Lecture 14. Knowledge models

The purpose of the lecture: to discuss: an introduction to the basic models of representation and formalization of knowledge, their attributes and structures.

Lecture plan:
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1 Formalism
2 Classification
3 Category and functor
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5 Semantic web
6 Frame model
7 Logical model
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Keywords: intelligence, knowledge representation, knowledge, subject area, conceptual, constructive, procedural, factual, meta-knowledge, conceptual knowledge, constructive knowledge, procedural knowledge, representation, formalism, heuristics, decision-making, informatics, reliability, regularity, recording, joining , classification, equivalent objects, search, table, firm, lexicographic ordering, list, fee, tree, toolkit, category, functor, object-oriented design, equivalence, experience, generalization, operations, mapping, semantic web, frame, bound variable, tuple, signature, free variable, algorithm, program, intelligent system, descriptive model, frame, production model, mixed strategy, forward, backward, inference, main model, vertex, object, inheritance, subgraph, frame model, skeleton, slot, presentation data, credit, server, evolution, function, scope, argument, value, calculation, description of the system, logical, model, logical model, relation, operation of implication, PROLOGUE, domain model, group, formal model, computer, model type, production, semantic model.

Contents of the lecture:

Introduction

The basic models of knowledge, their structure, attributes, examples are considered.

1 Formalism

Concepts such as "intelligence", "intellectuality" among specialists of various profiles (systems analysis, computer science, neuropsychology, psychology, philosophy, etc.) may differ somewhat, and this does not pose any danger.

Let's accept, without discussing its positive and negative sides, the following "formula of intelligence":

"Intelligence = purpose + facts + ways of applying them",

or, in a somewhat more "mathematical", formalized form:

"Intellect = goal + axioms + rules of inference from axioms".

When searching for the most convenient, rational means and forms of information exchange, a person most often encounters the problem of a compact, unambiguous and fairly complete representation of knowledge.

Knowledge is a system of concepts and relationships for such an exchange. You can conditionally classify knowledge in the subject area into conceptual, constructive, procedural, factual knowledge and meta-knowledge.

Conceptual knowledge is a set of concepts used in solving a given problem, for example, in fundamental sciences and theoretical fields of sciences, i.e. it is the conceptual apparatus of science.

Constructive knowledge is a set of structures, subsystems of a system and interactions between their elements, for example, in technology.

Procedural knowledge – methods, procedures (algorithms) for their implementation and identification, for example, in applied sciences.

Factographic – quantitateive and qualitative characteristics of objects and phenomena, for example, in experimental sciences.

Metaknowledge – knowledge about the order and rules of applying knowledge (knowledge about knowledge).

Knowledge representation is a process, the ultimate goal of which is the presentation of information (semantic meaning, meaning) in the form of informative messages (syntactic forms): phrases of oral speech, sentences of written speech, pages of a book, directory concepts, objects of a geographical map, brushstrokes and characters of a picture, etc.

For this, it is necessary to use a certain constructive system of rules for their presentation and perception (pragmatic meaning). Let us call such a system of rules the knowledge representation formalism. Unformalizable knowledge is knowledge obtained using unknown (unformalizable) rules, for example, heuristics, intuition, common sense and decision-making based on them.

A person uses natural formalism – language, writing. Language, linguistic constructions develop due to the fact that human knowledge constantly needs linguistic representation, expression, compression, storage, exchange. A thought that cannot be expressed in a language construction cannot be included in information exchange. Language is a form of knowledge representation. The more diverse the language of the people, the more knowledge it can reflect, the richer the culture of the people. At the same time, sentences and words of a language must have an unambiguous semantic meaning. A special role is played by the language of mathematics as the language of sciences (not only exact, but also humanitarian), the formalization of knowledge, the basis of the presentation of the system of knowledge in the natural sciences. Chemistry, physics, economics, computer science, etc. have their own language. The languages of science often overlap and mutually enrich in the study of interdisciplinary problems.

The use of language systems and dialects increases the reliability of information exchange, reducing the possibility of misinterpretation of the transmitted information and the level of noise in messages. The main purpose of the language of science is to create and use typical, "standard" forms of presentation, compression and storage of knowledge, the elimination of polysemy (semantic polysemy) of a natural language. Polysemy, enriching the natural language, making it richer and more expressive, nevertheless, is in the information exchange a source of semantic noise, semantic ambiguity, and often - illogical, non-algebraic.

Example. Let's find and formalize the pattern in the sequence 1, 10, 11, 100, 111, 1000, 1111, 10000, ... From a comparison of the members A[i] (i = 1,2, ...) of the sequence standing in even places and odd places, it can be seen that: 1) an element at an odd place is obtained from an element at the previous odd place by adding one to the right to him; 2) each element at an even place is obtained from an element at the previous even place by adding zero to it on the right. This verbally described (non-formalized) rule can be written in mathematical language, in an analytical form. We obtain for cases 1) and 2): A[2n] = 10A[2n – 2], A[2n – 1] = 10A[2n – 1] +1, n = 1, 2, ... You can write a formula that combines both of these formulas: A[2n + m] = 10A[2n + n – 2] + m, where m = 0 or m = 1. Better form (with less polysemy): A[2n + mod(n, 2)] = 10A[2n + mod(n, 2) – 2] + mod(n, 2).

Example. Let's formalize the law of sequence formation: AB, AAB, ABB, AAAB, ABBB, ... The verbal description of the rule is as follows: the character "B" is added from the end to the word at the next odd place, and the character "A" is added to the word at the next even place to the left. "Formula" notation of the rule: $X_{2n+1} = X_{2n-1} + B$, $X_{2n} = A + X_{2n-2}$, n = 1, 2, 3, ... Here the "+" operation means concatenation (joining the text to the text on the right), and X_n is the element of the sequence at the nth place.

2 Classification

One of the important forms (methods) of formalizing knowledge is its presentation by a class (classification).

Classification – the allocation of some criterion (some criteria) of the distribution and the grouping of systems or processes in such a way that only those systems (processes) that meet this criterion (value of the criterion) fall into one group. Classification is a method of scientific systematics, which is especially important at the initial stage of the formation of basic knowledge of a scientific direction. Classification, establishment of the equivalence of objects, systems allows solving such important problems of informatics as fixing knowledge, searching by pattern, comparison, etc.

Example. Such systems are the classification system of K. Linnaeus in botany, the systematics of living organisms, the table of elements of D. Mendeleev, the systematics of economic systems, mechanisms, the "table of ranks" introduced by Peter the Great in 1722. This table subdivided ranks into 14 ranks. Each rank corresponded to a certain position. The first 6 ranks of state and court services and the first chief officer rank in the army gave the right to receive hereditary nobility, which contributed to the formation of a noble bureaucracy. Thus, the "table of ranks" carried out the socio-economic classification of a certain (determining) part of society, the socio-economic stimulating ordering.

The above classification systems are hierarchical structures (models) of knowledge representation. Separate concepts, facts, knowledge are interconnected by relations of inductive (from the particular to the general), deductive (from the general to the particular) or inductive-deductive inference and are formalized by the corresponding formal structures: tree-like, morphological, relational, etc.

Example. Consider the Firm system. Let us describe all employees of the company in a lexicographically ordered list with the name "Employees", indicating the personnel number, full name, year of birth, education, specialty, category, length of service. This list gives us knowledge about the team, its age and professional qualities, etc. Let's make another list – "Salary", where we will indicate for each employee the terms of payment, the amount of their earnings (the cost per unit of their work time). This list gives us knowledge about the system of payment of the company, its financial condition, etc. Both lists contain the necessary amount of knowledge about the labor collective, if the purpose of studying this system is payroll. Here we observe tree-like, morphological, and relational models of knowledge representation.

For a more rigorous formalization of (complex and dynamic) knowledge, such promising tools as categories and functors have recently been used. However, the mathematical complexity of such an apparatus does not allow it to be applied at the initial stages of formalization of knowledge, and it is more often used only when knowledge has received a sufficiently complete mathematical form of description.

3 Category and functor

The emergence and development of object-oriented technologies and object-oriented design, using ideas similar in spirit, nevertheless, actualize the apparatus of categories and functors, therefore, we will introduce the basic initial concepts.

Category $K = \langle S, M \rangle$ is a collection of S elements (components, characteristics, parameters, properties and other parameters of the system under study), called objects of the category, and a collection of transformations, morphisms M - a special type of transformations that allow you to describe (define), for example, equivalence, invariance and other properties. Objects and morphisms are related to each other so that:

1. *each ordered pair of objects $A, B \in S$ is associated with a set $M(A, B)$ of morphisms from M;*
2. *each morphism $m \in M$ belongs to only one of the sets $M(A, B)$;*
3. *in the class of morphisms M, the law of composition of morphisms was introduced: the product $a°b$ of the morphism $a \in M(A, B)$ and the morphism $b \in M(C, D)$ is defined and belongs to $M(A, B)$ if and only if the object $B \in X$ coincides with the object $C \in X$, and the composition of morphisms is associative: $(a°b)°c = a°(b°c)$;*
4. *each set $M(A, A)$ contains the identity or identity morphism I_A: $\forall\, a \in M(X, A)$, $\forall\, b \in M(A, Y)$, $\forall\, A, X, Y \in F$, $\exists\, I_A$: $a°I_A = a$, $I_A°b = b$.*

Categories, their use for representing knowledge are adequate to human mental procedures that take into account experience, intuition, understanding of the world in terms of categories, to which we then assign real shells, concrete structures. Objects of a category can be related to each other, influence each other, even if they have no general (formal) similarity, and the properties of categories reflect the essence of a person's abilities, his behavior in the environment.

A functor is a generalization of the concept of a category. To introduce a transformation between categories, we use the concept of a functor. A functor is an analogue of a semantic operation, i.e. transformation of information leading to the appearance of some semantic (semantic) content.

The functor is defined by a pair of mappings that preserve the composition of morphisms and identical mappings (preserve the meaning of information under transformations): one mapping transforms objects S (roughly speaking, information), and the other transforms morphisms M (roughly speaking, semantic meaning).

The most poorly formalized process in computer science is the process of the formation of semantic meaning. The strict mathematical basis of the apparatus of categories and functors allows us to study the semantic meaning mathematically correctly (by building semantic networks, analyzing frames, production rules, etc.), which is a necessary condition for formalizing knowledge, developing knowledge bases and intelligent decision support systems.

The categorical functorial approach to the problem of knowledge formalization allows one to formalize many intuitively used concepts.

Example. Let's formalize, for example, the concepts "formula", "theory". Formula F_i is a notation of the form $R_i(k)$ (x_1, …, x_k), which should be read as follows: k variables x_1,:, x_k satisfy the relation $R_i(k)$. Each i-th formula F_i can contain a different number of free (unbound) variables. The concept of "(formal) theory" can be defined as a tuple T = <S, F>, where S is the signature (the set of defined, permitted operations), and F is the set of formulas without free variables (the axioms of the theory). If the set of inference rules P is additionally defined, then T = <S, F, P>. This shows that the formal theory is based on a specific subject area defined by a signature.

For computer representation and processing of knowledge and data about the subject area (about objects, processes, phenomena, their structure and relationships), they must be formalized and presented in a certain formalized form.

With the traditional method of implementing a mathematical model, the knowledge embedded in it, a modeling algorithm (modeling program) is built, i.e. knowledge procedurally depends on the processing method (algorithm). In intelligent systems (in artificial intelligence systems, in particular), knowledge about the subject area is presented in the form of a declarative (descriptive) model of the formation of a knowledge base and the corresponding inference rules from it and clearly does not depend on the procedure for their processing. For this, special models of knowledge representation are used, for example, production, frame, network and logical. When processing a knowledge model, inference procedures are used, also called an inference engine or engine. Usually, the knowledge base contains general patterns, rules describing the problem environment and subject area.

Inference procedures allow, based on general rules, to derive a solution for a given specific situation, described by some initial data. The inference chain is built as we approach the solution, depending on the data deduced at each step and new knowledge deduced to this step. The specific forms of organizing deductive inference depend on the form in which knowledge is presented in the knowledge base (in which language of knowledge representation).

4 Production model

The production model of knowledge representation is most common in applications. The model is implemented by production rules:

if <condition> then <conclusion>.

Any set of judgments connected by logical connectives and (⋀) or (⋁) can act as a condition.

Example. The production will be the following rule:

if (rate\dollar-increases) ⋁(season-autumn) ⋀(number of\sellers-decreases) then (forecast of prices in the housing market – growth of tenge prices for apartments).

This kind of rules and knowledge about prices, supply and demand in the housing market can become the basis for a knowledge base about the housing market and an expert system for a real estate group (firm).

There are two main inference strategies for a set of production rules:

1. *direct inference (inference from the initial data-facts, axioms - to the goal, along the way of inference replenishing the original knowledge base with new obtained true facts; the process ends only when a fact equivalent to the desired one is derived);*
2. *inverse conclusion (inference from the target fact to the data, at the next step the next fact is found, the final part contains a fact equivalent to the original fact; the process ends when for each fact derived at the next step no rule is found that has this fact in as a conclusion, and the premises are the initial facts or facts deduced in the previous steps).*

Both of the above withdrawal strategies have disadvantages, advantages, and modifications.

Example. If the entire set of production rules is divided into groups according to some attribute (structured), then instead of a complete or random enumeration of all the rules with direct and reverse inference, a purposeful transition from one group of rules to another is carried out. Mixed withdrawal strategies are also used, combining forward and backward withdrawal.

Production models are convenient for representing logical relationships between facts, since they are more formalized and rather rigorous (theoretical), modular (products are clearly not related to each other, therefore they can be modified using modular technology), correspond to a person's long-term memory.

5 Semantic web

Knowledge representation in the form of a semantic network is one of the main models for knowledge representation.

A semantic network is an oriented graph structure, each vertex of which displays some concept (object, process, situation), and the edges of the graph correspond to relations such as "this is", "belong", "cause", "enter into", "consist of "," to be like "and similar between pairs of concepts. On semantic networks, special inference procedures are used: network replenishment, property inheritance, pattern search, etc.

Example. Consider the fact: "the reason for the irregular work of the enterprise is the old equipment, and the reason for the latter is the lack of working capital". The semantic network can contain the vertices "circulating assets", "old equipment", connected by edges – relationns of the "cause" type.

The advantage of semantic networks is the visibility of the presentation of knowledge, with their help it is convenient to represent the cause-effect relationships between elements (subsystems), as well as the structure of complex systems. The disadvantage of such networks is the complexity of the output, the search for a subgraph that matches the query.

A characteristic feature of semantic networks is the presence of three types of relationships:

1. *class – class element (part – whole, class – subclass, element – set, etc.);*
2. *property – value (to have a property, to have a value, etc.);*
3. *example of a class element (element for, element for, earlier, later, etc.).*

6 Frame model

The frame model of knowledge representation sets the framework for describing a class of objects and is convenient for describing the structure and characteristics of objects of the same type (processes, events) described by frames – special cells (concept templates) of a frame network (knowledge).

The frame is a hub of knowledge and can be activated as a separate autonomous element and as a network element. A frame is a model of a quantum of knowledge (abstract image, situation), activating a frame is similar to activating this quantum of knowledge – for explanation, prediction, etc. The individual characteristics (description elements) of an object are called frame slots. Network frames can inherit slots from other network frames.

A distinction is made between sample frames (prototypes) stored in the knowledge base and instance frames created to display real-life situations for specific data.

The data frame representation is quite versatile. It allows you to display knowledge using:

- ✓ *frame structures – to designate objects and concepts;*
- ✓ *frame roles – to indicate role responsibilities;*
- ✓ *frame scripts – to indicate behavior;*
- ✓ *frame situations – to designate modes of activity, states.*

Example. Frame structures are the concepts of "loan", "bill", "credit". Frame roles – "cashier", "client", "server". Frame scenarios – "insurance", "banking", "bankruptcy". Frame situations – "evolution", "functioning", "unemployment".

Example. For example, let's take a concept like "function". Various functions may differ from each other, but there is a certain set of formal characteristics for describing any function (the "Function" frame): the type and the allowable set of changes in the argument (the scope of the function), the type and the allowable set of values of the function (the set of values of the function), analytical a rule for associating an argument with a function value. Accordingly, the "Argument", "Function Value", "Correspondence Law" frames can be defined. Next, you can define the "Argument Type", "Function Value Calculation", "Operation" and others frames. An example of slots for the "Law of Correspondence" frame: analytical way of setting a law; the complexity of the calculation (implementation). To describe the specific meaning of the frame, it is necessary to assign a specific meaning to each slot, for example, in this way:

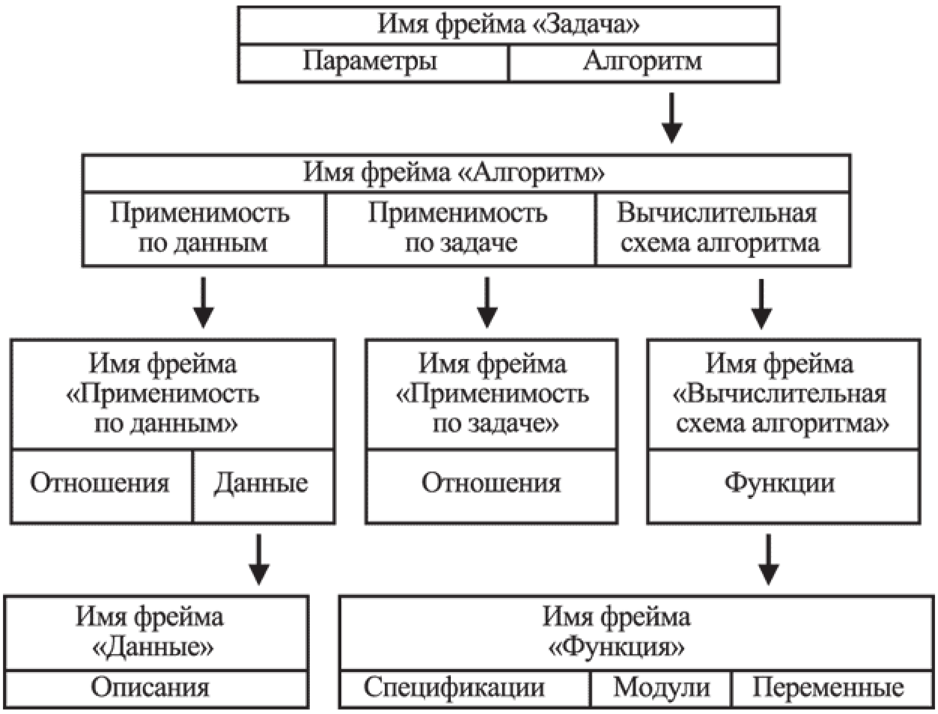

Figure 14.1. The structure of the frame "Problem of computational type"

Frame name - Function;
The argument is x;
Function value - y;
The correspondence law is quadratic.
Slots:
The argument values are R;

The way of defining the function is $y = ax^2 + bx + c$;

Computation complexity - 7.

Example. The frame "Problem of computational type" – in fig. 14.1.

The frame representation is visual and structured (modular) and allows you to get a description of the system in the form of related, hierarchical structures (modules – frames, knowledge representation units).

7 Logical model

The logical (predicate) model of knowledge representation is based on the algebra of statements and predicates, on the system of axioms of this algebra and its inference rules. Of the predicate models, the most widespread is the model of first-order predicates, based on terms (arguments of predicates - logical constants, variables, functions), predicates (expressions with logical operations). The subject area is described with the help of predicates and a system of axioms.

Example. Let's take the statement: "Inflation in the country is twice the last year's level". This can be written as a logical model: r(InfNew, InfOld, n), where r (x, y) is a relation of the form "x = ny", InfNew is the current inflation in the country, InfOld is inflation last year. Then one can consider true and false predicates, for example, r(InfNew, InfOld, 2) = 1, r(InfNew, InfOld, 3) = 0, etc. Very useful operations for logical inference - operations of implication, equivalence, etc.

Logical models are convenient for representing logical relationships between facts, they are formalized, rigorous (theoretical), for their use there is a convenient and adequate toolkit, for example, the logic programming language Prolog.

The domain model can be defined in a simplified way:

<domain model> = <conceptual knowledge> + <constructive knowledge>.

When implementing the above models, heuristics are used - empirical or semi-empirical rules, with the help of which an expert (expert group) in the absence of an algorithm (for example, a problem is poorly structured) tries to find a solution, simulating a possible course of the expert's reasoning based on heuristic information obtained as a result of experience, observation, collection and analysis of statistics.

Example. The collection of heuristic information from market representatives leads to the following knowledge, which can be represented, for example, by a semantic network or products:

1. *you need to advertise your product actively during the initial period;*
2. *need to raise prices in the absence of competition;*
3. *you need to lower prices in a highly competitive environment;*
4. *you need to try to be a monopolist in the market, etc.*

Many knowledge, especially those at the intersection of sciences, is difficult to formalize and describe by formal models, to investigate analytically. In such cases, heuristics are often used, heuristic procedures using analogs, the experience of searching for a new one, the study of related problems, enumeration of options taking into account intuition.

Example. These procedures teach the computer to play chess. The chess program is one of the earliest examples of non-computational computer applications. If in the 50s she “played” at the level of a “discharger”, then in 40 – 50 years she “learned to play” at the level of a world champion.

Conclusion

The basic models of knowledge, their structure, attributes, examples are considered.

Control questions

See the manual on the organization of students' independent work.