists hasQuality.Canadian$.

2.2. Subsective adjectives in description logic notation

Whenever an individual is denoted by an adjective-noun compound containing a subsective adjective, the individual can be independently referred to by a modified noun: $\forall x(AN(x) \rightarrow N(x))$. However, the adjective cannot unveil the class membership of the individual: $\forall x(AN(x) \nrightarrow A(x))$.

When it comes to subsective adjective formalization, one has to deal with the representation of concept inclusion and gradability. Amoia and Gardent (2006) define an adjective denoted class as a subclass of a class obtained by imposing an existential restriction on the object property *has_property*. The restriction is imposed through a class denoted by a derivationally related noun, with the latter class undergoing intersection with a class represented by an existential restriction applied to the datatype property *has_measure*: $Tall \sqsubset \exists has\_property.(Tallness \sqcap \exists has\_measure.Top)$. Pareti and Klein (2011) enhanced this approach, by introducing conceptually related nouns to define an existential restriction imposed on the *hasProperty* object property and clarifying the threshold values applied to the *hasMeasure* datatype property: $Expensive \equiv \exists hasProperty.(Cost \sqcap \exists hasMeasure.(\geq, X))$. Gangemi et al. (2016) impose an adjective specified existential restriction on the property *hasIntensionalQuality* in order to outline an adjective-noun compound represented class as a subclass of a class labeled with a modified noun: $SkillfulSurgeon \equiv \exists hasIntensionalQuality.Skillful \sqsubseteq Surgeon$.

2.3. Non-subsective adjectives in description logic notation

Non-subsective adjectives are referred to as intensional modifiers since they are applied to modify the intension of a syntactically bound noun (McNally, 2016). Non-subsective adjectives are divided into two groups: ordinary non-subsective adjectives and privative adjectives (Morzycki, 2016). Ordinary non-subsective adjectives, instantiated by the adjectives: *alleged*, *probable*, and *potential,* cannot be used to define the class membership of an individual represented by an adjective-noun compound: $\forall x(AN(x) \nrightarrow A(x))$. Moreover, it is unfeasible to identify an individual with a class denoted by a modified noun: $\forall x(AN(x) \nrightarrow N(x))$. In order to provide a description logic based formal representation of an adjective-noun compound, Gangemi et al. (2016) use classes denoted by an ordinary non-subsective adjective and a modified noun to impose existential restrictions on *hasModality* and *associatedWith* properties accordingly: $AllegedThief \equiv \exists hasModality.Alleged \sqcap \exists associatedWith.Thief$.

Privative adjectives appear to negate the core semantic properties of a modified noun: $\forall x(AN(x) \rightarrow \neg N(x))$, and, simultaneously, extend a modified noun's intension so that the noun could denote a broader class (Partee, 2010). Following this conception, Gangemi et al. (2016) apply negation to convey the semantics of both privative adjectives and intersective adjectives with privative readings: $FakeSphinx \equiv \neg Sphinx \sqsubseteq Sphinx\_(broad)$, $StoneLion \equiv \exists hasQuality.Stone \backslash Lion \sqsubseteq Lion\_(broad)$. Alternatively, a privative adjective and a modified noun might be used to specify existential restrictions imposed on *hasIntensionalProperty* and *associatedWith* properties: $FakeSphinx \equiv \exists hasIntensionalQuality.Fake \sqcap \exists associatedWith.Sphinx$ (Gangemi et al., 2016).

The proposed approaches were developed in order to enhance question answering systems over knowledge bases (Ding et al., 2019), knowledge extraction tools (Gangemi et al., 2016), ontology revision applications (Pareti and Klein, 2011), and ontology lexicons (McCrae et al., 2014; Walter et al., 2017). The techniques for formal representation of adjectives were intended to harness certain properties and classes of existing ontologies. On the contrary, the proposed set of rules is intended to be applicable for the development of ontologies and associated lexicons from scratch.

3. A system of rules for description logic based formalization of attributive and predicative adjectives

Following the functional approach to the semantics of adjectives (Partee, 2010; Morzycki, 2016), we currently implement compositional type-theoretic semantics in order to obtain formal representations of adjectives and introduce the resulting formulas in a string of symbols composing a DL-based formal definition. Therefore, semantic values of syntactic nodes of a parsed natural language definition are represented functionally: within each branch, sister nodes are correlated as a function and its argument, with a corresponding parent node representing the value of the applied function (see Figure 1). The parent node is implemented further either as a function or as an argument of a function within the process of functional application that carries on until the root node of the definition is reached (Chierchia and McConnell-Ginet, 2000; Winter, 2016).

Under the assumption that a DL-definition retains its truth-value in the whole scope of possible worlds (Gritz, 2018b), we represent the process of functional application, using the semantic types produced by a combination of the elementary types *e* and *t*: *e* stands for an entity on a domain and typically characterizes a proper noun, *t* stands for a truth-value and typically characterizes a syntactically well-formed definition as a declarative sentence (Chierchia and McConnell-Ginet, 2000).

In order to obtain a DL-definition, three type combinations are utilized: <e, t>, <<e, t>, t>, and <<e, t><e, t>>. The type <e, t> assigns the role of the characteristic function to a syntactic node that denotes a concept *C,* which is related to an individual by virtue of a concept assertion: *C:a*. The type <<e, t>, t> delivers a semantic value of a phrase introducing a defined term and performing the subject role within the main clause of a definition. This type reserves an argument position to be filled in by a concept denoted by the verb phrase occupying the sister node. Finally, the type <<e, t><e, t>> is used to mark all other functions that should return the denotation of a parent node, applying a concept denoted by a sister node as an argument. This type is implemented to characterize the semantics of the copular verb *to be,* bearing the identity function, and an article used as a determiner. A function of the type <<e, t><e, t>> expressed by definite and indefinite articles is not explicated within formalization examples in the current paper in order to make formal descriptions more concise.

The implementation of these semantic types is instantiated through the process of formalization of a natural language definition of the term *Agentive: An agentive is an agent* (the formal definitions are represented in first-order logic and in description logic notations).

$NP(x) = \lambda x. Agent(x)/< e,t >$
$V(x) = \lambda NP. NP(x)/\ll e,t >< e,t \gg$
$VP(x) = \lambda x. Agent(x)/< e,t >$
$NP_{subj}(x) = \lambda VP. \forall x(Agentive(x) \leftrightarrow VP(x))/ << e,t > t >$
$\forall x(Agentive(x) \leftrightarrow Agent(x))/t$

$NP = Agent/< e,t >$
$V = \lambda NP. NP/\ll e,t >< e,t \gg$
$VP = Agent/< e,t >$
$NP_{subj} = \lambda VP. Agentive \equiv VP/<< e,t > t >$
$Agentive \equiv Agent/t$

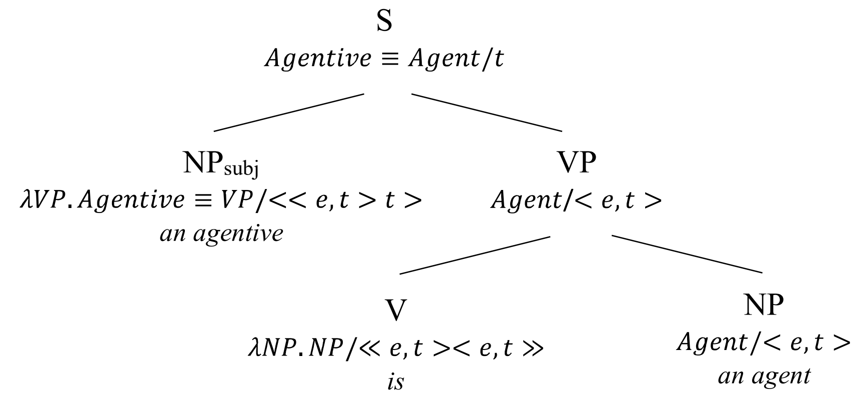

Figure 1: An analysis of the syntactic structure and semantics conveyed by a natural language definition of the term *Agentive*

In the current example, the lexical meaning of a term is defined by virtue of a synonym. We have proposed a system of rules to obtain DL-based formal representations of attributive and predicative adjectives that might be used to describe the lexical meaning of a term within the right part of a definition (see Table 1). An adjective acquires either the semantic type <<e, t><e, t>>, bearing the role of a function with an argument conveyed by virtue of a sister node, or the type <e, t>, performing the role of a function's argument (see Table 2 for examples).

The DL-based concept descriptions obtained by virtue of the rules acquire interpretations within the framework of model-theoretic semantics (Baader et al., 2007). Model-theoretic semantics is applied as a referential theory of meaning that studies meaning as a relation of symbols to objects. In other words, the meaning of a resulting concept description is determined by attaching an interpretation function I from possible worlds to subsets on a domain: $C^I: W \rightarrow D$ (Fitting, 2015). If the interpretation function returns a non-empty subset, the concept description is considered to be satisfiable. The resulting DL-based concept descriptions are checked for satisfiability on a domain in order to evaluate the rules proposed for DL-based formal representation of adjectives (see Table 1).

Rules for formal representation of adjectives	Interpretations for satisfiability check of the resulting concept descriptions
$Adj^{attr}_{\ll e,t><e,t\gg} = \lambda NP_{<e,t>}. A \sqcap NP$ (1)	$\lVert NP' \rVert = \{x \in \Delta^I \mid x \in A^I \wedge x \in \lVert NP \rVert\}$
$Adj^{attr}_{\ll e,t><e,t\gg} = \lambda NP_{<e,t>}. \exists A^{-}. \top \sqsubseteq NP$ (2)	$\lVert NP' \rVert = \{x \in \Delta^I \mid \exists x. (y,x) \in A^I \rightarrow x \in \lVert NP \rVert\}$
$Adj^{attr}_{\ll e,t><e,t\gg} = \lambda NP_{<e,t>}. \exists A. NP$ (3)	$\lVert NP' \rVert = \{x \in \Delta^I \mid \exists y. (x,y) \in A^I \wedge y \in \lVert NP \rVert\}$

$Adj^{pred}_{<e,t>} = A$ (4)	$\|VP\| = \{x \in \Delta^I \mid x \in A^I\}$/ $\|VP\| = \{x \in \Delta^I \mid \exists y.(x,y) \in V^I \land y \in A^I\}$
$Adj^{pred}_{\ll e,t><e,t\gg} = \lambda NP^{extsubj}_{<e,t>}.NP^{extsubj} \sqsubseteq A$ (5)	$\|AdjP\| = \{x \in \Delta^I \mid x \in \|NP^{extsubj}\| \rightarrow x \in A^I\}$
$Adj^{pred}_{\ll e,t><e,t\gg} = \lambda NP^{obl/adj}_{<e,t>}.\exists A\_P.NP^{obl/adj}$ (6)	$\|AdjP\| = \{x \in \Delta^I \mid \exists y.(x,y) \in A\_P^I \land y \in \|NP^{obl/adj}\|\}$
$Adj^{pred}_{\ll e,t><e,t\gg} = \lambda VP^{comp/adj}_{<e,t>}.A \sqcap VP^{comp/adj}$ (7)	$\|AdjP\| = \{x \in \Delta^I \mid x \in A^I \land x \in \|VP^{comp/adj}\|\}$
$Adj^{pred}_{\ll e,t><e,t\gg} = \lambda VP^{comp/adj}_{<e,t>}.A \sqsubseteq VP^{comp/adj}$ (8)	$\|AdjP\| = \{x \in \Delta^I \mid x \in A^I \longrightarrow x \in \|VP^{comp/adj}\|\}$
$Adj^{pred}_{\ll e,t><e,t\gg} = \lambda VP^{comp/adj}_{<e,t>}.A \sqsubseteq \neg VP^{comp/adj}$ (9)	$\|AdjP\| = \{x \in \Delta^I \mid x \in A^I \longrightarrow x \notin \|VP^{comp/adj}\|\}$

Table 1: The rules for description logic based formal representation of adjectives.

Evaluation of the rules

Within the process of the development of the rules, the adjective type heterogeneity hypothesis (Morzycki, 2016) was assumed in order to differentiate property-denoting adjectives (type <e, t>) from adjectives functioning as predicate modifiers (type <<e, t>, <e, t>>). However, a semantic type of an adjective is supposed to be determined by its syntactic relations rather than by its entailment-based category (see Section 2).

In the current research, we maintain the discrimination of intersective, subsective, and non-subsective adjectives used in the attributive function. Since a modified noun phrase and an attributive intersective adjective might be entailed to denote the class membership of an individual represented by an adjective-noun compound, we use the intersection constructor to represent the compound's semantics formally: $BlueFence \equiv Blue \sqcap Fence$. Hence, the resulting compound is supposed to denote an intersection of two sets on a domain: $\|Blue\ Fence\| = \{x \in \Delta^I \mid x \in Blue^I \land x \in Fence^I\}$ (see Rule 1 and Example 1).

In order to retain the analytic truth of a DL-definition despite the use of subsective and non-subsective adjectives in the attributive function, we impose specific existential restrictions on adjective nominated roles so as to provide a formal account for a scope of domain entities that hold for: $\lambda x.AN(x)$. We assume that a subsective adjective represents a binary relation with a set of observers as its domain and a set of observed objects as its range. We use the inverse role constructor, impose an existential restriction on the resulting role, and introduce an inclusion axiom within a DL-definition of an adjective-noun compound: $ProfessionalArtist \equiv \exists professional^{-}.\top \sqsubseteq Artist$. We define a subset denoted by the adjective-noun compound within a set of entities denoted by a modified noun phrase: $\|Professional\ Artist\| = \{x \in \Delta^I \mid \exists x.(y,x) \in professional^I \rightarrow x \in Artist^I\}$ (see Rule 2 and Example 2).

In order to represent the meaning of a noun phrase including a non-subsective adjective used as a modifier, we impose an existential restriction on an adjective nominated role by virtue of a concept represented by a modified noun phrase (see Rule 3 and Example 3). Rule 3 is supposed to be applicable to ordinary non-subsective adjectives: $AllegedCriminal \equiv \exists alleged.Criminal$, and privative adjectives in the attributive function: $FakePearl \equiv \exists fake.Pearl$, since the resulting formulae do not imply unintended entailments and successfully convey the adjectival modification of a noun phrase's intension.

Whereas in the previous examples attributive adjectives were viewed as units incorporated into noun phrases, predicative adjectives are represented as units of verb phrases. Rule 4 provides a formal account of a predicative adjective that is related formally to a modified noun phrase in one of the two ways: as an atomic concept standing in an intersection with a noun phrase nominated concept (see Example 4.1); as a concept imposing an existential restriction on a predicate nominated role to deliver a concept standing in an intersection with a noun phrase nominated concept (see Example 4.2). Example 4.1 illustrates the case when a predicative adjective is bound by the copula verb *to be* (see Table 2). For Rules 4, 5, 7, 8, 9 to give a proper formal account for predicative uses of subsective and privative adjectives (e.g. *Tanja is skillful, The document is fake*), the corresponding general concepts are presumed to denote domains of adjective nominated roles: $\exists skillful^{-}.\top \sqsubseteq Skillful$, $\exists fake.\top \sqsubseteq Fake$.

Rule 5 was designed to formalize a predicative adjective related within an open predicative complement (or an open predicative adjunct) to an external subject expressed with a noun phrase that is used as an object of the main clause predicate. The predicative adjective is formalized as a concept related through inclusion to a concept represented by the external subject used to specify an existential restriction imposed on a role nominated by the main clause predicate: $\|paints\ a\ fence\ blue\| = \{x \in \Delta^I | \exists y.(x,y) \in paints^I \wedge y \in Fence^I \rightarrow y \in Blue^I\}$ (see Example 5). Rule 6 represents a predicative adjective related to a noun phrase used as an oblique argument or an adjunct. The adjective denotes a role with an existential restriction being imposed on it by virtue of a concept represented by the noun phrase: $\|busy\ at\ work\| = \{x \in \Delta^I | \exists y.(x,y) \in busy\_at^I \wedge y \in Work^I\}$ (Example 6). The noun phrase is supposed to be introduced within a prepositional phrase; the head of the prepositional phrase undergoes concatenation with the adjective in the process of formalization (see Rule 6).

Rules 7, 8, and 9 were designed for formal representation of a predicative adjective attaching a clausal complement with an omitted subject, an open predicative complement, or an open predicative adjunct. The choice between the rules depends either on the grammatical form of a verb used as a predicate within the complement/adjunct or on the semantics of the predicative adjective. A concept expressed by the predicative adjective is supposed to undergo intersection with a concept represented by a related verb phrase: $\|busy\ packing\ a\ bag\| = \{x \in \Delta^I | x \in Busy^I \wedge x \in \|pack\ a\ bag\|\}$, whenever a predicate of the complement/adjunct is delivered by virtue of a participle (see Rule 7). In contrast, a concept expressed by the predicative adjective is supposed to denote a concept subsumed by a verb phrase introduced concept or by the negation of that concept: $\|busy\ to\ pack\ a\ bag\| = \{x \in \Delta^I | x \in Busy^I \rightarrow x \notin \|pack\ a\ bag\|\}$ (see Rules 8 and 9), whenever a predicate of the complement/adjunct is delivered by means of an infinitive. The negation of a concept expressed by the verb phrase is used in case the predicative adjective bears privative semantics: i.e. the adjective indicates the fact that the agent characterized by the adjective (see Example 9) does not perform the action denoted by the related verb phrase.

A worker paints a **blue** fence (1)	A man invites a **professional** artist (2)
$NP = Fence/<e,t>$ $\boldsymbol{Adj = \lambda NP.Blue \sqcap NP/\ll e,t><e,t\gg}$ $NP_{obj} = Blue \sqcap Fence\ /<e,t>$ $V = \lambda NP_{obj}.\exists paints.NP_{obj}/\ll e,t><e,t\gg$ $VP = \exists paints.(Blue \sqcap Fence)/<e,t>$ $NP_{subj} = \lambda VP.Worker \sqcap VP/<<e,t>t>$ $Worker \sqcap \exists paints.(Blue \sqcap Fence)/t$	$NP = Artist/<e,t>$ $\boldsymbol{Adj = \lambda NP.\exists professional^{-}.\top \sqsubseteq NP/\ll e,t><e,t\gg}$ $NP_{obj} = \exists professional^{-}.\top \sqsubseteq Artist\ /<e,t>$ $V = \lambda NP_{obj}.\exists invites.NP_{obj}/\ll e,t><e,t\gg$ $VP = \exists invites.(\exists professional^{-}.\top \sqsubseteq Artist)\ /<e,t>$ $NP_{subj} = \lambda VP.Man \sqcap VP/<<e,t>t>$ $Man \sqcap \exists invites.(\exists professional^{-}.\top \sqsubseteq Artist)/t$
A policeman arrests an **alleged** criminal (3)	A child is **happy** (4.1)
$NP = Criminal/<e,t>$ $\boldsymbol{Adj = \lambda NP.\exists alleged.NP\ /\ll e,t><e,t\gg}$ $NP_{obj} = \exists alleged.Criminal\ /<e,t>$ $V = \lambda NP_{obj}.\exists arrests.NP_{obj}/\ll e,t><e,t\gg$ $VP = \exists arrests.\exists alleged.Criminal/<e,t>$ $NP_{subj} = \lambda VP.Policeman \sqcap VP/<<e,t>t>$ $Policeman \sqcap \exists arrests.\exists alleged.Criminal/t$	$\boldsymbol{Adj = Happy/<e,t>}$ $V = \lambda Adj.Adj/\ll e,t><e,t\gg$ $VP = Happy/<e,t>$ $NP = \lambda VP.Child \sqcap VP/<<e,t>t>$ $Child \sqcap Happy/t$
A child feels **happy** (4.2)	A worker paints a fence **blue** (5)
$\boldsymbol{Adj = Happy/<e,t>}$ $V = \lambda Adj.\exists feels.Adj/\ll e,t><e,t\gg$ $VP = \exists feels.Happy/<e,t>$ $NP = \lambda VP.Child \sqcap VP/<<e,t>t>$ $Child \sqcap \exists feels.Happy/t$	$NP_{obj} = Fence/<e,t>$ $\boldsymbol{Adj = \lambda NP_{obj}.NP_{obj} \sqsubseteq Blue/\ll e,t><e,t\gg}$ $AdjP = Fence \sqsubseteq Blue/<e,t>$ $V = \lambda AdjP.\exists paints.AdjP/\ll e,t><e,t\gg$ $VP = \exists paints.(Fence \sqsubseteq Blue)/<e,t>$ $NP_{subj} = \lambda VP.Worker \sqcap VP/<<e,t>t>$ $Worker \sqcap \exists paints.(Fence \sqsubseteq Blue)/t$
A woman is **busy** at work (6)	A woman is **busy** packing a bag (7)
$NP_{obl/adj} = Work/<e,t>$ $\boldsymbol{Adj = \lambda NP_{obl/adj}.\exists busy\_at.NP_{obl/adj}/\ll e,t><e,t\gg}$ $AdjP = \exists busy\_at.Work/<e,t>$ $V = \lambda AdjP.AdjP/\ll e,t><e,t\gg$	$NP_{obj} = Bag/<e,t>$ $V = \lambda NP_{obj}.\exists pack.NP_{obj}/\ll e,t><e,t\gg$ $VP_{comp/adj} = \exists pack.Bag/<e,t>$ $\boldsymbol{Adj = \lambda VP_{comp/adj}.Busy \sqcap VP_{comp/adj}/\ll e,t><e,t\gg}$

$VP = \exists busy\_at.Work/< e,t >$ $NP_{subj} = \lambda VP.Woman \sqcap VP/<< e,t > t >$ $Woman \sqcap \exists busy\_at.Work/t$	$AdjP = Busy \sqcap \exists pack.Bag/< e,t >$ $V = \lambda AdjP.AdjP/\ll e,t >< e,t \gg$ $VP = Busy \sqcap \exists pack.Bag/< e,t >$ $NP_{subj} = \lambda VP.Woman \sqcap VP/<< e,t > t >$ $Woman \sqcap Busy \sqcap \exists pack.Bag/t$
A woman feels **eager** to pack a bag (8)	A woman feels **reluctant** to pack a bag (9)
$NP_{obj} = Bag/< e,t >$ $V = \lambda NP_{obj}.\exists pack.NP_{obj}/\ll e,t >< e,t \gg$ $VP_{comp/adj} = \exists pack.Bag/< e,t >$ $\boldsymbol{Adj = \lambda VP_{comp/adj}.Eager \sqsubseteq VP_{comp/adj}/ \ll e,t >< e,t \gg}$ $AdjP = Eager \sqsubseteq \exists pack.Bag/< e,t >$ $V = \lambda AdjP.\exists feels.AdjP/\ll e,t >< e,t \gg$ $VP = \exists feels.(Eager \sqsubseteq \exists\ pack.Bag)/< e,t >$ $NP_{subj} = \lambda VP.Woman \sqcap VP/<< e,t > t >$ $Woman \sqcap \exists feels.(Eager \sqsubseteq \exists\ pack.Bag)/t$	$NP_{obj} = Bag/< e,t >$ $V = \lambda NP_{obj}.\exists pack.NP_{obj}/\ll e,t >< e,t \gg$ $VP_{comp/adj} = \exists pack.Bag/< e,t >$ $\boldsymbol{Adj = \lambda VP_{comp/adj}.Reluctant \sqsubseteq \neg VP_{comp/adj}/ \ll e,t >< e,t \gg}$ $AdjP = Reluctant \sqsubseteq \neg\exists\ pack.Bag/< e,t >$ $V = \lambda AdjP.\exists feels.AdjP/\ll e,t >< e,t \gg$ $VP = \exists feels.(Reluctant \sqsubseteq \neg\exists\ pack.Bag)/< e,t >$ $NP_{subj} = \lambda VP.Woman \sqcap VP/<< e,t > t >$ $Woman \sqcap \exists feels.(Reluctant \sqsubseteq \neg\exists\ pack.Bag)/t$

Table 2: Examples of application of the rules for DL-based formal representation of adjectives

4. Implementation of the system of rules for description logic based formalization of attributive and predicative adjectives

In order to test the proposed system of rules, 400 syntactic units were extracted and formalized: 200 English syntactic units were retrieved from a Dictionary of Linguistics and Phonetics (Crystal, 2008) and the British National Corpus[1], 200 Russian syntactic units were derived from a Dictionary of Linguistic Terms (Akhmanova, 2012) and the Russian National Corpus[2]. Attributive and predicative adjectives were equally represented in both languages. The precision of formalization rules for attributive adjectives equals 96,5%, the rules yield satisfiable formal expressions for predicative adjectives with the precision of 93,5%.

Rules 1 and 2 are successfully applied to provide formal representations of intersective and subsective adjectives in both Russian and English languages (we implement the automatic transliteration in accordance with the ISO-9 standard[3]): $Stilističeskaâ \sqcap Kategoriâ$ (*stilističeskaâ kategoriâ*, "a stylistic category"), $\exists major^{-}.\top \sqsubseteq Component$ (major components). Nevertheless, whenever a subsective or an intersective adjective yields a binary relation between entities of a set denoted by a modified noun phrase, Rules 1 and 2 fail to obtain satisfiable concept descriptions. For instance, Rule 1 returns an intersection of two concepts: $Divergent \sqcap Form$, whereas the phrase *divergent forms* should be formalized as: $Form \sqcap \exists divergent.Form$. Rule 2 represents a subsective adjective by virtue of a role that binds a set of observers with a set of observed entities. For this reason, the concept description: $\exists alternative^{-}.\top \sqsubseteq Grammar$, is an invalid representation of the compound *alternative grammars*, and the expression: $\exists vzaimosvâzannoe^{-}.\top \sqsubseteq Izmenenie$, does not yield the semantics of the following compound: взаимосвязанные изменения (*vzaimosvâzannye izmeneniâ*, "interrelated changes"). On the contrary, Rule 3 returns only valid expressions for both languages: $\exists fallacious.Argument$ (fallacious argument), $\exists vozmožnyj.Predšestvennik$ (*vozmožnyj predšestvennik*, "a possible predecessor").

Rule 4 has proved to be efficacious, being applied flawlessly to formalize Russian and English sentences. Rule 4 is utilized when predicative adjectives are related to modified nouns via the copular verb *to be*, used in finite and infinite forms: $Grammar \sqcap Adequate$ (Grammars are adequate), $Značenie \sqcap Proizvodnoe$ (*značenie, âvlâûŝeesâ proizvodnym,* "a meaning being derived"). Rule 4 is also applicable in cases a predicative adjective is related to the main predicate by virtue of the copular verb *to be*: Grammar $\sqcap \exists said\_to\_be.Adequate$ (Grammars are said to be adequate) or a preposition, which is subjected to concatenation: $Predmet \sqcap \exists myslitsâ\_kak.Izvestnyj$ (*Predmet myslitsâ kak izvestnyj,* "An entity is regarded as familiar"). The negation constructor is inserted to represent a

[1] https://www.english-corpora.org/bnc/
[2] http://www.ruscorpora.ru/new/
[3] https://www.translitteration.com/transliteration/en/russian/iso-9/

predicative adjective whenever a negative particle is used: $\check{C}len Predlo\check{z}eni\hat{a} \sqcap \neg Glavnyj$ (*členy predloženiâ, ne âvlâûŝiesâ glavnymi,* "members of a sentence not being main"), or a negative prefix is utilized: $Word \sqcap \neg Variable$ (The words are invariable).

Rule 5 is flawlessly implemented for both Russian and English syntax: $Technology \sqcap \exists make.((Rural \sqcap Life) \sqsubseteq Feasible)$ (The technologies make rural life feasible), $Govor\hat{a}\hat{s}ij \sqcap \exists s\check{c}itaet.(Mysl' \sqsubseteq \check{C}u\check{z}a\hat{a})$ (*Govorâŝij sčitaet mysl' čužoj*, "The speaker considers the idea to be borrowed"). Rule 5 alike Rule 4 is appropriate to use for predicative adjectives bound by means of the copular verb *to be*: $Theory \sqcap \exists assumes.(Assertion \sqsubseteq True)$ (The theory assumes the assertion to be true), or by virtue of a preposition, both units are omitted in the process of formalization: $Vid \sqcap \exists Predstavl\hat{a}et.(Dejstvie \sqsubseteq Posto\hat{a}nnoe)$ (*vid, predstavlâûŝij dejstvie kak postoânnoe*, "the aspect representing an action as constant"). Rule 6 returns valid formal representations of predicative adjectives that attach noun phrases as oblique arguments or adjuncts in English and in Russian languages: $Form \sqcap \exists present\_in.Language$ (The form is present in the language), $Dvi\check{z}enie \sqcap \exists neobhodimoe\_dl\hat{a}.\exists Proiznesenie.Zvuk$ (*dviženiâ neobhodimye dlâ proizneseniâ zvukov*, "the movements necessary for the articulation").

Rule 7 is applicable to yield a valid representation of a predicative adjective that attaches a clausal complement with an omitted subject, an open predicative complement, or an open predicative adjunct, a predicate included in the attached verb phrase being expressed through a participle: $Woman \sqcap \exists fell.Silent \sqcap \exists stare\_into.Night$ (A woman fell silent staring into the night), $Pisatel' \sqcap Prav \sqcap To\check{c}en \sqcap \exists opisat'.\exists harakter.Geroin\hat{a}$ (*Pisatel' prav i točen, opisyvaâ harakter geroini*, "The writer is right and exact describing the character of the heroine"). However, whenever a predicative adjective and a predicate incorporated into an attached verb phrase imply different agents as their arguments, Rule 7 produces an unsatisfiable expression: $Digital \sqcap Signal \sqcap Possible \sqcap \exists use.(Available \sqcap Technology)$ (Digital signals are possible using available technology). Rule 7 also fails in case a predicative adjective binds a verb phrase incorporated in a prepositional phrase: $\exists source\_of.Energy \sqcap Capable\_of \sqcap \exists being\_used\_in.\exists production.SpeechSound$ (A source of energy is capable of being used in speech sound production), since the predicative adjective is intended to render a binary relation on a domain.

Rules 8 and 9 replace Rule 7 in case a predicate of an attached complement/adjunct is expressed by virtue of an infinitive, and these rules have also proved to be efficient for both languages: $Separation \sqcap Slow \sqsubseteq \neg\exists produce.(Audible \sqcap Friction)$ (The separation is slow to produce audible friction), $Slovo \sqcap Vyra\check{z}enie \sqcap Sposobnoe \sqsubseteq \exists vystupat'\_v.(Sintaksi\check{c}eska\hat{a} \sqcap Funkci\hat{a})$ (*slova i vyraženiâ, sposobnye vystupat' v sintaksičeskoj funkcii*, "words and expressions able to perform a syntactic function"). Nevertheless, both rules produce invalid expressions whenever a predicative adjective and a predicate of an attached complement/adjunct imply different agents as their arguments: $Affricate \sqcap Easy \sqsubseteq \exists define.\top$ (Affricates are easy to define), $Sentence \sqcap Problematic \sqsubseteq \neg\exists analyse.\top$ (Sentences are problematic to analyze).

In case a predicative adjective and a predicate of an attached complement/adjunct are related to the same external subject, but the subject (whether overt or omitted) refers to a set of events: Мужчина находит занятным подделывать банковские чеки (*Mužčina nahodit zanâtnym poddelyvat' bankovskie čeki, "The man finds it enjoyable to fake bank cheques"),* the proposed system of rules yields a concept description that fails to receive an adequate interpretation on a domain: $Mu\check{z}\check{c}ina \sqcap \exists nahodit.(Zan\hat{a}tnyj \sqsubseteq \exists poddelyvat'.(Bankovskij \sqcap \check{C}ek))$. An adjective phrase formal representation, instantiated by: $Zan\hat{a}tnyj \sqsubseteq \exists poddelyvat'.(Bankovskij \sqcap \check{C}ek)$, acquires the type <e, t>, yet there is no such entity on a domain that could be characterized as enjoyable and produce fake bank cheques at the same time. As far as Rule 9 is concerned, a double negation exemplified by an invalid formal expression: $Triangle \sqcap \neg Able \sqsubseteq \neg(\neg 3 have.Side)$ (A triangle is unable not to have three sides), which implies an affirmative false statement: $Triangle \sqcap \neg Able \sqsubseteq 3 have.Side$, allows us to deduce that Rule 9 is also inapplicable in case a predicate of an attached complement/adjunct binds a negative particle.

5. Conclusion

As a result of the conducted research, a comprehensive set of rules for description logic based formal representation of attributive and predicative adjectives was devised in order to contribute to Question Answering over Linked Data and to improve the technologies for ontology lexicon modeling. The system was developed as an integral part of the formalization technology intended to provide DL-based definitions of domain terms. The system was designed to be implemented in a semi-automatic fashion: syntactic features and semantic characteristics of adjectives and related syntactic units should be specified manually so that high rates of precision could be achieved.

In the current research, the emphasis was put on the development of rules for both predicative and attributive adjectives. A scope of efficient rules for DL-based formal representation of predicative adjectives involved in a variety of syntactic relations was proposed. The implementation of existential restrictions on roles for the representation of attributive adjectives' semantics resulted in a novel technique for subsective and non-subsective adjectives formalization, with a description logic being used as a first-order formalism. The set of rules allows flexibility in formalization, representing adjectives' semantics through the implementation of both concept and role constructors.

The proposed set of formalization rules is supposed to deliver DL-based concept descriptions that should be incorporated in a rigid structure of a DL-definition that is essentially a chain of concept intersections. The DL-definitions yield fairly complicated concept descriptions designed to provide accurate delimitations of subsets denoted by defined terms on a domain. The proposed set of rules delivers a limited selection of DL-based concept descriptions. The concept descriptions are intended to provide satisfiable descriptions of subsets denoted by defined terms, rather than to provide accurate formal representations of various syntactic structures applied in natural language definitions. Therefore, the devised system of rules has to be augmented with the formalization solutions introduced for the syntactic structures that failed to acquire valid formal representations by virtue of the proposed system.

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