Сведения об авторе

Банкова Людмила Львовна — кандидат филологических наук, доцент кафедры восточных и европейских языков Нижегородского государственного лингвистического университета им. Н.А. Добролюбова. Почтовый адрес: 603155, Нижний Новгород, ул. Минина, 31а. Тел.: (831) 416-60-09. Электронная почта: lwittsa@yandex.ru

Bankova, Liudmila — PhD (Philology), Associate Professor, Dpt. of Oriental and European Languages, Linguistics University of Nizhny Novgorod named for N.A. Dobroliubov. Postal address: 31a, Minin St., 603155, Nizhni Novgorod, Russia. Tel.: (831) 416-60-09. E-mail: lwittsa@yandex.ru

УДК 81’32

М.А. Гриц

Онтология как средство формализации лексического значения
(на английском языке)

Статья посвящена проблеме формализации лексического значения, ставшей актуальной в области информатики в рамках парадигмы семантической паутины. Семантическая паутина представляет собой новую ступень развития интернета, на которой поиск по ключевым словам может быть заменен поиском, основанным на смысловом анализе веб-документов. Для осуществления смыслового анализа веб-документов в автоматическом режиме необходимы специальные базы знаний — онтологии. Онтология представляет собой логическую теорию, дающую формальное описание лексических значений терминов в соответствии с концептуализацией, лежащей в основе онтологии. Лексическое значение термина выражено аксиомами теории, написанными на формальном языке, разработанном с целью создания онтологий, при этом термин является единицей словаря формального языка. Точность формальных дефиниций зависит от выразительных возможностей формального языка, применяемого для создания онтологии. Сегодня в практике создания онтологий широкое применение имеет язык OWL, рекомендованный консорциумом Всемирной паутины. Первый стандарт языка OWL (OWL1) был опубликован на официальном сайте консорциума в 2004 году, в настоящее время используется второй стандарт этого языка (OWL2), опубликованный в 2009 году. В статье рассматриваются базовые синтаксические правила формального языка OWL2, применение которых иллюстрируется двумя формальными дефинициями, извлеченными из онтологий ENVO и UBERON. По результатам анализа извлеченных дефиниций впервые поднимается проблема избыточности формальных дефиниций, составляющих современные онтологии. Решением проблемы, по мнению автора, должна стать методика формализации лексических значений терминов посредством языка OWL2.

формализация лексического значения, онтология, концептуализация, формальный язык OWL, формальная дефиниция, семантическая паутина

Gritz, Maria

An ontology as a medium of lexical meaning formal representation

The article examines the issue of lexical meaning formalization raised in computer science within the Semantic Web paradigm. An ontology is a logical theory that provides a formal account for lexical meanings of terms in accordance with an underlying conceptualization. A lexical meaning of a term is conveyed by axioms of a theory written in a formal language developed for the purpose of ontology engineering, the term being considered as a formal language vocabulary unit. The accuracy of formal definitions depends on expressiveness of the formal language implemented for ontology development. The article discusses the basic syntactic rules of a highly expressive ontology language OWL2, and their use in formal definitions construction is instantiated by means of two formal definitions extracted from the ENVO ontology and the UBERON ontology.

lexical meaning formalization, ontology, conceptualization, the Web Ontology Language (OWL), formal definition, the Semantic Web

The issue of lexical meaning formalization came up as soon as the Semantic Web paradigm of the World Wilde Web evolution had emerged. The term *Semantic Web* was coined by Tim Berners-Lee, the creator of the World Wide Web, to mean "*an extension of the current one (Web), where information is given a well-defined meaning, better enabling computers and people to work in co-operation*" [1]. The idea was meant to address the challenge of search engine power evolution imposed by current World Wide Web constraints.

Although the World Wide Web is seen as one of the greatest achievements in the sphere of information search and share throughout the human history, the current Web keyword-based search technology is being subjected to wide criticism because search results are frequently flooded with an array of irrelevant data that seems to be unmanageable to a user. Besides, search engines are still unable to integrate information from different Web resources to answer complex queries. The problem stems straight from the reliance of Web content on languages like HTML that were designed to present information on a Web page correctly and render it to a browser, but that were not intended to make a machine understand the presented data and reason about it [2].

A technology that allows to render series of machine understandable statements defining lexical meanings of domain terms is supposed to be a key to the Semantic Web. Within the Semantic Web paradigm lexical meaning is understood in the same manner as intension within the intensional logic paradigm: a lexical meaning of a term is a scope of attributes an object or a relation must possess to be denoted by means of the term [3]. The core of the technology is a knowledge base that integrates all the statements that constitute a formal description of a lexical meaning. Knowledge bases of this kind are signified as ontologies [4]. The term *ontology* has been borrowed from philosophy and is currently used in the field of Artificial Intelligence (AI) to refer to an engineering artifact, which is essentially "*a logical theory accounting for intended meaning of a formal vocabulary*" [5]. The key role of ontologies in formal representation of lexical meaning was emphasized by T. Gruber, who defined an ontology as "*a specification of a representational vocabulary for a shared domain of discourse*" [6].

A logical theory of a domain is a set of axioms – formal statements that convey something true about the domain of discourse in a particular interpretation I, which is referred to as a model of a statement:

$$I \vDash S$$

and is definable in terms of the set theory [7]. The statements are composed by means of formal language logical symbols with fixed meanings and non-logical symbols with application-dependent

[1] Berners-Lee T., Hendler J., Lassila O. The Semantic Web // Scientific American. 2001. N 284 (5). P. 35.

[2] Berners-Lee T., Hendler J., Lassila O. The Semantic Web. P. 35–43 ; Heflin J. An Introduction to the OWL Web Ontology Language. 2007. URL : http://www.cse.lehigh.edu/~heflin/IntroToOWL.pdf (date of access: 1.03.2017) ; Horrocks I. Ontologies and the semantic web // Communications of ACM. 2008. N 51 (11). P. 58–67 ; OWL: a Description Logic Based Ontology Language for the Semantic Web / I. Horrocks, P.F. Patel-Schneider, D.L. McGuiness, C.A. Welty // The Description Logic Handbook: Theory, Implementation, and Applications. ch. 14. Second edition. Chambridge University Press, 2007. P. 458–487.

[3] Fitting M. Intensional Logic // The Stanford Encyclopedia of Philosophy. Summer 2015 Edition. URL : https://plato.stanford.edu/entries/logic-intensional/ (date of access: 1.03.2017) ; Gasparri L., Marconi D. Word Meaning // The Stanford Encyclopedia of Philosophy. Spring 2016 Edition. URL : https://plato.stanford.edu/archives/spr2016/entries/word-meaning/ (date of access: 16.03.2017) ; Hirst G. Ontologies and lexicons // A Handbook on Ontologies. International Handbooks on Information Systems. Berlin ; Heidelberg : Springer, 2004. P. 209–230.

[4] Berners-Lee T., Hendler J., Lassila O. The Semantic Web. P. 35–43 ; Gruber T.R. A Translation Approach to Portable Ontology Specifications // Knowledge Acquisition. 1993. N 5 (2). P. 199–220 ; Horrocks I. Ontologies and the semantic web. P. 58–67 ; Maedche A., Staab S. Ontology Learning for the Semantic Web // IEEE Intelligent Systems and Their Applications. 2001. Vol. 16, N 2. P. 72–79 ; OWL: a Description Logic Based Ontology Language for the Semantic Web. P. 458–487.

[5] Guarino N. Formal Ontology and Information Systems // Formal Ontology in Information Systems. Proceedings of the FOIS'98, Italy, Trento, 1998, June 6–8. P. 7.

[6] Gruber T.R. A Translation Approach to Portable Ontology Specifications. P. 199.

[7] Grimm S., Hitzler P., Abecker A. Knowledge Representation and Ontologies: Logic, Ontologies and Semantic Web Languages // Semantic Web Services. USA, New York : Springer, 2007. P. 51–105 ; Hodges W. Model Theory // The Stanford Encyclopedia of Philosophy. Fall 2013 Edition. URL : https://plato.stanford.edu/entries/model-theory/ (date of access: 1.03.2017).

meanings. Non-logical symbols constitute a formal language vocabulary. A term is viewed as a unit of a formal language vocabulary equal to a predicate, functional, or constant symbol of the first order logic. The logical category ascribed to a term depends on a type of reference, i.e. constant symbols designate individuals; predicate and functional symbols denote relations and functions over a domain [8]. In accordance with the traditions of intensional logic a scope of referents a symbol designates is denoted as an extension of the symbol, whereas a scope of attributes a referent has to possess to be denoted by a symbol is designated as an intension of the symbol [9].

A domain of discourse is regarded in a set of possible worlds, otherwise a term could only be used to denote a particular relation, which takes place in a particular state of affairs. For this reason, the opposition between intensional relations and extensional relations has been introduced, the former referring to units of a conceptualization, the latter denoting units of a domain [10]. A conceptualization is understood as a set of intensional relations [11]. An intensional relation is a function from possible worlds to extensional relations feasible in a domain of discourse:

$$\mathfrak{R}^n: W \rightarrow 2^{D^n}.$$

In other words, every intensional relation is a set of homogeneous extensional relations observed in a scope of possible worlds. Every intensional relation forms a set of extensions relative to an intended world structure of the conceptualization:

$$E_{\mathfrak{R}} = \{\mathfrak{R}(w) | w \in W\},$$

an intended world structure refers to a possible world [12]. A conceptualization underlies an ontology, and it might be shared by several ontologies [13].

Domain units and conceptualization units are represented by units of a formal language vocabulary, the language being designed for the purpose of ontology development. Vocabularies of RDFS [14] and OWL [15], the formal languages recommended for ontology development by the WWW Consortium, include predicate symbols and constant symbols that acquire extensional interpretation in reference to extensional relations and bound domain individuals:

$$I: V \rightarrow R \cup D,$$

and intensional interpretation in reference to intensional relations and bound domain individuals:

$$\mathfrak{I}: V \rightarrow \mathfrak{R} \cup D.$$

A set of all extensional interpretations of language symbols is a set of logical models of a formal language L, whereas a set of intensional interpretations forms an ontological commitment K for the

[8] Brachman R.J., Levesque H.J. Knowledge representation and reasoning. USA, San Francisco : Morgan Kaufmann Publishers, 2004. 413 p. ; Trentelman K. Survey of Knowledge Representation and Reasoning Systems. Australia, Edinburgh : Defence Science and Technology Organisation (DSTO), 2009. 61 p.

[9] Fitting M. Intensional Logic.

[10] Guarino N. Formal Ontology and Information Systems. P. 3–15.

[11] Guarino N. Formal Ontology and Information Systems. P. 3–15 ; Guarino N., Giaretta P. Ontologies and knowledge bases: Towards a terminological clarification // Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing. The Netherlands, Amsterdam : IOS Press, 1995. P. 25–32.

[12] Guarino N. Formal Ontology and Information Systems. P. 3–15 ; Guizzardi G. Ontological Foundations for Structural Conceptual Models. The Netherlands, Enschede, 2005. 441 p.

[13] Gruber T.R. Toward Principles for the Design of Ontologies used for Knowledge Sharing // International Journal of Human-Computer studies. 1995. N 43 (5). P. 907–928.

[14] McBride B. The Resource Description Framework (RDF) and its Vocabulary Description Language RDFS // A Handbook on Ontologies. International Handbooks on Information Systems. Berlin ; Heidelberg : Springer, 2004. P. 51–66.

[15] Antoniou G., van Harmelen F. Web Ontology Language: OWL // A Handbook on Ontologies. International Handbooks on Information Systems. Berlin ; Heidelberg : Springer, 2004. P. 67–92 ; Heflin J. An Introduction to the OWL Web Ontology Language ; OWL: a Description Logic Based Ontology Language for the Semantic Web. P. 458–487.

formal language L. The scope of logical models that are compatible with the ontological commitment K constitutes a set of intended models $I_K(L)$ of the formal language L [16]. An intended model of a constant symbol represents an object the constant symbol is supposed to designate in accordance with a conceptualization, i.e. in a whole set of possible worlds under investigation. An intended model of a predicate symbol represents a set of objects the predicate symbol is supposed to designate in accordance with a conceptualization, i.e. in a whole set of possible worlds under investigation. Therefore, in reference to an intended model of a predicate symbol we undermine its actual extension understood as a scope of referents it designates.

For example, if we assume that within a domain "Building industry" in a possible world A there is one welder named John who welds reinforcement bars, in a possible world B there are three welders named John, Paul, and Wolf who weld reinforcement bars, and in a possible world C there are two welders named John and George who weld reinforcement bars, we can conclude that a conceptualization of the domain "Building industry" includes the intensional relations represented by the predicate symbols *Welder* and *Welds*:

$$IR1\text{"}Welder\text{"} = \{welder_A\,\{John\}, welder_B\,\{John, Paul, Wolf\},\ welder_C\{John, George\}\},$$

$$IR2\text{"}Welds\text{"} = \left\{\begin{matrix} welds_A\,\{(John, bars)\}, \\ welds_B\,\{(John, bars), (Paul, bars), (Wolf, bars)\}, \\ welds_C\{(John, bars), (George, bars)\} \end{matrix}\right\}.$$

The set of individuals denoted by means of the constant symbols: *John*, *Paul*, *George*, *Wolf* is an intended model of the predicate symbol *Welder*. In other words, we might conclude that the predicate symbol *Welder* has the following extension:

$$\text{Welder}^{\,I} = \{\text{John}, \text{Paul}, \text{George}, \text{Wolf}\}.$$

The set of pairs of individuals denoted by means of the constant symbols: *John*, *Paul*, *George*, *Wolf*, *bars* [17] is an intended model of the predicate symbol *Welds*. In other words, we might conclude that the predicate symbol *Welds* has the following extension:

$$\text{Welds}^{\,I} = \{(\text{John}, \text{bars}), (\text{Paul}, \text{bars}), (\text{George}, \text{bars}), (\text{Wolf}, \text{bars})\}.$$

An extension of a predicate symbol could be described by means of formal statements that contain the predicate symbol and constant symbols playing the role of the predicate's arguments. A predicate symbol represents a set, whereas a constant symbol represents a member of the set. An unary predicate designates a set of domain individuals, while its argument designates a member of the set. For instance, the extension of the predicate *Welder* could be described by means of four statements: *Welder(John), Welder(Paul), Welder(George), Welder(Wolf).* A binary predicate designates a set of pairs of domain individuals, while its first argument designates the first member of a pair and its second argument denotes the second member of the pair. For instance, the extension of the predicate *Welds* could be described by means of four statements: *Welds(John, bars), Welds(Paul, bars), Welds(George, bars), Welds(Wolf, bars).*

It must be emphasized that since a toy domain is being conceptualized, the sets represented by the predicates *Welder* and *Welds* are considered to be finite, whereas if a real world domain is under conceptualization, most of the denoted sets are supposed to be infinite. There are some exceptions, however. For instance, the set of oceans on the planet Earth is finite so the extension of the predicate *Ocean* could be fully covered by means of four statements: *Ocean(Pacific Ocean),*

---

[16] Guarino N. Formal Ontology and Information Systems. P. 3–15 ; Guizzardi G. Ontological Foundations for Structural Conceptual Models.

[17] In the example the constant symbol *bars* is used to refer to the construction material a named welder is supposed to work on in a whole set of possible worlds, and the predicate symbol *Bars* is used to denote the set of reinforcement bars under operation in all possible worlds.

Ocean(Arctic Ocean), Ocean(Indian Ocean), Ocean(Atlantic Ocean). Yet, an extension of a predicate could not be covered completely by a scope of statements composed of predicate and constant symbols in most cases, rather these statements allude to definite extensional relations observed in a single possible world or in a scope of possible worlds. Statements of this type are referred to as assertions and are used for the purpose of instantiation of predicate symbols' intended meanings and in the process of ontology population. Statements that render an intension of a predicate are referred to as terminological axioms [18].

Expressive power of terminological axioms depends on syntactic rules imposed by a formal language used for ontology development. For instance, if we assume the first order logic to be a formal language used for the purpose of conceptualization explicit specification, composition of terminological axioms will be conducted by means of the following connectives: "¬", which stands for logical negation, "∧", which stands for logical conjunction, "∨", which stands for logical disjunction, "→", which stands for logical implication, and "=", which stands for logical equality, and two quantifiers: existential quantifier ∃ and universal quantifier ∀. There are several combinations admissible by syntactic rules of the first order logic:

$$\neg\alpha, \alpha \wedge \beta,\ \alpha \vee \beta, \alpha \rightarrow \beta, \alpha = \beta, \forall x.\alpha, \exists x.\alpha,$$

with α and β referring to statements with a predicate symbol and variables in argument positions and x standing for a variable [19]. The intensions of the two predicate symbols that represent the units of our toy conceptualization would acquire the following logical specification:

$$Welds^I \subseteq Welder^I \times Bars^I \vDash \forall x \forall y. Welds(x,y) \rightarrow Welder(x) \wedge Bars(y),$$

$$Welder^I \subseteq Person^I \vDash \forall x. Welder(x) \rightarrow Person(x).$$

These two axioms unveil the intended meanings of the predicates: the unary predicate *Welder* signifies an object as a person whose job is to weld bars; the binary predicate *Welds* signifies the relation that holds between a welder as a subject of the action and reinforcement bars as an object of the action.

Although the first order logic is considered to be the basic knowledge representation formalism, first order logic theories have proved to be semi-decidable [20]. For this reason, in current AI practice the Web Ontology Language (OWL) is used as a decidable fragment of the first order logic for ontology development [21]. OWL is implemented in its last modification OWL2 [22] and its expressive power is used by ontology engineers to convey an intension of a predicate [23]. An unary predicate is signified in OWL2 notation in the same manner as in the preceding version of OWL — as "owl:Class", and a binary predicate is denoted as "owl:ObjectProperty" [24]. Basic syntactic rules of OWL2 implemented in construction of terminological axioms that might be used to clarify an intension of an unary predicate are instantiated in Table 1.

[18] Baader F., Nutt W. Basic Description Logics // The Description Logic Handbook: Theory, Implementation and Applications. USA, New York : Cambridge University Press, 2004. P. 43–95.

[19] Brachman R.J., Levesque H.J. Knowledge representation and reasoning ; Genesereth M.R., Nilsson N.J. Logical foundations of artificial intelligence. USA, San Francisco : Morgan Kaufmann Publishers, 1987. 405 p. ; Trentelman K. Survey of Knowledge Representation and Reasoning Systems.

[20] Grimm S., Hitzler P., Abecker A. Knowledge Representation and Ontologies: Logic, Ontologies and Semantic Web Languages. P. 51–105.

[21] Hitzler P., Krötzsch M., Rudolph S. Knowledge Representation for the Semantic Web. Part 1: OWL2 // Knowledge Representation and Reasoning for the Semantic Web – OWL 2 Rules. A tutorial at KI 2009, Germany, Paderborn, 2009, September 15. URL : http://semantic-web-book.org/w/images/b/b0/KI09-OWL-Rules-1.pdf (date of access: 1.03.2017).

[22] OWL 2 Web Ontology Language Primer / P. Hitzler, M. Krötzsch, B. Parsia, S. Rudolph (ed.) // W3C Recommendation 11 December 2012. Second edition. URL : https://www.w3.org/TR/owl2-primer/ (date of access: 1.03.2017).

[23] OWL 2 Web Ontology Language Direct Semantics / B. Motik, P.F. Patel-Schneider, B.C. Grau (ed.) // W3C Recommendation 11 December 2012. Second edition. URL : https://www.w3.org/TR/owl2-direct-semantics/ (date of access: 1.03.2017).

[24] Hitzler P., Krötzsch M., Rudolph S. Knowledge Representation for the Semantic Web.

Table 1

Basic OWL2 admissible statements in set theory based interpretation

OWL2 admissible statement	Set theory based interpretation
<owl:Class rdf:ID="Noun"> <owl:subClassof rdf:resource = "#Part of Speech"/> </owl:Class>	$Noun^I \subseteq PartofSpeech^I$
<owl:Class rdf:ID="Multlingualism"> <owl:equivalentClass rdf:resource="#Polylingualism"/> </owl:Class>	$Multilingualism^I = Polylingualism^I$
<owl:Class rdf:ID="Vowel"> <owl:disjointWith rdf:resource="#Consonant"/> </owl:Class>	$Vowel^I \cap Consonant^I = \emptyset$
<owl:Class rdf:ID="Adverb"> <owl:equivalentClass> <owl:Class> <owl:intersectionOf rdf:parseType="Collection"> <owl:Class rdf:resource="#Part of Speech"/> <owl:Class rdf:resource="#Modifier"/> </owl:intersectionOf> </owl:Class> </owl:equivalentClass> </owl:Class>	$Adverb^I = PartofSpeech^I \cap Modifier^I$
<owl:Class rdf:ID="Morpheme"> <owl:equivalentClass> <owl:Class> <owl:unionOf rdf:parseType="Collection"> <owl:Class rdf:resource="#Free Morpheme"/> <owl:Class rdf:resource="#Bound Morpheme"/> </owl:unionOf> </owl:Class> </owl:equivalentClass> </owl:Class>	$Morpheme^I = FreeMorpheme^I \cup BoundMorpheme^I$
<owl:Class rdf:ID="Dead Language"> <owl:equivalentClass> <owl:Class> <owl:complementOf rdf:resource="#Modern Language"/> </owl:Class> </owl:equivalentClass> </owl:Class>	$DeadLanguage^I = \neg ModernLanguage^I$
<owl:Class rdf:ID="Phoneme"> <owl:equivalentClass> <owl:Restriction> <owl:onProperty rdf:resource="#has Realization"/> <owl:allValuesFrom rdf:resource="#Allophone"/> </owl:Restriction> </owl:equivalentClass> </owl:Class>	$Phoneme^I = \{ x \in \Delta^I \mid \forall y.(x,y) \in hasRealization^I \rightarrow y \in Allophone^I \}$
<owl:Class rdf:ID="Adjective Phrase"> <owl:equivalentClass> <owl:Restriction> <owl:onProperty rdf:resource="#has Headword"/> <owl:someValuesFrom rdf:resource="#Adjective"/> </owl:Restriction> </owl:equivalentClass> </owl:Class>	$AdjectivePhrase^I = \{ x \in \Delta^I \mid \exists y.(x,y) \in hasHeadword^I \wedge y \in Adjective^I \}$

Table 1 (end)

OWL2 admissible statement	Set theory based interpretation
<owl:Class rdf:ID="Bilingual Person"> <owl:equivalentClass> <owl:Restriction> <owl:onProperty rdf:resource="#speaks"/> <owl:onClass rdf:resource="#Language"/> <owl:qualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">2 </owl:qualifiedCardinality> </owl:Restriction> </owl:equivalentClass> </owl:Class>	$BilingualPerson^I = \left\{ x \in \Delta^I \mid \lvert \{ y \mid (x,y) \in speaks^I \wedge y \in Language^I \} \rvert = 2 \right\}$
<owl:Class rdf:ID="Multilingual Person"> <owl:equivalentClass> <owl:Restriction> <owl:onProperty rdf:resource="#speaks"/> <owl:onClass rdf:resource="#Language"/> <owl:minQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">3 </owl:minQualifiedCardinality> </owl:Restriction> </owl:equivalentClass> </owl:Class>	$MultilingualPerson^I = \left\{ x \in \Delta^I \mid \lvert \{ y \mid (x,y) \in speaks^I \wedge y \in Language^I \} \rvert \geq 3 \right\}$
<owl:Class rdf:ID="Monolingual Person"> <owl:equivalentClass> <owl:Restriction> <owl:onProperty rdf:resource="#speaks"/> <owl:onClass rdf:resource="#Language"/> <owl:maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1 </owl:maxQualifiedCardinality> </owl:Restriction> </owl:equivalentClass> </owl:Class>	$MonolingualPerson^I = \left\{ x \in \Delta^I \mid \lvert \{ y \mid (x,y) \in speaks^I \wedge y \in Language^I \} \rvert \leq 1 \right\}$

According to the data presented in Table 1, OWL2 axioms might be used to define an unary predicate's intension in terms of set inclusion, disjointness, and equivalence relations, Boolean combinations: intersection, union, and complement, as well as quantification and cardinality restrictions imposed on a range of a binary relation represented by a binary predicate on condition that the unary predicate designates the domain of the binary relation.

In practice, however, OWL2 statements used to define unary predicates' intensions are much more sophisticated and complicated. The definitions of the terms *pair of nares* and *hydrographic feature* proposed in the UBERON ontology [25] and the ENVO ontology [26] are suitable illustrations (see Figures 1, 2). Please note that some ontology metadata have been withdrawn from the original code so that the remaining part of the code could represent precisely the formal definitions of the terms.

Each term defined by means of an ontology is an rdf resource identified by a unique URI (Uniform Resource Identifier). An URI of a term is usually represented both in the form of a URL (Uniform Resource Locator) used to locate the term on the Internet and in the form of a relative

[25] Uberon, an integrative multi-species anatomy ontology / C.J. Mungall, C. Torniai, G.V. Gkoutos [et al.] // Genome Biology. 2012. N 13: R5. URL : http://genomebiology.biomedcentral.com/articles/10.1186/gb-2012-13-1-r5 (date of access: 16.03.2017).

[26] The Environment ontology in 2016: bridging domains with increased scope, semantic density, and interoperation / P.L. Buttigieg, E. Pafilis, S.E. Lewis [et al.] // Journal of Biomedical Semantics. 2016. N 7(1), 57. URL : http://jbiomedsem.biomedcentral.com/articles/10.1186/s13326-016-0097-6#Abs1 (date of access: 16.03.2017).

URI, which is a string of literals or numbers [27]. Since most terms in the examples under investigation are represented in OWL2 code by means of URLs, their literal values have been identified via the OBO Foundry service (see Table 2).

```
    <owl:Class
rdf:about="http://purl.obolibrary.org/obo/UBERON_0002109">
        <owl:equivalentClass>
            <owl:Class>
                <owl:intersectionOf rdf:parseType="Collection">
                    <rdf:Description
rdf:about="http://purl.obolibrary.org/obo/UBERON_0034925"/>
                    <owl:Class>
                        <owl:intersectionOf
rdf:parseType="Collection">
                            <owl:Restriction>
                                <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/RO_0002351"/>
                                <owl:minQualifiedCardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">
2</owl:minQualifiedCardinality>
                                <owl:onClass
rdf:resource="http://purl.obolibrary.org/obo/UBERON_0000003"/>
                            </owl:Restriction>
                            <owl:Restriction>
                                <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/RO_0002351"/>
                                <owl:maxQualifiedCardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">
2</owl:maxQualifiedCardinality>
                                <owl:onClass
rdf:resource="http://purl.obolibrary.org/obo/UBERON_0000003"/>
                            </owl:Restriction>
                        </owl:intersectionOf>
                    </owl:Class>
                </owl:intersectionOf>
            </owl:Class>
        </owl:equivalentClass>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/BFO_0000050"/>
                <owl:someValuesFrom
rdf:resource="http://purl.obolibrary.org/obo/UBERON_0000004"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/BFO_0000051"/>
                <owl:someValuesFrom
rdf:resource="http://purl.obolibrary.org/obo/UBERON_0000003"/>
            </owl:Restriction>
        </rdfs:subClassOf>
…
        <rdfs:label
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">pair of
nares</rdfs:label>
    </owl:Class>
```

Fig. 1. Formal definition of the term *pair of nares* proposed in the UBERON ontology

[27] Berners-Lee T., Hendler J., Lassila O. The Semantic Web. P. 35–43 ; Heflin J. An Introduction to the OWL Web Ontology Language.

```
<owl:Class
rdf:about="http://purl.obolibrary.org/obo/ENVO_00000012">
        <rdfs:label
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">hydrographic
feature</rdfs:label>
        <owl:equivalentClass>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <owl:Class>
                        <owl:intersectionOf
rdf:parseType="Collection">
                            <rdf:Description
rdf:about="http://purl.obolibrary.org/obo/ENVO_00002297"/>
                            <owl:Restriction>
                                <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/RO_0002220"/>
                                <owl:someValuesFrom
rdf:resource="http://purl.obolibrary.org/obo/ENVO_00000063"/>
                            </owl:Restriction>
                        </owl:intersectionOf>
                    </owl:Class>
                    <owl:Restriction>
                        <owl:onProperty
rdf:resource="http://purl.obolibrary.org/obo/ENVO_01001307"/>
                        <owl:someValuesFrom
rdf:resource="http://purl.obolibrary.org/obo/ENVO_00002006"/>
                    </owl:Restriction>
                </owl:unionOf>
            </owl:Class>
        </owl:equivalentClass>
        <rdfs:subClassOf
rdf:resource="http://purl.obolibrary.org/obo/ENVO_00000000"/>
…
    </owl:Class>
```

Fig. 2. Formal definition of the term *hydrographic feature* proposed in the ENVO ontology

Table 2

URIs of the terms under investigation

Resource identification of the terms (full URI)	Literal identification of the terms (relative URI)
http://purl.obolibrary.org/obo/UBERON_0002109	Pair of nares
http://purl.obolibrary.org/obo/RO_0002351	Has member
http://purl.obolibrary.org/obo/UBERON_0000003	Naris
http://purl.obolibrary.org/obo/UBERON_0034925	Anatomical collection
http://purl.obolibrary.org/obo/BFO_0000051	Has part
http://purl.obolibrary.org/obo/BFO_0000050	Part of
http://purl.obolibrary.org/obo/UBERON_0000004	Nose
http://purl.obolibrary.org/obo/ENVO_00000012	Hydrographic feature
http://purl.obolibrary.org/obo/ENVO_00002297	Environmental feature
http://purl.obolibrary.org/obo/RO_0002220	Adjacent to
http://purl.obolibrary.org/obo/ENVO_00000063	Water body
http://purl.obolibrary.org/obo/ENVO_01001307	Partially surrounded by
http://purl.obolibrary.org/obo/ENVO_00002006	Water
http://purl.obolibrary.org/obo/ENVO_00000000	Geographic feature

Under the basic principles of OWL2 terminological axioms interpretation (see Table 1) the formal definitions of the terms *pair of nares* and *hydrographic feature* proposed in the UBERON ontology and in the ENVO ontology should be given the set theory based interpretations proposed in Tables 3 and 4. Informal interpretations of the definitions are introduced in the right columns of Tables 3 and 4.

Table 3

Interpretation of the formal definition of the term *pair of nares* given in the UBERON ontology

Set theory based interpretation of the formal definition of the term *pair of nares*	Informal interpretation of the formal definition of the term *pair of nares*
$(PairofNares^I = AnatomicalCollection^I \cap (\{x \in \Delta^I \| \|\{y \| (x,y) \in hasmember^I \wedge y \in Naris^I\}\| \geq 2\} \cap \{x \in \Delta^I \| \|\{y \| (x,y) \in hasmember^I \wedge y \in Naris^I\}\| \leq 2\})) \subseteq (\left\{x \in \Delta^I \middle\| \begin{matrix} \exists y.(x,y) \in partOf^I \\ \wedge\ y \in Nose^I \end{matrix}\right\} \cup \left\{x \in \Delta^I \middle\| \begin{matrix} \exists y.(x,y) \in hasPart^I \\ \wedge\ y \in Naris^I \end{matrix}\right\})$	A pair of nares is an anatomical collection that has no more and no less than two naris as members and is considered to be a part of a nose and to have a naris as a part.

In the UBERON ontology the term *pair of nares* has been given a fairly simple informal definition: the term has been defined by means of the synonym *pair of nostrils*. In contrast, the formal definition is overburdened with details: the term *pair of nares* is supposed to denote a set equal to the intersection of a set designated by the term *anatomical collection* with an unnamed set of individuals that have no more and no less than two members belonging to a set designated by the term *naris*. The intersection is supposed to be a subset of an unnamed set of individuals that are considered to be a part of a nose and a subset of an unnamed set of individuals that have a naris as a part. The formal definition of the term *pair of nares* given in the UBERON ontology should be given the following informal interpretation: "*A pair of nares is an anatomical collection that has no more and no less than two naris as members and is considered to be a part of a nose and to have a naris as a part*". In order to shorten this overburdened formal definition, we should remove some redundant details such as the axiom stating that a set designated by the term *pair of nares* is a subset of an unnamed set of individuals that have a naris as a part and specify that an anatomical collection is supposed to have naris as members in the quantity of 2. As a result, the formal definition interpreted by means of the set theory based formula:

$$(PairofNares^I = AnatomicalCollection^I \cap \{x \in \Delta^I \| \|\{y \| (x,y) \in hasmember^I \wedge y \in Naris^I\}\| = 2\}) \subseteq \left\{x \in \Delta^I \middle| \begin{matrix} \exists y.(x,y) \in partOf^I \\ \wedge\ y \in Nose^I \end{matrix}\right\},$$

might be used to state that a pair of nares is an anatomical collection that has only two naris as members and is considered to be a part of a nose.

Table 4

Interpretation of the formal definition of the term *hydrographic feature* given in the ENVO ontology

Set theory based interpretation of the formal definition of the term *hydrographic feature*	Informal interpretation of the formal definition of the term *hydrographic feature*
$(HydrographicFeature^I = (Environmental\ feature^I \cap \left\{x \in \Delta^I \middle\| \begin{matrix} \exists y.(x,y) \in adjacentto^I \\ \wedge\ y \in WaterBody^I \end{matrix}\right\}) \cup \left\{x \in \Delta^I \middle\| \begin{matrix} \exists y.(x,y) \in part.surroundedby^I \\ \wedge\ y \in Water^I \end{matrix}\right\}) \subseteq Geographicalfeature^I$	A hydrographic feature is a geographical feature which is an environmental feature that is adjacent to a water body or any other geographical feature that is partially surrounded by water.

According to the formal definition given in the ENVO ontology the term *hydrographic feature* is supposed to denote a set equal to the union of an unnamed set, which is equal to the intersection of a set designated by the term *environmental feature* with an unnamed set of individuals adjacent to a water body, and an unnamed set of individuals partially surrounded by water. The union is supposed to be a subset of a set designated by the term *geographical feature*. The formal definition of the term *hydrographic feature* given in the ENVO ontology should be given the following informal interpretation: "*A hydrographic feature is a geographical feature which is an environmental feature that is adjacent to a water body or any other geographical feature that is partially surrounded by water*". In order to shorten this overburdened formal definition, we should remove the axiom that states the intersection of a set designated by the term *environmental feature* with an unnamed set of individuals adjacent to a water body since in the ENVO taxonomy a geographical feature is considered to be a kind of an environmental feature. As a result, the formal definition interpreted by means of the set theory based formula:

$$(HydrographicFeature^I = \left\{x \in \Delta^I \middle| \begin{array}{c}\exists y.(x,y) \in adjacentto^I \\ \wedge\ y \in WaterBody^I\end{array}\right\} \cup \left\{x \in \Delta^I \middle| \begin{array}{c}\exists y.(x,y) \in part.surroundedby^I \\ \wedge\ y \in Water^I\end{array}\right\}) \subseteq Geographicalfeature^I,$$

might be used to state that a hydrographic feature is a geographical feature that is either adjacent to a water body or is partially surrounded by water.

The revised formal definition of the term *hydrographic feature* specifies the informal definition: "A *hydrographic feature is a geographical feature associated with water*" given in the ENVO ontology by clarifying the way a geographical feature can be associated with water: it might be either adjacent to a water body or be partially surrounded by water.

All the above-mentioned points considered, an ontology is an efficient medium of lexical meaning formal representation on condition that natural language terms are considered as non-logical symbols of a formal language used for ontology development. OWL2 designed and recommended by the WWW Consortium as a universal ontology language provides a variety of syntactic means for comprehension of a term's intension. However, a sophisticated method of lexical meaning formalization is yet to be developed in order to overcome redundancy and insufficiency of formal definitions written in OWL2.

References

1. Antoniou, G. Web Ontology Language: OWL [Text] / G. Antoniou, F. van Harmelen // A Handbook on Ontologies. International Handbooks on Information Systems. — Berlin ; Heidelberg : Springer, 2004. — P. 67–92.

2. Baader, F. Basic Description Logics [Text] / F. Baader, W. Nutt // The Description Logic Handbook: Theory, Implementation and Applications. — USA, New York : Cambridge University Press, 2004. — P. 43–95.

3. Berners-Lee, T. The Semantic Web [Text] / T. Berners-Lee, J. Hendler, O. Lassila // Scientific American. — 2001. — N 284 (5). — P. 35–43.

4. Brachman, R.J. Knowledge representation and reasoning [Text] / R.J. Brachman, H.J. Levesque. — USA, San Francisco : Morgan Kaufmann Publishers, 2004. — 413 p.

5. Fitting, M. Intensional Logic [Electronic resource] // The Stanford Encyclopedia of Philosophy. — Summer 2015 Edition. — Mode of access : https://plato.stanford.edu/entries/logic-intensional/ (date of access: 1.03.2017).

6. Gasparri, L. Word Meaning [Electronic resource] / L. Gasparri, D. Marconi // The Stanford Encyclopedia of Philosophy. — Spring 2016 Edition. — Mode of access : https://plato.stanford.edu/archives/spr2016/entries/word-meaning/ (date of access: 16.03.2017).

7. Genesereth, M.R. Logical foundations of artificial intelligence [Text] / M.R. Genesereth, N.J. Nilsson. — USA, San Francisco : Morgan Kaufmann Publishers, 1987. — 405 p.

8. Grimm, S. Knowledge Representation and Ontologies: Logic, Ontologies and Semantic Web Languages [Text] / S. Grimm, P. Hitzler, A. Abecker // Semantic Web Services. — USA, New York : Springer, 2007. — P. 51–105.

9. Gruber, T.R. Toward Principles for the Design of Ontologies used for Knowledge Sharing [Text] // International Journal of Human-Computer studies. — 1995. — N 43 (5). — P. 907–928.

10. Gruber, T.R. A Translation Approach to Portable Ontology Specifications [Text] // Knowledge Acquisition. — 1993. — N 5 (2). — P. 199–220.
11. Guarino, N. Formal Ontology and Information Systems [Text] // Formal Ontology in Information Systems. — Proceedings of the FOIS'98, Italy, Trento, 1998, June 6–8. — P. 3–15.
12. Guarino, N. Ontologies and knowledge bases: Towards a terminological clarification [Text] / N. Guarino, P. Giaretta // Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing. — The Netherlands, Amsterdam : IOS Press, 1995. — P. 25–32.
13. Guizzardi, G. Ontological Foundations for Structural Conceptual Models [Text]. — The Netherlands, Enschede, 2005. — 441 p.
14. Heflin, J. An Introduction to the OWL Web Ontology Language [Electronic resource]. — 2007. — Mode of access : http://www.cse.lehigh.edu/~heflin/IntroToOWL.pdf. (date of access: 1.03.2017)
15. Hirst, G. Ontologies and lexicons [Text] // A Handbook on Ontologies. International Handbooks on Information Systems. — Berlin ; Heidelberg : Springer, 2004. — P. 209–230.
16. Hitzler, P. Knowledge Representation for the Semantic Web. Part 1: OWL2 [Electronic resource] / P. Hitzler, M. Krötzsch, S. Rudolph // Knowledge Representation and Reasoning for the Semantic Web — OWL 2 Rules. — A tutorial at KI 2009, Germany, Paderborn, 2009, September 15. — Mode of access : http://semantic-web-book.org/w/images/b/b0/KI09-OWL-Rules-1.pdf (date of access 1.03.2017).
17. Hodges, W. Model Theory [Electronic resource] // The Stanford Encyclopedia of Philosophy. — Fall 2013 Edition. — Mode of access : https://plato.stanford.edu/entries/model-theory/ (date of access: 1.03.2017).
18. Horrocks, I. Ontologies and the semantic web [Text] // Communications of ACM. — 2008. — N 51 (11). — P. 58–67.
19. Maedche, A. Ontology Learning for the Semantic Web [Text] / A. Maedche, S. Staab // IEEE Intelligent Systems and Their Applications. — 2001. — Vol. 16, N 2. — P. 72–79.
20. McBride, B. The Resource Description Framework (RDF) and its Vocabulary Description Language RDFS [Text] // A Handbook on Ontologies. International Handbooks on Information Systems. — Berlin ; Heidelberg : Springer, 2004. — P. 51–66.
21. OWL 2 Web Ontology Language Direct Semantics [Electronic resource] / B. Motik, P.F. Patel-Schneider, B.C. Grau (ed.) // W3C Recommendation 11 December 2012. — Second edition. — Mode of access : https://www.w3.org/TR/owl2-direct-semantics/ (date of access: 1.03.2017).
22. OWL 2 Web Ontology Language Primer [Electronic resource] / P. Hitzler, M. Krötzsch, B. Parsia, S. Rudolph (ed.) // W3C Recommendation 11 December 2012. — Second edition. — Mode of access : https://www.w3.org/TR/owl2-primer/ (date of access: 1.03.2017).
23. OWL: a Description Logic Based Ontology Language for the Semantic Web [Text] / I. Horrocks, P.F. Patel-Schneider, D.L. McGuiness, C.A. Welty // The Description Logic Handbook: Theory, Implementation, and Applications. — Ch. 14. — Second edition. — Chambridge University Press, 2007. — P. 458–487.
24. The Environment ontology in 2016: bridging domains with increased scope, semantic density, and interoperation [Electronic resource] / P.L. Buttigieg, E. Pafilis, S.E. Lewis [et al.] // Journal of Biomedical Semantics. — 2016. — N 7 (1), 57. — Mode of access : http://jbiomedsem.biomedcentral.com/articles/10.1186/s13326-016-0097-6#Abs1 (date of access: 16.03.2017).
25. Trentelman, K. Survey of Knowledge Representation and Reasoning Systems [Text]. — Australia, Edinburgh : Defence Science and Technology Organisation (DSTO), 2009. — 61 p.
26. Uberon, an integrative multi-species anatomy ontology [Electronic resource] / C.J. Mungall, C. Torniai, G.V. Gkoutos [et al.] // Genome Biology. — 2012. — N 13: R5. — Mode of access : http://genomebiology.biomedcentral.com/articles/10.1186/gb-2012-13-1-r5 (date of access: 16.03.2017).

Сведения об авторе

Гриц Мария Александровна — аспирант кафедры образовательных технологий в филологии Российского государственного педагогического университета имени А.И. Герцена. Почтовый адрес: 199004, г. Санкт-Петербург, 1-я линия Васильевского острова, д. 52. Тел.: 8-911-935-26-50. Электронный адрес: maria.gritz@yandex.ru

Gritz, Maria — postgraduate student, the Department of Educational Technologies in Philology, Herzen State Pedagogical University of Russia. Postal address: Vassilievsky Ostrov, Line 1, 52, St. Petersburg, Russia, 199004. Telephone: 89119352650. E-mail: maria.gritz@yandex.ru