Semantization of information technology development: concepts, models and methods

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***Abstract*—The paper discusses the conceptual aspects of the modern understanding of semantic technologies, semantic resources and semantic applications in artificial intelligence. The basic terminology used in this field is analysed. On base of this analysis definitions of the main components of semantic technologies are proposed. Main attention is paid to differentiation of elements based on semantics from other entities of intelligent information systems. Proposed approach is approved on estimation of examples of semantic software.**

***Keywords*—ontology, semantic technologies, Semantic Web**

I. Introduction

Semanticization as a direction of information technology development: concepts, models and methods The modern world exists in the information space, where a huge number of intelligent information systems (IIS) interact for solving a variety of problems. Ontology-based semantic technologies (STs) allow to build powerful applied IISs aimed on analysis and modeling of complex objects and processes of different nature. The development of such IISs is based on the results of knowledge structuring in order to construct the schemes of knowledge bases (KBs) and to define main subjects and objects of IIS functional support. The IIS intelligence depends on level of problem solving automation that is based on general and specialized knowledge about user, user current problem and adapting the problem solutions to the current state of the information environment. Such automation needs in integration of IISs knowledge developed independently for various purposes.

From the point of view of the ontological approach, the integration of different ISSs can be realized by mapping and alignment of ontologies of individual ISSs. Such operations can use an approach that combines different ontologies through a top-level ontology, or relationships can be established directly between elements of individual ontologies.

The quality of IIS integration depends on the proximity of their ontologies and quality of their mapping that are determined by the presence or absence of links, primarily information ones, between ontological classes and instances. Establishing such links is a separate complex problem based on the use of background knowledge acquired from various external information sources and from domain experts, and on evaluation and normalization of the obtained results.

Today, the semantization of information technologies (IT) is one of the basic directions of their development that has both a broad theoretical basis and significant practical results related to the development of intelligent applications in various fields. One of the most well-known projects in this field is the Semantic Web that provides a large number of standards and tools for representation and processing of information at the meaning level. Unfortunately, the popularity of this area causes a rather incorrect use of terminology: such concepts as "artificial intelligence", "knowledge processing", "semantics" are applied to various types of software and information processing methods. This determines the need to determine more formally what models of data representation and methods of information processing should be considered as semantic ones, and what information technologies that implement them are semantic, and what subset of intelligent applications use semantics. Now much attention is paid to this issue in scientific research [1] but at present a single generally accepted point of view on the basic concepts of semantic information processing is not defined.

II. Task definition

Development of semantic applications oriented on the Web needs in more accurately defined terminology that provide possibility of comparison and integration of various methods, resources and services. On base of analysis of existing approaches to definition of main components used in semantic technologies and on experience of development ontology-based applications we try to define such concepts as semantic information resources, semantic applications and semantic computing. These definitions are aimed on differentiation of semantic-based elements of IIS from the all spectrum of intelligent software and methods of intellectualizing for considering of their specifics.

III. Semantics of information systems

Semantics is a part of several scientific disciplines such as Knowledge Representation, Information Extraction, Information Retrieval, Computational Linguistics, Artificial Intelligence and Knowledge Management. Such different views imply very different views of cognition, of concepts, and of meaning. Usually, efforts related to formal semantics have involved limiting expressiveness to allow for acceptable computational characteristics.

Various syntactic structures are used in IRs for knowledge representation where these structures define semantic interpretations associated with them.

Semantics can be classified into formal (explicit) and informal (implicit) semantics. Formal semantics operate on formal notation; informal described and transmitted in natural languages (NL). The result of cognition of an abstract object is semantics; and the consequence of behavior is the semantics of execution. Implicit semantics is either present in most IRs on the Web or can be extracted from them with the help of Data Mining and Machine Learning that provide acquisition of structured knowledge or enrichment of existing structured formal representations. Such semantics can be transformed into formal one with human involvement. Formal semantics definite meaningful interpretation of data for their machine processing [2].

Semantics is a section of logic devoted to the study of the meaning of concepts and statements, as well as their formal analogues — expressions (terms and formulas) of different calculuses (formal systems) [3]. The tasks of semantics, first of all, include the clarification of the most important general concepts such as "meaning", "truth", "interpretation", "model", etc. — up to general concepts such as "set", "subject", "correspondence". A number of important semantic problems are grouped around the difference between the meanings and denotations of concepts and between the meaning and significance (truth) of statements. Properties related to the meaning of concepts and statements are called intensional, and properties related to the scope of concepts and the truth values of statements are called extensional.

We can see that a lot of intelligent problems are not semanic — for example, various logical games such as chess, mahjong or kakuro. These tasks are solved by fixed rules and don‘t use external information about context of situation. Their solving don‘t need in some knowledge about world and is based only on logical inference. From other hand, other simple intelligent games such as crosswords are semantic because they need in matching of NL definitions of pictures with words that satisfy some restrictions. For more complex tasks these distinction are less evident and for software applications can depend on realization.

In [4] semantic applications are defined as software tools that explicitly or implicitly use domain semantics to improve usability validity, and completeness. An example of a semantic application is semantic information retrieval systems that use synonyms, superclasses and subclasses of domain terms from the relevant ontology to enrich the search results by keywords. But it should be noted that almost all software uses the knowledge of developers about domain, but these knowledge can be not formalized and represented explicitly. The main advantage of knowledge-based systems is the separation of knowledge from means of their processing. The external knowledge for the Web-oriented applications is usually represented by ontologies.

IV. Ontological analysis as an instrument of semantization

Most authors associate semantic technologies with creation, use and processing of ontologies in semantic applications (SAs) [4]. The knowledge contained into the relevant ontologies should ensure the processing of natural language (NL) information, data integration and semantic search. Ontologies that can be used for these purposes differ significantly in expressiveness, volume, level of abstraction and means of representation.

Ontologies include the set of classes (concepts) and descriptions of the various relations between them, as well as the set of class individuals. Semantics of data is defined by connection with element of description of domain knowledge and meaning of this connection

Ontologies are usually divided into: 1) top-level ontologies that represent knowledge common to many domain; 2) domain ontologies that describe the features of some subject area; 3) ontologies of tasks that contain the knowledge required to run a particular software. But such division is quite conditional because domain scope depends on the problem specifics and application usually are based on some complex hierarchy of ontologies.

Ontologies are used to integrate data and knowledge, and can also become the basis for a more intelligent user interface – for example, the user communicates with the program through NL queries interpreted with the help of of ontology knowledge. However, the NL interface is not a mandatory feature of the SAs.

Source of ontologies for semantic application is one of important questions of semantic technologies. Retrieval or generation of pertinent ontology is a task for domain experts but technical features of such ontology are defined by ISS developers. For some important domains such as medicine, domain ontologies are recognized universally, but for specialized business and science sectors fitting ontologies often do not yet exist and need to be created. More often we have situation that some ontology is developed for sufficiently near domain but it needs in some reduction or expansion. An important issue in the application of semantic technologies is finding the pertinent domain ontology [5]. Although a number of ontology engineering methodologies developed in an academic context are widely used for various practical problems and are tested in the context of real-world or corporate applications.

Thus, there is a problem of matching the user task solved by IIS and a set of existing ontologies or information resources (IRs) that can be used for generation of domain ontologies (for example, semantically marked IRs).

A. IRs used in semantic technologies

Effectiveness of STs depends of quality, relevance and actuality of information that is processed by SAs. Important factors of IR selection are their structuring and semantization, use of generally accepted standards and languages, etc.

Now the main part of information for IISs is provided by the Web. The current Web is primarily a very large number of hyperlinked documents. Part of them designed for human reading is represented in HTML or more controlled XHTML formats. But much of information relating to real-world or abstract notions and the relationships between them is stored in relational and quasi-relational SQL databases. Information processed by IIS can be trusted, dynamic, transparent, user-friendly [6].

Semantic information resource (SIR) is a term that needs in more detail definition. Every IR is a set of one ore more documents that can be stored and used by ISs. IR contains some information (at least its name and size) that can be interpreted into some meaning. But in sphere of semantic technologies SRs correspond to some non-empty subset of all available data and IRs.

SIRs can use various terminological and lexical resources, KBs, ontologies and other SRs. Such SRs include some formal semantic components that define relations between content and formal semantic representation. The paper [7] analyzes the approach to information processing at the semantic level oriented on processing of NL. Various researchers combine term "semantic resources" with lexics, annotations, thesauri, etc. Researchers analyse semantics of NL entities on base of NL documents and single out such three components of ST: 1) ontologies; 2) models of NL entities; and 3) semantic IRs.

In our research we have to process different types of information objects (IOs) (their composition is defined by problem) of different levels of complexity, where NL-entities represent only one of the elements along with multimedia IOs and structured IOs. Information about individuals of IOs them can be contained into heterogeneous IRs – NL texts, multimedia (video, audio, images), structured and semi-structured components and links between them. Knowledge about IO structure and relations can be represented by ontologies too but we can consider other representations (for example, rules, decision trees or semantic networks).

IRs used by STs in general can be described by combination of three main components:

- KBs (external and internal) that define main concepts, their features and relations;
- IO models that define structure of typical elements processed by application;
- IRs that contain information about these IOs (explicitly or implicitly).

KBs represent the upper level of abstraction of the application knowledge structure. For example, domain ontology define the set of concepts that can be used by application, their possible and illegal relations and parameters. Expressiveness of knowledge representation is defined by selected formal language. IO models represents the structure and elements of those typical elements that are processed by application in terms of selected KB. For example, ontology classes can become the base of corresponding typical IO.

Level of IRs identifies what types of sources can process IS to take information about individuals of IOs. For semantic IRs such information can be extracted automatically. Structures but not semantic IRs need in explicit linking of data fields with IO properties. Non-structured IRs require various specialized means of processing that depend on IR data (for example, methods of image recognition for pictures, speech recognition for audio and text recognition for scan copies of text documents, NL processing for text documents). Semantization of IRs reduces the computational complexity of algorithms used by SAs and provides processing of the task-specific aspects of data only.

If we consider these components on the example of Wiki resource based on Semantic MediaWiki, an ontology provides structure and concepts of domain knowledge for semantic markup terms, IO models are represented by templates of typical IOs, and semantic IRs are individual Wiki pages and arbitrary sets of such Wiki pages. It should be noted that in this case not only NL content is used, but also multimedia IOs and their metadata.

Different types of IRs such as taxonomies, vocabularies, thesauri or ontologies can be used as SRs if they have means of their simultaneous use [8], and their semantic interoperability consists in preventing problems of misunderstandings between users by taking into account the semantics associated to the data, and ensuring exchanged information share the same meaning. SRs can be heterogeneous and their analysis can be implemented at different levels. For NL such levels are syntax (representation format), structure (data organization) and semantics (different points of view).

The Semantic Web project proposes a set of languages for knowledge representation such as Resource Description Framework (RDF) [9] and Web Ontology Language

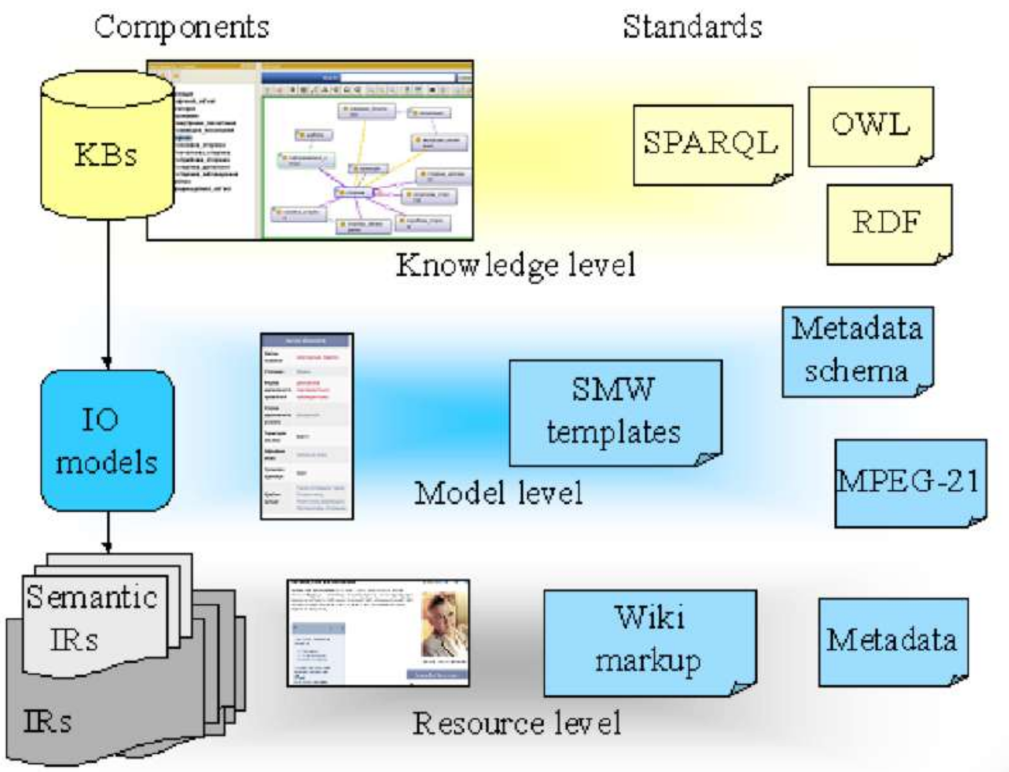

Figure 1. IRs used in semantic technologies.

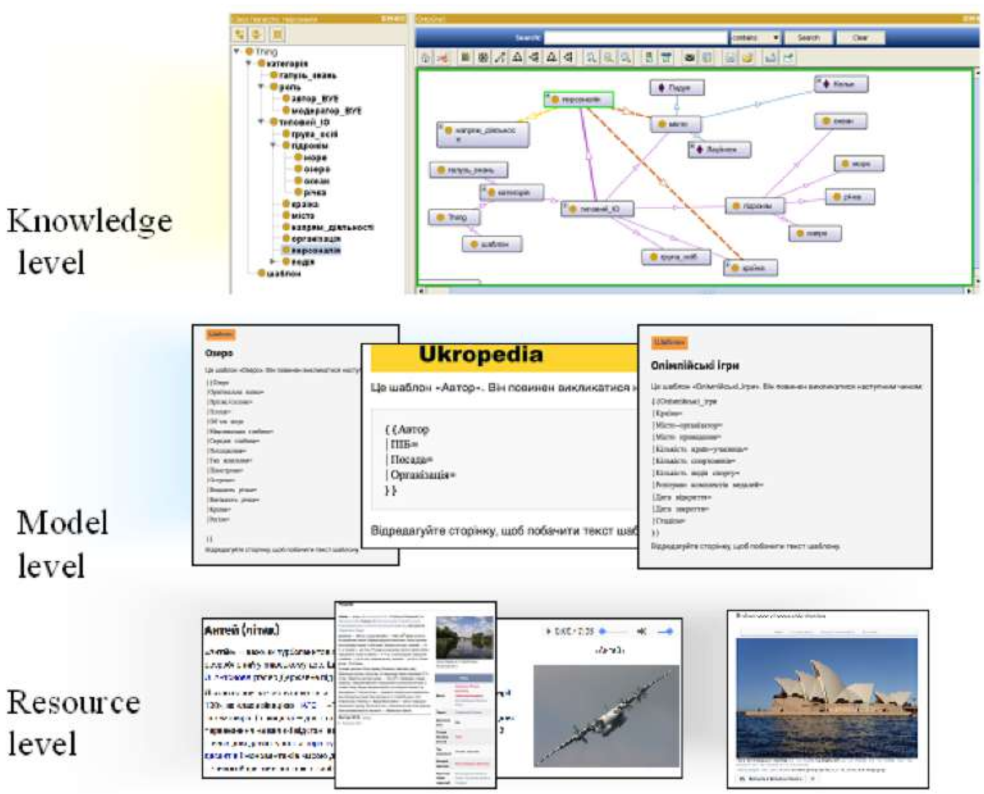

Figure 2. IRs used in semantic technologies.

(OWL) [10]. Every IR specified by means of RDF or OWL is SR.

Some researchers base definition of SR on context [11] where context of IO (i.e. an object, an event or a process) is considered as a collection of semantic situational information that characterizes features of this IO and its relations with other IOs. Contextual information can include metadata of IRs, links with other knowledge descriptions, models of IOs, etc. Examples of SRs that use different types of knowledge are considered in [7][xx] : Wiki and Web resources accessed by information retrieval systems (IPS). But this work doesn‘t propose definition of SRs.

In this study, we distinguish the following types of IRs that can be used by SA: SRs -– IRs with elements (content and/or metadata) that contain elements of semantic markup for clear connection of the IR fragments with domain concepts formalized by some knowledge representation means; non-semantic IRs -– all other IRs where information is not explicitly related to domain concepts (but such relationships can be determined by various means of analysis such as Text mining).

The main difference between SRs and non-semantic IRs deals with unambiguous interpretation of their semantics with the help of external standards and KBs. SRs have clear references to the formally described knowledge about the semantics of their structuring -– ontology, taxonomy, thesaurus, Examples of SRs are metadata of the Dublin Core standard, semantic Wiki resources based on Semantic MediaWiki, multimedia IRs with metadata in the MPEG-21 standard. etc.

V. Models of semantics

Models of semantics (MSs) depend on IO and IR specifics and on modelling approaches. Various models are oriented on some type of information (NL text, multimedia, images, structured data, etc.). Such models reflect the specific features of information type. Models of semantics of NL-entities in [7] contain models of semantic primitives, texts and their comparison. They have various expressiveness that depends on IIS purposes. For example, NL text can be represented as a semantic net that connect all words for every simple or complex sentence on base of syntax analysis but the same text can be represented as a set of links between sentences.

Other MSs are oriented on some fixed type of IOs (or group of connected IOs). Examples of such MSs are user profiles used by learning SAs that can be exported from one IIS to another by matching of corresponding ontologies [12]. Even the most typical characteristics of the users can be modelled by user profiles with various terms and categories that causes need in standardization of user profiling.

The examples of these standards are DCMI has several elements for defining different categories (roles) of users with respect to a document(Dublin Core Metadata Initiative and FOAF (Friend of a Friend) -– an RDF-based general-purpose model for description of users on the Web. Many of them use ontological representation of knowledge. For example, FOAF is a lightweight ontology aimed at creating an annotated network of homepages for people, groups, companies, etc. It is implemented in RDF Schema and contains such basic classes as agent, person, organization, group, project, document, image, as well as some basic properties of instances of these classes.

Now a lot of standards are developed for representation of metadata for various types of IRs. They can be considered as SRs too. For example, Dublin Core is an example of a lightweight ontology that is used to specify the characteristics of electronic documents. Now this ontology is most widely applied for metadata semantization.

An other example of universal MSs are templates from Semantic MediaWiki that formalize the structure, categories and semantic properties of Wiki page with arbitrary content. Use of ontologies in creation of MSs makes them more interoperable and simplifies integration of different modelling approaches.

To model IOs with complex structure we can use models of simple and complex IOs (CIO), as well as methods of CIO. CIOs are formed by the meaningful relations between simpler IOs. For example, CIO “Family” can be formed by relations “child-parent” and “married” applied to CIOs “Person” and by relation “address” for CIO “place of residence”.

On base of above analysis we propose following definition: SIR as IR where elements of content or IR in whole are connected explicitly with elements of some formalized representation of knowledge with unambiguous semantic interpretation. Examples of such SIRs are: 1) IRs with semantic markup where ontology classes are used as markup tags; 2) documents with metadata based on standards defined by ontologies.

VI. Algorithms used in semantic technologies

Structuring of information is one of the ST tasks that helps in selection of important for user attributes. Such attributes can be considered as information factors acquired from data by various machine learning (ML) algorithms, means of Data Mining and other elements of artificial intelligence (AI) such as pattern recognition and logical inference.

Instruments that are used for analysis of SR content from the point of view of Data mining depend on specifics of these resources, means of their semantization and goals of analysis. For example, NL documents can be processed by Text Mining methods.

VII. Semantic computing and semantic applications

Semantic computing (SC) is a term used to describe a set of methods, algorithms, and software used to process data based on their semantics, which are uniquely defined and interpreted. This research direction is based on success in three areas:

- methods and means of practical engineering of ontologies as structures for integration and representation of heterogeneous distributed knowledge and data that make knowledge and data equally accessible to both man and computer;
- use and retrieval of the Web IRs with varying degrees of structuring as a universal source of knowledge about the meaning of concepts, words and other entities;
- methods, algorithms and tools for processing and analysis of large amounts of data [13].

SC combines different disciplines — multimedia computing, Semantic Web, soft computing [14], Cognitive calculations, computational intelligence, computational linguistics, etc. The use of SC allows to link informal intentions of people with content that may contain structured and semi-structured data, multimedia, natural language text, programs, services, and so on. Use of SC helps to disseminate traditional IT of character processing and content syntax in the direction of knowledge processing.

SAs are those software tools where the components of formal models at the conceptual level are described by formal knowledge representation, for example, by set of concepts and relations of pertinent ontology, and data transformation processes are performed with use of semantic computing. Some authors [xx] associate SC only with NL processing, for example, in semantic clustering and classification problems. However, although methods for establishing the semantics of text entities, their comparison with the use of semantic proximity measures are used in many SAs, but there is a large number of other SAs that process structured information, multimedia, etc.

In [7] semantic applications are defined as software that explicitly or implicitly use the domain semantics. But such definition does not make it possible to divide arbitrary software into semantic and non-semantic because implicit domain semantics is used in some way by almost any software. The main criterion for identifying software as a SA as a separation of KB from the means of knowledge processing, i.e. clear representation of both semantics.Therefore, we propose to use the term “semantic application” only for software where domain knowledge is separated from the built-in knowledge of IIS and can be changed independently of the IIS itself. Applications designed to solve problems that traditionally belong to the field of artificial intelligence (AI) but with knowledge that fully integrated into IIS and can not be changed without software transformation, can be considered intelligent or intellectualized, but are beyond the scope of this research and are not considered as semantic ones. The central component of any SA is KB that contains knowledge about task. Interpretation of this knowledge allows to obtain results that the user needs and that can not be obtained without the use of this knowledge (or which lack requires much more time and calculations).

VIII. Use of the Semantic Web for semantics applications

Recently, developers of distributed IISs exhibit a tendency to transition from the use of relational databases to ontological knowledge bases (KBs). This process causes semantization of IISs and their transformation to SAs with differentiation of interoperable knowledge and formally described means of their processing on base of common standards.

The Semantic Web [15] is a project that aims to transform the Web information space into a distributed KB and to ensure the interoperability of knowledge representation. These goals require the use of generally accepted standards in SAs for the languages of knowledge representation and requests for them. For example, semantic search can use ontologies that characterize the user’s area of interest or describe his profile, and such ontologies can be selected (by the user or developers) regardless of the implementation of search and mapping algorithms from any external repositories of ontologies. Main components of the Semantic Web

The Semantic Web conception is based on tree main elements -– ontologies [16] for knowledge representation, Web-services [17]for representation of knowledge processing means and software agents [18] that can activate Web-services for knowledge processing for the benefit of users. In SAs ontologies are used for formal modeling of the system structure, i.e. they define the relevant objects, subjects of domain and relations between them. Now domain ontologies are usually represented by the OWL [10] language developed by the Semantic Web initiative that is an add-on to the RDF language [11]. RDF provides information in the form of an oriented marked graph. The basic elements of RDF are triplets <subject, predicate, object>.

However, SAs are not equivalent to IISs based on the Semantic Web standards: now many IISs use ontologies as KBs but their usage is not a prerequisite for IIS semantization. IIS can be based on other formalisms of knowledge formalization which for some reasons better meet the domain needs or already are accumulated in previously created IISs and KBs.

SC is a computational methodology and computational technology with machined descriptions of content and intentions proposed by [12] that provides communication between the content of IRs and the user based on:

- semantic analysis of content for transformation of arbitrary IRs into SIRs with semantically described content;
- semantic integration of knowledge from content of different SIRs with unified model;
- semantic services (for example, Web-services, semantic search engines) and means or their integration oriented on user tasks;
- semantic user interface that process NL requests provide user-friendly representation of processing results (visualization, structuring).

SC models and implements computational structures and behavior at the level of semantics or knowledge that exceeds the level of symbolic data with use of such categories as “to be”, “to have” and “to do”.

The semantics of "being" defines the meaning of the equivalent relationship between unknown and known entities or concepts. The semantics of "mother" gives meaning to the structure or compound essence. The semantics of "do" gives meaning to the action or behavior of a system or person.

Formalization of semantic computations is considered in [20] Is defined in terms of objects, their attributes, relationships and content.

This ontology represents main components of semantic technologies and relations between these components. Ontology can be expanded by links to external ontologies that define more precisely some particular aspects of this research sphere. For example, “inductive inference” can be specified by ontology of inductive modeling algorithms that by-turn can be supplemented with ontology of by The Group Method of Data Handling (GMDH) linked with individuals of methods, their properties and software realizations [21].

IX. Conclusion and future work

To test the correctness of proposed definitions we apply them to various ISSs and IRs that we develop. Such decision is explained by reason that we don‘t know exactly all characteristics of IRs and ISS of other developers and don‘t sure of meanings of concepts in their manuals.

We consider three IISs: e-learning system M(e)L for distant control of student skills by formal model of domain knowledge [22], information retrieval system MAIPS [23] oriented on personified user needs and advisory system AdvisOnt [24]. All these IISs use external ontologies (in OWL) that can be changed by any others according to changes of user needs without any changes of software and apply ontological knowledge for processing of user requests. Therefore we can designate them SAs. We also consider some IRs on base of Semantic MediaWiki (for example, portal version of Great Ukrainian Encyclopedia e-VUE) where we take part in development of the KB structure [25]. Markup of Wiki-pages is based on terms from pertinent ontology, and content elements are connected explicitly with ontology classes by semantic properties connected with ontology relations. Therefore we can consider this IRs as SIR.

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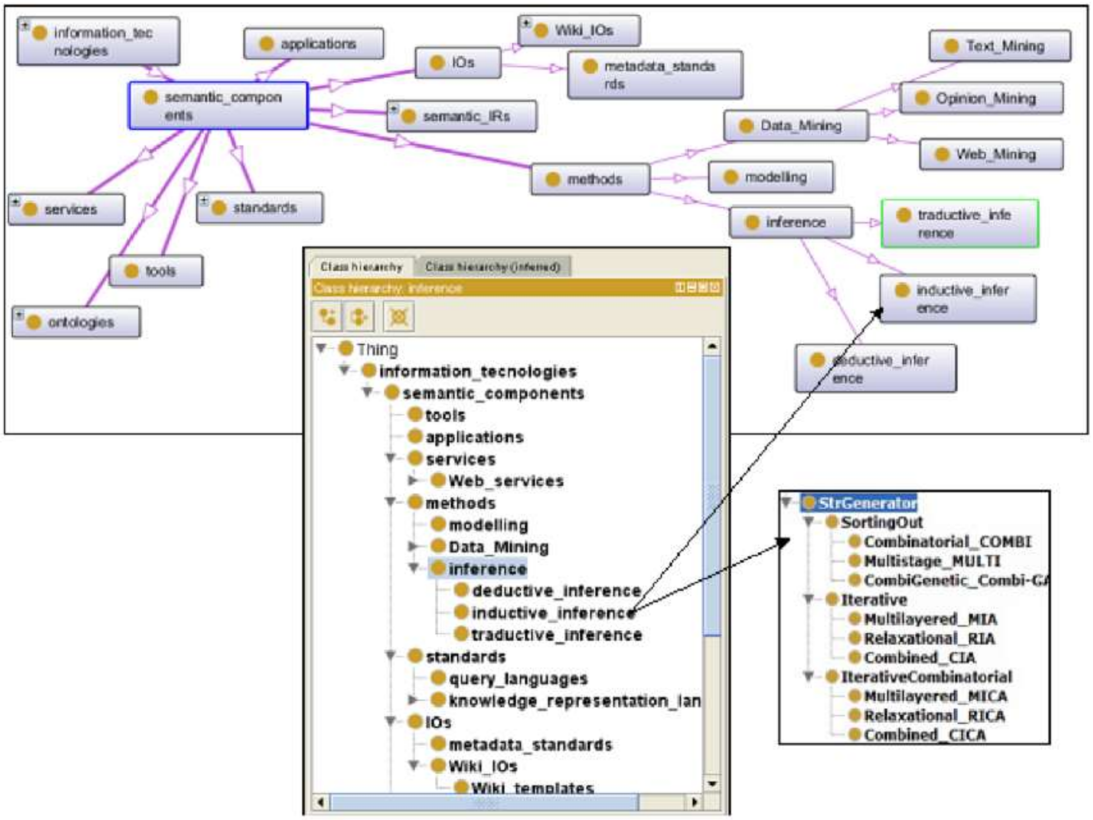

Figure 3. IRs used in semantic technologies.

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Семантизация развития информационных технологий: понятия, модели и методы

Рогушина Ю.В.

Рассматриваются концептуальные аспекты анализа современных семантических технологий, семантических ресурсов и семантических приложений. Предлагаются определения основных компонентов, используемых в семантических технологиях, и анализируются связи между ними. Основное внимание уделяется отличиям между елементами информационных технологий, базируюзихся на семантике, от других элементов интеллектуальных систем.Предлагается онтологическая модель компонентнов семантических технологий.

Онтологический анализ рассматривается как один из наиболее широко используемых инструментов семантизации. Анализируются проблемы использования онтологий в различных интеллектуальных системах и специфика их применения в семантических приложениях. Рассматриваются примеры семантических ресурсов Веб и их связь с онтологиями (в частности, семантические Вики-ресурсы).

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