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Using Intelligent Multi-agent Systems Based on Ontologies in Education

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Abstract

The article discusses the problems of designing intelligent systems on the example of intelligent multi-agent training systems designing. The concept of constructing intelligent multi-agent training systems based on ontological modeling is considered. The proposed approach allows one to build formalized ontological models and flexibly configure the intelligent multi-agent training system without laborious programming.

Keywords 1

Multi-agent system, intelligent multi-agent training system, subject area (domain), ontology, ontology model, intelligent software agent.

1. Introduction

One of the promising approaches to the creation of intelligent trainang systems is the use of multi-agent technologies [1, 2]. A multi-agent system consists of autonomous software objects (agents) capable of perceiving a situation, making decisions, and interacting with other agents.

The design of intelligent multi-agent training systems involves the use of parallel and asynchronous interactions of software agents of the system until the agents reach the so-called "competitive equilibrium", which is interpreted as a kind of "consensus" (balance of interests), when none of the agents can improve their performance anymore.

This approach makes it possible to switch to a distributed solution of the learning problem, where the interests of all participants (subjects) of learning can be presented and taken into account.

In this case, the learning process can be considered as a non-deterministic process of self-organization of agents, since each agent makes a decision on its own to establish or break connections both with the system itself and with other agents of the system at an arbitrary point in time, eliminating possible conflicts with other agents.

Designing intelligent multi-agent training systems requires a lot of efforts from developers both at the design and development stage, and at the stage of implementation and operation.

The basic principles of building multi-agent systems based on the ontologies were formulated in [1, 2], which shows the structure of a typical multi-agent resource planning system, the data model of which is built on the basis of a project management ontology.

The presented work develops well-known principles in terms of creating a basic ontology for planning and developing models and methods for making decisions in training, as well as in implementing a complex of software tools, in which ontologies allow not only expanding the set of restrictions, but also rebuilding scenarios for providing subjects of training with information resources of the system [3].

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2. Modeling of learning processes

Learning – extracting information from relevant information resources and testing the assimilation of this information by students – can be viewed as a model of processes that includes as submodels:

- model of information requests of the user;
- models of various information resources of an intelligent multi-agent training system.

Intellectualization of learning processes involves the definition of the main components of the corresponding model, their properties and the relationship between them.

The main objects of the proposed model are:

- subject area (direction of training of students, specialty, training courses, etc.);
- user (student, teacher, methodologist, knowledge manager, knowledge engineer, expert, stakeholder, etc.);
- user group - a subset of all users of the intelligent multi-agent training system, grouped by some criterion;
- information request of the user;
- classes of tasks for the solution of which an intelligent multi-agent training system is designed;
- base of information resources;
- information resource:
  - type of resource (educational and methodological content, tests, reference information, documents of various types, library of program codes, etc.);
  - property of the resource, including its assessment by users;
  - relations between information resources;
- base of information resources;
- user agent (intelligent software agent that represents the interests of the user when interacting with an intelligent multi-agent training system);
- relationships between different groups of model objects and individual objects within groups.

The use of a user agent makes it possible to provide means and methods for predicting the behavior (behavior scenario) of a user in an intelligent multi-agent training system.

A formalized description of the objects of the model of intellectualization of learning processes involves the use of an ontological representation of knowledge about these objects [4].

Thus, to describe the processes of managing information resources and user behavior, it is necessary to build an ontological model, the classes of which correspond to the objects of the model, and the relations correspond to the connections between them [5].

2.1. Modeling of student learning

Students' education is provided, in particular, by such entities as:

- teachers (lecturers, professors);
- information and intelligent multi-agent training systems;
- information and analytical departments of the university;
- information sources (libraries, databases, knowledge bases, etc.).

Educational material is a set of subject units – didactically verified blocks that reflect the content of the academic discipline. Relationships between subject units reflect the structure of educational material. In this context, subject knowledge is a system of knowledge that consists of subject units and relationships between them. These relationships reflect knowledge about the composition and structural properties of the educational material.

Let E be a set of subject units. The set of structural relations (connections) between subject units will be designated as $S \subset E \times E$. E and S are formed by an expert for a given training course (stakeholder, representative of the scientific community, teacher, graduate, etc.). The basic subject units are academic topics. Among all the topics of the course, a subset of supporting (basic) topics can be distinguished. The level of mastering by the student of these topics determines the success of the learning process.

When formalizing the learning process, it is necessary to highlight the learning objectives and criteria for evaluating the processes. The presence of several consistent goals allows for the variability of training and thereby ensure the individualization of student learning at the university.

Alternative customized versions of the theme can have different difficulty levels. An expert assessment of the complexity of each version of the theme version is subjective. This complicates the usage of precise quantitative methods in its formal description based on the corresponding ontological model of the course.

The structure of subject knowledge is characterized by an attitude $S \subset E \times E$. Representation of subject knowledge can be represented by the ontograph G.

The multitude of nodes of the ontograph reflects the multitude of subject units, the multitude of arcs represent the structural relations between the subject units.

Such a formalized description of subject knowledge makes it possible to clearly define:

- presentation of subject knowledge (selection of a variety of subject units);
- options for providing subject knowledge (for example, the procedure for submitting subject units, the number and level of subject units, etc.);
- options for learning objectives in the formation of educational material;
- options for criteria for assessing learning outcomes;
- options for the trajectory of assimilation of educational material;
- requirements for the type, quantity and sequence of the educational material provided or the corresponding tests for the comprehension and consolidation of the theoretical material.

The developed ontology of the educational process was based on the basic principles of organizing the learning process at the State University of Infrastructure and Technology (Kyiv, Ukraine).

In accordance with these principles, the structure was formed and the main components of the ontology were identified. At first, a dictionary of ontology was formed, on the basis of which a taxonomy was built and a knowledge base with selected classes, objects, object properties and data properties was developed.

The limits of admissible values of components of ontology were defined, expressions for restrictions are formulated, areas of existence and areas of values (Domains and Ranges in Protégé 5.5 [6]) for objects and their properties are specified.

The developed taxonomy was implemented in the form of OWL-ontology [7] by means of the ontology editor Protégé 5.5. RDF/XML was chosen as the language of knowledge representation.

The main components of the ontology are classes, the main of which is the mandatory class defined in the standard Thing.

Domain according to the constructed taxonomy seven classes and subclasses are created: some of which are primitive class, others are defined, which are formed by the list of individuals or by means of equivalence theorems.

As primitive classes selected:

- Faculty;
- Department;
- Program;
- Discipline.

As defined classes, that specified by sets of valid values of individuals are defined:

- CertForm (Reporting Form): {Differential Credit, Credit, Exam};
- PartDis (Type of discipline): {Basic, Elective};
- SciWork (Additional task): {CP - course project, CW - control work, CGW - calculation and graphic work}.

Description of the discipline ADS (Algorithms and Data Structure) is presented on the Figure 1.

The designed ontology has the form of an oriented graph, the nodes of which are classes, and the arcs are properties that are relations (connections) between classes.

In Figure 2 shows the result of ontological modeling of the educational process at the level of the university faculty.

To search for data in the ontology, there are different query languages: OWL-QL, SQWRL, SPARQL Query, DL Query. OWL DL and SQWRL provide new knowledge using reasoning algorithms, which are formally described in descriptive logic.

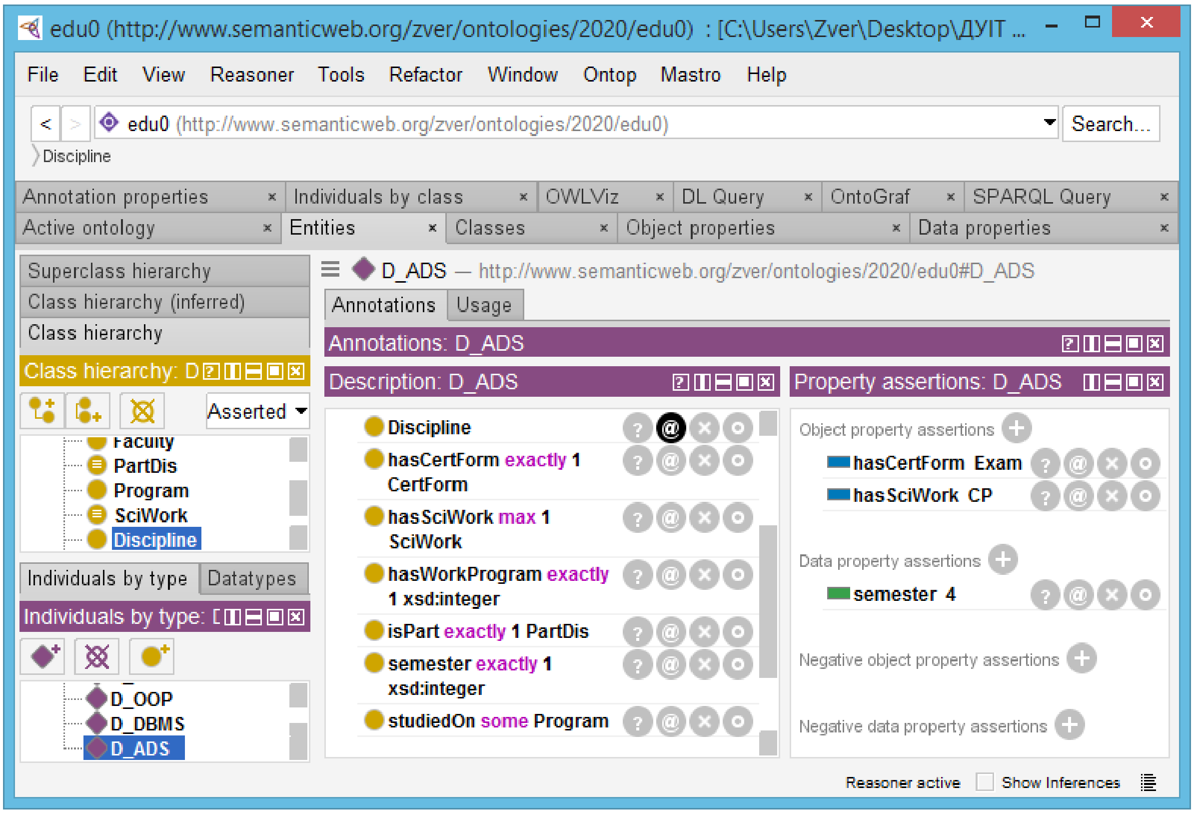

Figure 1: Description of the discipline "Algorithms and Data Structures"

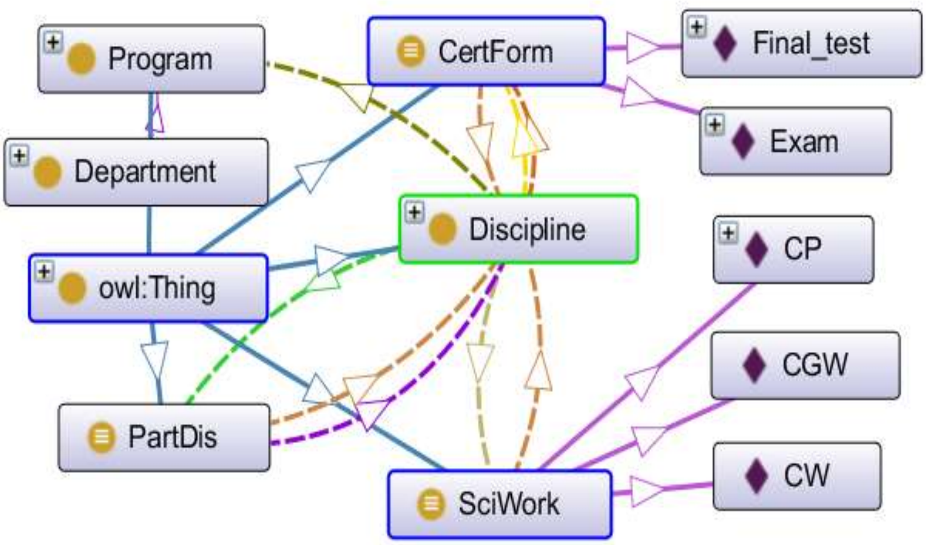

Figure 2: Part of the ontology graph is constructed by Protégé OntoGraf

2.2. Modeling student knowledge control

In addition to theoretical educational material, each academic course contains diagnostic material to control students' knowledge. Operational control of knowledge is often performed using tests that are made up of a set of test items (questions).

A test item is a clear and precise item from a specific subject area. It requires an unambiguous answer or the implementation of an appropriate algorithm of actions.

The ontological model of teaching and monitoring students' knowledge provides for the use of prompts (*information*, *help*) either from the teacher or from the corresponding intelligent multi-agent training system.

Questions on each topic should have a different level of difficulty for a more accurate assessment of the student's level of knowledge. In most tests, the answers to the questions are assessed as correct or incorrect. In contrast to intelligent multi-agent training system, the teacher, who controls the student's knowledge, also takes into account the partially correct answers. Using them, he determines the gaps in the student's knowledge.

Among the test items are:

- *Choice of answer*.
- *Compliance (ordering)*.
- *Entering numerical data*.
- *Entering text (character data)*.

Questions that are asked to a student can be assigned to one of the following grades:

1. Questions that require an explicit assignment of key concepts in the answer (relations are explicitly asked in the question).

For example, this class of questions includes following questions:

- "Write a program for calculating a function in Java";
- "What is the composition of the library of Java mathematical functions";
- "List the hardware components of the system".

This class of questions corresponds to classes of answers, which necessarily explicitly contain key concepts.

For example:

- answers of the selective type (several answers are given, you must indicate the correct answer);
- answers like "YES / NO";
- answers of a fixedly constructed type (when part of the answer is given and it is necessary to add the missing tokens);
- numerical answers, etc.

2. Questions that require disclosure in the answer of a typical relationship of one main concept.

These are examples of the questions:

- "Which array takes up more memory in Java: an array of 100 elements of an integer type or an array of 100 elements of a character type?"
- "What is done before: system design or testing?"
- "Which runs first: compilation or download?"
- "Which is easier to learn Java or Chinese?"

It is possible to specify the following classes of responses that reveal typical relationships of the same name:

- Composition.
- Inclusion.
- Action.
- Condition.
- Temporary relationship.
- Spatial relationship.
- Quantitative ratio.
- Quality attitude.

3. Questions that require disclosure in the answer of a compound relationship of one main concept.

A compound relationship can consist of several simple relationships. For example, such a composite relation is the relation "Function", which in the text of the answer simultaneously reflects the relation of the main concept to both the argument and the result.

This class of questions includes, for example, such questions:

- "What is the function of the interpreter?"

- "What is the purpose of the central processor",
- "What does a software tester do?"

This class of questions corresponds to the classes of answers in which the main concept is revealed through a composite relation.

For example, the answer: "A tester is testing the program code" belongs to the "Function" response class, which reflects the relationship of the main concept "Tester" to the concept-argument "Code", as well as to the concept-result "Program".

4. Questions that require disclosure in the answer of an arbitrary combination of simple typical and / or compound relations of one main concept.

This class of questions includes, for example, the following questions:

- "Give a description of the for loop operator in C ++."
- "What do you know about knowledge bases?"
- "Give the definition of an intelligent system."
- "Give a definition of ontological modeling"
- "Give a definition of the software life cycle."

These questions correspond to classes of answers in which the main concept is revealed through its simple type relation and / or compound relation.

The following classes of responses can be distinguished, for example:

1. *Description* is a class of answers in which arbitrary combinations of a typical relationship and / or a composite relationship of the main concept with other concepts are revealed.
2. *Definition* – a class of answers in which the main concept is revealed through a generalizing concept (a concept at a higher level of the hierarchy) and a Description class. For example, this class can include the answer:

- "A student is a person who studies at a university, institute or academy."
- "A student who has failed is a student who has not passed the exam or test."
- "Algorithmic efficiency – is a property of an algorithm which relates to the number of computational resources used by the algorithm".

3. *Reason* – a class of answers in which the condition for the existence of some relations of the main concept with other concepts is revealed. It is assumed that the main concept of the consequence and its relationship with other concepts are given in the question. For example, consider the answer:

- "Ice does not sink in water, because the specific gravity of ice is less than the specific gravity of water."

If this is the answer to the question:

- "Why doesn't ice sink in water?" then the answer belongs to the class *Reason*.

Here the main concept of the consequence "ice" and its relation to the object "Water" is given in the question itself. The part of the answer “Because the specific gravity of ice is less than the specific gravity of water” reveals the condition for the existence of the indicated effect.

4. *Consequence* – a class of answers in which the consequence of the existence of some relations of the main concept with other concepts is revealed.

The previous example answer in this case demonstrates the answer to the question:

- "What follows from the fact that the specific gravity of ice is less than the specific gravity of water?"

Here the main concept of the cause "specific gravity of ice" and its ratio "less" to another concept of "specific gravity of water" are given in the question. In the part of the answer: "Ice does not sink in water", the consequence of the existence of this condition is revealed.

In the answers to questions in grades 1-4, the main concept does not change while viewing the text. Answers are assumed to contain information on only one main concept.

5. Questions that require disclosure in the answer of more than one main concept.

For example, questions of this class include questions:

- "Prove the Pythagorean theorem."
- "Prove Bayes' theorem."
- "Prove Laplace's theorem."

This class of questions can correspond to answers in which the main concept changes in the process of viewing the answer, i.e. the role of the main concept is transferred to that concept, the relationship of which with other concepts is disclosed further in the response text.

The work identified the following classes of answers, which contain the main concepts related only to the general context.

Detailing class is taken as an example. In the answers of this class, there is a *detailing* of concepts that are in some relation to the main concept.

Example question from class 5:

- "What is the connection between the research institute and the plant?"

The answer can be the following text related to the class of detail:

- "The research institute has developed a production automation system, which is used to design drilling devices that are introduced at the plant."

There are three main concepts in this answer:

- "research institute",
- "production automation system",
- "drilling devices".

The following relationships of these concepts with other concepts are consistently revealed:

- developed – "a research institute has developed a production automation system",
- designs – "the production automation system designs drilling devices",
- being introduced – "drilling devices are being introduced at the plant."

Another example of a class 5 question:

- "What is the relationship between the university and the employing enterprise?"

The answer can be the following text related to the class of detail:

"The university trained specialists who proposed a new development strategy that brought the employer company to the European market."

This answer has the following main concepts:

- "university",
- "specialists",
- "development strategy",
- "enterprise-employer",

The following relationships of these concepts with other concepts are consistently revealed:

- prepared – "the university prepared specialists",
- suggested – "experts have proposed a development strategy",
- brought out – "the development strategy brought the enterprise to the European market."

The division of texts into semantic classes is carried out according to the type of relationship of the main concept, which:

- is revealed in the answer;
- does not depend on a specific domain,
- does not depend on the concepts of the given domain,
- does not depend on the specific language of communication with the system.

This allows you to build answer analyzers that are focused on revealing a certain type of relationship of the main concept within the corresponding class of answers.

With the semantic approach to the classification of questions and answers, there is a direct relationship between the class of the question and the class of the answer. The belonging of an answer to a certain class of answers is determined not by its volume and content, not by the form of the question, but by the class of the question and the expected meaning.

The student and the teacher must have a holistic picture of the subject area of the discipline being studied and be aware of the links of this discipline with others. The ontological model allows you to form such a holistic representation of the subject area.

In the learning process, ontology can be useful as a reference for one or more related disciplines. For this, various comments (annotations) are used for classes, properties and individuals.

The ontology can be stored on a university or faculty server and provide access through a convenient interface using, for example, keywords that are transformed into SPARQL queries. Thus, using such an access point, you can get all the necessary information in one place.

Testing students' knowledge can also be implemented using ontologies. Each discipline studied contains a set of concepts, methods, tasks, often having a hierarchical structure, which is reflected in the hierarchy of classes and properties. The components of the concepts of each section of the discipline can be described not only in the comments, but also in the description of the class itself corresponding to this concept. Having such a metadata base, it is not difficult to form questions based on the existing statements, axioms and descriptions.

Then they can be entered, for example, in Google Classroom or Moodle using the tools available there. For example, in the section "Sorting algorithms" you can suggest the following questions, the answers to which are stored directly in the class hierarchy of the ontology (Figure 3):

- Which groups are sorting algorithms divided into?
- Which groups are elementary sorting algorithms divided into?
- What are sorting algorithms from the «quicksort», “merge” and other sorting group?

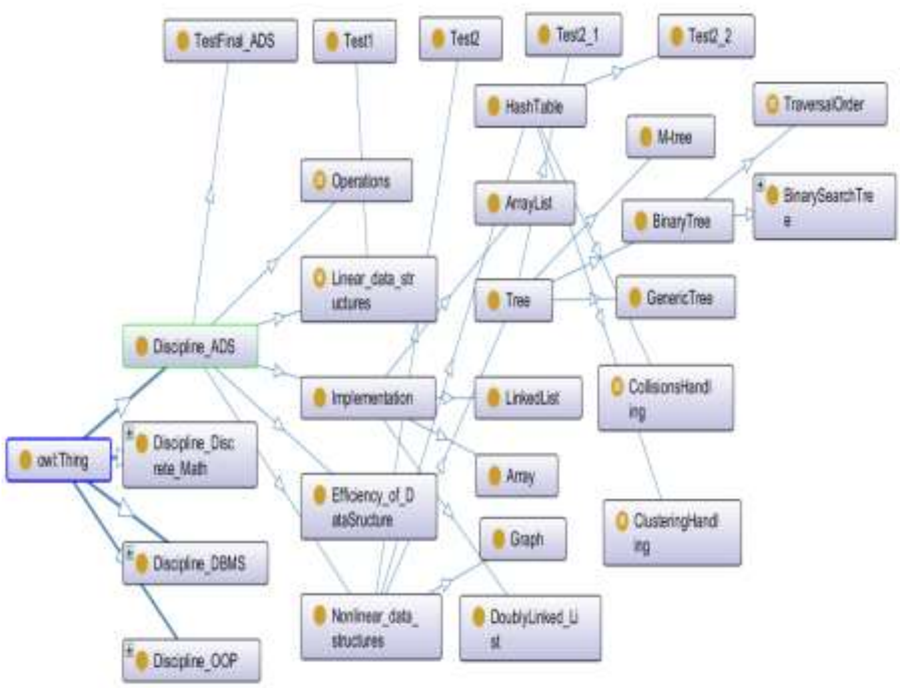

Figure 3: Part of the ontology graph for the testing of knowledge (discipline ASD) is constructed by Protégé OntoGraf

By combining correct and incorrect possible answers to these and similar questions on a given topic, you can find out the depth of the student's knowledge. To answer the question "What types of linear data structures exist?", It is enough to display the components of the corresponding defined class, which contains the enumeration of the individual names of these structures.

Likewise, all defined classes can be used as ready-made reference materials for specific topics and subtopics. For example, on the topic "Hash tables", you can thus provide information about methods of handling collisions and clustering not only by simply listing the methods, but also by a brief description of them.

Also, links can be additionally given to literary and other sources (including the author's methodological developments of the teacher), which are available in the university library or are stored on the department's website. Links to external resources - access points or sites are also issued.

To search for more complete information in the ontology, you can use full-text search tools.

We can implement the full-text search function using a special extension of the properties function ARQ-text: query to find in the ontology a given word that is present in the rdfs: label property.

You can use test questions to establish hierarchies and relationships between concepts, problems and methods of solving them. So, for example, for a fragment of the described ontology on the topic "Numerical algorithms", invite students to indicate the connections of tasks and methods that are used here, and then compare with the ontology data. It is possible to propose to restore deleted links on the concept graph and supplement the graph with individuals.

Studying the topic "Methods of analysis of algorithms" a student can give a relative assessment of the effectiveness of sorting algorithms by establishing hierarchy methods according to various criteria.

You can use test questions to establish hierarchies and relationships between concepts, problems and methods of solving them. So, for example, for a fragment of the described ontology on the topic "Numerical algorithms", invite students to indicate the connections of tasks and methods that are used here, and then compare with the ontology data. It is possible to propose to restore deleted links on the concept graph and supplement the graph with individuals.

Studying the topic "Methods of analysis of algorithms" a student can give a relative assessment of the effectiveness of sorting algorithms by establishing a hierarchy methods according to various criteria. Ontology is developed in Ukrainian and English for conducting classes in groups of both Ukrainian and foreign students, as well as for acquaintance with international terminology in the relevant subject area.

Relationships between classes-concepts or sections of the studied discipline in an ontology are supported by object properties. For example, the means of implementing linear structures by constructs in programming languages can generally be specified using the implementedBy object property that links the Linear_data_structure class to the Implementetion class. By linking the ASD course with the course on a specific programming language in ontology, one can answer the question of how such structures are implemented in a specific programming language.

Ontological data, including those on interdisciplinary relationships between disciplines of a particular department, can also be used for:

- drawing up:
  - curricula;
  - syllabuses;
  - curricula and work curricula;
- acquaintance:
  - students with curricula in the choice of variable disciplines;
  - potential employers (stakeholders) with educational programs and training courses to make their wishes and recommendations for improving these programs and courses, their possible changes, etc.;
- drawing up final tests and exam questions for students.

When choosing variable disciplines, inference rules can be used using OWL DL.

OWL DL, which is based on SHIQ Description Logic, makes it possible to use so-called "reasoning algorithms", which are well developed within the descriptive logic. The implementation of such algorithms provides the possibility of automatic derivation of knowledge from the ontology, which is not explicitly specified, but follows from the knowledge available in the ontology.

To query the OWL DL ontology, there are various query languages, such as: OWL-QL, SQWRL, SPARQL Query, DL Query.

Using the OWL DL, you can create, for example, classes that will not be defined in the ontology explicitly, but will be built automatically during the execution of DL-queries. This will allow the formation of groups of individuals in the ontology in accordance with predefined criteria, which will be available for further processing.

3. Intelligent multi-agent training system

An intelligent multi-agent training system provides a semantic search for various information resources (educational and methodological content, tests, reference information, documents of various types, a library of program codes, etc.) based on the knowledge contained in ontologies.

The system under consideration is designed to search for information in the information described by the user (teacher, methodologist, knowledge engineer, knowledge manager, etc.) regarding the subject area related to the interests of users (students), and recommends to the user those resources of the intelligent multi-agent training system that correspond to the information needs of the student.

The considered intelligent multi-agent training system uses the OWL ontology representation language and means of its processing. To represent knowledge, ontologies and thesauri of the subject area are used. In this case, the thesaurus is built by the user according to the corresponding ontology independently.

The system user can access ontologies created by other users, revise them, set the context for obtaining an information resource based on them, copy the necessary fragments from them, but cannot change them.

The intelligent multi-agent training system provides the search for ontologies that contain the terms entered by the user (teacher, methodologist, expert, stakeholder), as well as the search for ontologies similar to the ontology selected by the user.

This allows you to create groups of users with common information interests and prevent duplication in the execution of the same reusable requests of different users (students).

An ontological model that describes the semantics of interaction between users and resources of an intelligent multi-agent training system in the general information learning space provides knowledge for performing actions related to learning processes and managing these processes.

Figure 4 shows the levels of an intelligent multi-agent training system. XML is a means of creating XML documents (information documents and reference information) and enabling intelligent software agents to process these documents.

RDF is a means of processing data semantics by intelligent software agents based on syntactic conventions and models. An evolution of RDF is the RDF Schema (RDFS), which introduces basic ontological models of primitives.

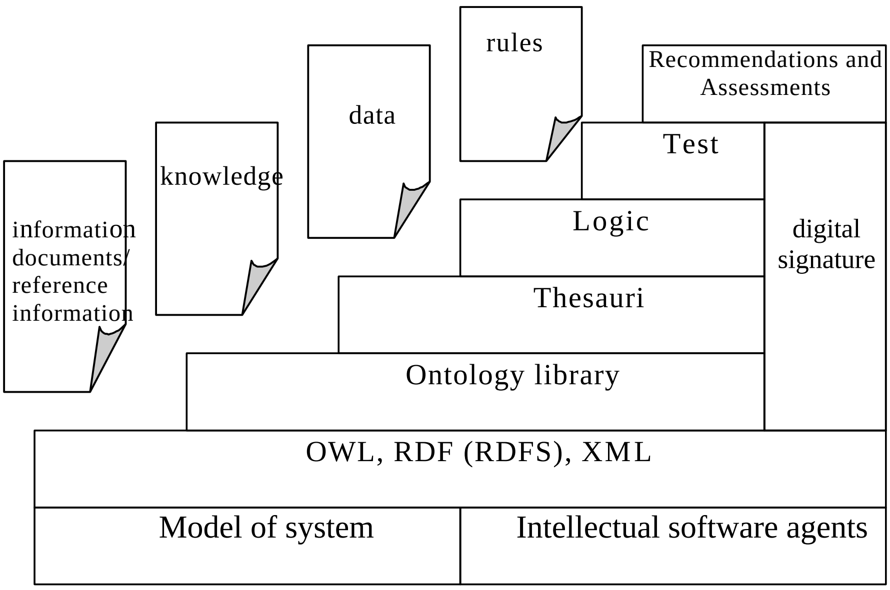

Figure 4: Levels of intelligent multi-agent training system

Stages of designing an intelligent multi-agent training system:

1. Preliminary stage:
   - creation of an ontological model describing the structure of the system, its main components (their description, properties, functions, etc.);
   - creation of an ontological model of the information base regarding the main objects with which the system works (users, resources, learning outcomes, etc.);
   - creation of a subject area ontology (training course, testing program);
   - the creation of thesauri that can be used in the provision of educational content or testing.

2. The stage of user registration (entering the information required to create a new instance of the "user" class).
3. The stage of forming a user agent
4. The stage of creating a user request:
   - selection of a basic ontology to provide semantic query processing;
   - creating a thesaurus of a query based on the selected ontology, which implies performing one of the following actions:
     - selection of several classes or instances of classes from the base ontology;
     - selection of several classes from the basic ontology and classes located from them at a semantic distance specified by the user;
     - selection of several classes from the base ontology and their superclasses and subclasses of a user-specified depth;
     - selection of several classes from the basic ontology and the classes associated with them by a specified user-specific relation to the subject area;
     - input of thesaurus terms that characterize the user's task;
     - application of the set-theoretic operations of union, intersection and complement to the already existing thesauri;
     - determination of the weight of the necessary terms of the thesaurus for the problem being solved.
   - formation of a list of keywords that characterize a specific information request;
   - creating a new group of information requests or joining a request to one of the existing groups
5. Execution of an information request:
   - transmission of a request (by keywords) to the information resource base of an intelligent multi-agent training system;
   - obtaining results and reordering them in accordance with the number and weight of thesaurus terms used in them;
   - taking into account other properties of information resources (for example, the level and completeness of teaching content, the level of test complexity, etc.).
6. Determination of the competence levels of system users, which takes into account:
   - the number of user requests based on this ontology;
   - self-assessment by the user of his competence in the subject area of interest;
   - selected by the user (determined by the system after preliminary testing of the user) the level and completeness of the presentation of the training content, the level of difficulty of the tests;
   - the relevance of the user's own publications of this subject area, which is determined by comparing the thesaurus built on the basis of the subject area ontology with the thesauri of publications;
   - the number of system users who choose a particular user as an expert in a given subject area.
7. Creation of recommendations to the user based on the results of his training, taking into account:
   - opinions (assessments) of other users of the system (teachers, stakeholders, experts);
   - opinions (assessments) of users whose information requests are based on the same ontologies;
   - opinions (ratings) of users who use similar (similar, related) keyword thesauri for information queries;
   - self-assessments of users on the selected educational topic, which is based on one common ontology and corresponding thesauri;
   - self-assessments of users on the selected educational topic, which is based on various ontologies and corresponding thesauri;
   - self-assessments of users on the chosen training course (set of training topics), which is based on one common ontology and corresponding thesauri;
   - self-assessments of users on the chosen training course (set of training topics), which is based on various ontologies and corresponding thesauri;

- information requests of the user himself that meet certain training conditions (for example, built in a specified time interval and using a keyword);
- answers of the user himself to information requests of the system itself that meet certain training conditions (for example, formed at a specified time interval and / or when using a keyword).

Recommendations allow the user (student) to advise those units of information resources of the system that have not been mastered by the student (in whole or in part), but are considered by the system to be interesting and important for him. The system generates a new sequence of units of information resources or provides the same previously presented units of resources in a new presentation, with new examples, tasks, etc.

8. Updating the system information base:
   - updating of ontologies;
   - updating thesauri;
   - updating educational content;
   - update of tests.

4. Modeling the behavior of an intelligent software agent

It is rather difficult to objectively assess the effectiveness of an intelligent multi-agent training system and its ability to satisfy various information needs of the user, since:

- user assessments are quite subjective;
- It is difficult for users to strictly indicate the parameters on the basis of which some units of information resources are preferable to others with sufficiently similar formal parameters.

This necessitates a formal description of the user's information needs and predicts the behavior of an intelligent software agent representing the interests of this user in the system.

Software agents are a modern programming paradigm that allows you to move to a new, more intelligent level of user interaction with software and hardware.

The software agent provides an increase in work efficiency and allows users to entrust an intelligent system with performing rather complex tasks for working with knowledge, for example, searching for knowledge, generating new knowledge, etc.

Normal human behavior is predicted and explained by the following relationship attributes:

- persuasion;
- desire;
- hope;
- concerns, etc.

The concepts that describe this relationship are called intensional concepts. The term intensional systems for describing entities, the behavior of which is predicted by attributing to them the attributes of belief, desire and rationality, was introduced in [5], and in [6] the area of applicability of such systems is considered. The less is known about a system and its structure, the more useful are intensional explanations of its behavior.

For a fairly complex system (even with complete information about it), an intensional explanation of its behavior is often more practical and understandable.

An intelligent software agent, as a system, is consistently described through intensional states [4] by information relations (belief, knowledge) and pre-attitudes (desire, intention, commitment, commitment, choice, goal, etc.).

Information relations are compared with the information that an intelligent software agent has about the entities of the world in which it exists, in particular about:

- user;
- subject area that interests the user;
- information objects that the user needs;
- information learning space, in which the process of searching and providing units of information resources is carried out.

A pre-relationship is something that in some way directs the actions of an intelligent software agent, in particular:

- information about the learning goals that need to be achieved by the user (student, teacher, methodologist, stakeholder, etc.);
- learning tasks that the user solves (student, teacher, methodologist);
- the user's idea of what needs to be had and what needs to be done to solve the problem.

Beliefs (beliefs) of an intelligent software agent express his opinion about the current state of the world, its essence and about the plausibility of the course of action leading to a certain effect.

Desires (desire) describe the preferences of an intelligent software agent regarding the future states of the world, its entities or behavior. An important characteristic of desire is that an intelligent software agent may have incompatible and unattainable desires.

Goals are a consistent subset of the desires of an intelligent software agent.

Intentions are a consistent subset of the goals achievable by a resource-constrained intelligent software agent and how to achieve them.

Pre- and informational relations are closely related, since intelligent software agents can make rational choices, form intentions based on the information they have about the world, its essences and the way of action, leading to the achievement of goals and the effective receipt of optimal solutions to learning problems.

Many intensional concepts (such as belief and desire) are opaque. For example, the truth value of the statement "A believes X" depends not only on the truth value of X, but also on A. And therefore, classical logic is unsuitable for their description.

To describe an intelligent software user agent of an intelligent multi-agent training system, it is proposed to use a formal model that includes the following relationships: knowledge, beliefs, intentions and goals, as well as connections between these relationships.

Consider, for example, statements like "R: S → P", where S_{in} is the subject of learning, P is an affirmative statement, and R is the relationship between S_{in} and P.

If the relation R is a belief, then the statement "Sin believes P" is true, means that P is recognized as true for S_{in}, regardless of whether or not P is true. It is assumed that there is an external subject K that asserts the truth of the whole statement "S_{in} believes P". Therefore, there are points of view of the inner subject S_{in} and the outer subject K.

Let W be the set corresponding to the knowledge of the external subject K. U is the set representing the knowledge of the internal subject S_{in}. The U evaluates statements expressing the judgments of the inner subject S_{in}.

The statement "S_{in} knows P" is true if and only if it is true in U. This means that the subject asserts that P is true, and P is indeed true.

The subject S_{in} does not always have complete and correct information about the entities of the subject area, therefore, to describe the entities from U, the values "true" and "false" are not enough (for example, there are statements whose truth value is unknown, but the subject S_{in} is sure of the possibility / impossibility of such an assessment).

An ontology is a hierarchically organized vocabulary of concepts used to describe an subject area and related relations. Basic concepts through the inheritance relation can be concretized by derivatives. Concepts and relationships from one ontology can be used to construct another – this allows you to structure knowledge, for example, by creating several ontologies that differ in the level of abstraction.

Qualitative and quantitative characteristics of concepts and relationships are set using attributes. The ontological model contains stable configurations of instances of classes specified in the ontology.

On the basis of the ontology and the ontological model, data structures are determined, which are used in the future to describe information models of objects and learning processes.

5. Conclusion

The benefits of using this approach include:

- creation of a single basis in which knowledge is described;

- the ability to make changes to the structure of knowledge representation as the goals and objectives of the system change;
- visibility and accessibility for perception by users of large volumes of complexly structured information;
- opportunities for the integration of heterogeneous sources of information.

Based on the analysis carried out, it can be concluded that the developed approach allows:

- to reduce the complexity and labor intensity of creating an intelligent multi-agent training system;
- increase the number of factors for decision-making (for example, when individualizing learning processes, choosing the level of complexity of presenting educational content);
- reduce the cost of creating and maintaining the systems under consideration.

A basic ontology of resource planning has been developed and the possibilities of its extension in an subject area are shown, which make it possible to use the same set of agents to control learning processes in different subject area. An extension of the multi-agent method based on the ontological learning model is presented.

The proposed approach allows one to build formalized ontological models and flexibly configure the intelligent multi-agent training system without laborious programming. The use of ontologies can reduce the cost of creating and maintaining of intelligent multi-agent training system. The created ontological models can become the basis for the creation of “digital twins” of training courses that are taught by teachers.

6. References

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