Intelligent Systems based on Notional Models

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Abstract. The article describes models, called notional models, which are based on primary mental abstractions: identification, generalization and association. The process of abstraction does not depend on any subject domain, but is determined only by the abilities of the cognizing human. A notional model consists of a notional structure and contents of notions. The notional structure describes each notion as a set of other notions united by one of the mental abstractions. The content of notion is described using various enumerating and resolving procedures. Using the primary mental abstractions allows increasing the level of model, developing an intelligent system, which requires performing a small number of base algorithms with a polynomial computational complexity. The refusal to describe associations in the form of links between concepts makes the notional model semantically invariant. This effect is because associations between notions are notions.

Keywords: mental abstractions, notional structure, notional model, knowledge representation, knowledge inference, intelligent system.

1 Introduction

By implementing modern intelligent systems, large companies expect to make decisions faster, discover hidden reserves and opportunities for the business, analyze the accumulated experience, and build forecasts based on identified regularities.

However, the actual return on intelligent systems is often much lower, and the implementation time and cost are higher than expected. There are many reasons for this, including those related to the inefficient management, the human factor, and outdated infrastructure.

There are significant disadvantages in the intelligent systems themselves. Many unresolved problems in the knowledge engineering and management make it difficult to implement intelligent systems effectively in practice [1, p. 15]. In particular, the extraction of knowledge is not a completely solved problem; forms of knowledge representation are poorly adapted to the mental and psychological characteristics of a person, the knowledge processing takes a long time and is subject to hidden contradictions.

Some of the existing problems were avoided by using notional models. Models are called notional to distinguish them from conceptual models. Conceptual models define concepts and various types of relations between them.

For example [2, p. 41], abstractions of the conceptual design are classification, aggregation and generalization, which is used for classifying primitive objects and building complex classes from them. For relation between classes is used the abstraction of association called the *n*-ary aggregation.

In the notional model, relations between notions are themselves notions [3]. The notional model is constructed by specifying the mental abstractions that formed the notion.

2 The notion of a notion

A notion is a kind of thought that relates to a certain set of unique representations (entities) of the inner or outer world of a person (subject domain). Notions are formed (defined) during the mental abstraction by performing mental operations on entities[1].

There are three types of notions and their generating abstractions: notion-signs (the abstraction of identification), notion-generalizations (the abstraction of generalization) and notion-associations (the abstraction of association).

2.1 Identification

Notion-signs are the result of the mental selection of unique representations in the subject domain and naming them. Notion-signs are formed to fix a certain state of

[1] A notion is an idea, a conception, an opinion, a vague view or an understanding of something. Notional is hypothetical, imaginary [4, p. 607]. A concept is a general notion, an abstract idea [4, p. 171]. Thus, unlike a concept, a notion is not objective; a notion is subjective.

feelings or elementary abstract ideas. When forming a notion-sign, the entity is mentally replaced by a sign, by another unique representation, by name for example (one-to-one correspondence). Hence, it follows that any entity is a notion. The opposite is also true.

Example 1. Examples of notion-signs are such notions as Green, Sour, One, Many, Love, etc.

2.2 Generalization

Notion-generalization is formed when entities of generalized notions are united (the union of the sets of entities). The abstraction of generalization is used to form notion-type that is a union of notion-signs[1]. Note that all entities of generalized notions are entities of a notion-generalization. The generalization has an inverse abstraction called specialization.

Example 2. An example of the notion-generalization is the notion of Fruit, which is the result of union the entities of such notions as Apple, Pear, Peach, Apricot, etc. In turn, notion of Apple is one of specializations of the notion of Fruit.

Example 3. An example of the notion-type is the notion Number, which is the union of notion-signs 1, 2, 3, etc.

2.3 Association

Notion-association is formed when entities of associated notions are joined, i.e. when each entity of the notion-association includes one of the entities of the associated notions (a subset of the Cartesian product of the sets of entities). Note that not all combinations of entities of associated notions can be entities of a notion-association[2]. The association has an inverse abstraction called individualization.

Example 4. An example of the notion-association is the notion of User, which joins such notions as Name, Gender, Phone, E-Mail, Login and Password. In turn, the notion of Phone is one of individualizations of the notion of User.

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[1] A special case of generalization is a classification that unions the same entities.

[2] A special case of association is an aggregation, in which all combinations of entities belong to the notion-aggregation.

3 Notional Analysis

Notional analysis consists in identifying notions and their abstractions that are used to describe a given subject domain. Abstractions of identification, association and generalization used in notional analysis are considered as mental operations necessary and sufficient for the mental isolation and transformation into notions of existing representations from the described subject domain.

3.1 Problem areas

In the process of notion analysis, one or more problem areas are identified. A problem area is a subject domain considered in some narrow aspect, from the point of view of some active problem. The same notion in different aspects (in different problem areas) may have different descriptions[1].

Example 5. The notion of Project in the first aspect characterizes a project in the managerial sense: the start date, end date, budget, attracted resources, etc. The notion of Project in the second aspect characterizes a project in the technical sense as an artifact (an object of artificial origin). The notion of Project in the third aspect characterizes a project in the activity sense as a work program. More aspects of project see in [4, p. 715].

3.2 Notional structures

The purpose of the notional analysis is to obtain the notional structure of the subject domain. The notional structure defines the names and aspects of notions, their abstractions, and the sets of notions that these notions are defined (notion attributes). The name of the notion without specifying the aspect defines a collective notion (a notion-generalization) that union all the specializations of this notion in the subject domain with various aspects[2].

3.3 Notion attributes

Any notion has a common attribute of Title – the notion identifier, a common attribute

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[1] Since the notion assumes a subjective reflection of the subject domain, it provides a plurality of descriptions of the same notion in different aspects. This allows us to objectify the notion in its collective (general) form.

[2] Generalization of similar notions can be used as a concept.

of Aspect – the identifier of the problem area, as well as a common attribute of Abstraction accepting entity of Sign, Type, Generalization and Association. Private attributes of notions are notions, which are determined as the result of the subject domain analysis.

Example 6. Consider the notional structure that describes the staffing of a company. In this structure, there may be such notions as Trainee, Employee, Position, Division, Vacancy (notion-generalizations of Trainee and Employee) and Staff (notion-associations of Division, Position and Vacancy). Here, Trainee and Employee are private attributes of Vacancy; "Vacancy" is the entity of Name, Generalization is the entity of Abstraction. And so on.

4 Notional models

A notional model consists of a notional structure and a description of the entities of notions using enumerating and resolving procedures.

4.1 Schemas of notions

The notional structure of a subject domain consists of schemas of notions. A schema of notion is an ordered set of notional attributes. The first three elements of this set are Title, Aspect, and Abstraction that are common attributes to all notions. Then follow private attributes of the notion.

Example 7. The notion of the staffing from Example 6 has the schema (Staff, Common, Associations, Division, Position, Vacancy), where Staff is the entity of Name; Common is the entity of Aspect; Associations is the entity of Abstraction; Division, Position and Vacancy are entities of Notion. Note that Title, Aspect and Abstraction are also entities of Notion.

4.2 Entities of notions

In intelligent systems, values of simple data types are used as notion-signs: numbers, characters, strings, etc. Simple data types themselves are considered as build-in notion-types: Bit, Integer, Float, Character, String, Binary, etc.

Notion-types of the subject domain have no private attributes. These notions are created as tables with a single field of Title. For example, such notions as Abstraction and Aspect are subject notion-types.

Notion-associations are created as structures, aggregate or composite classes, associative relations (links), and database tables. Notion-generalizations are created as unions, generalizing classes, and queries for union data from database tables.

4.3 Updating notional models

The describing of solutions to applied problems over notional models are procedures (algorithms) consisting of three elementary operations on notions: creating, editing, and deleting.

The creation operation occurs when the notional model becomes more complex and consists of specifying the name, aspect and abstraction of a new notion, and a list of notion attributes.

The editing operation is used when you need to fill the notion with specific subject content. In this case, you can perform three possible actions on the entity: changing, deleting, and adding.

The deletion operation occurs in the case of reengineering the notional model and consists of changing the description of all notions whose definitions include the notion being deleted.

5 Knowledge processing

Knowledge processing requires a form of representation of knowledge and methods of manipulating it in order to imitate human thinking. Facts are used to represent knowledge, and inference rules are used for reasoning, which allow making inferences based on existing facts and obtaining new facts about existing or newly introduced facts.

5.1 Facts

Facts are true propositions with logical connectives AND ($\wedge$), OR ($\vee$), NOT ($\neg$), parentheses, and two types of elementary propositions: a predicate $N(E)$ of belonging of the entity E to the notion N and $N[E] \bullet V$, where $N[E]$ is a functor that returns the entity of the attribute N of the entity E, $\bullet$ is a sign of the relation that allowed between entities $N[E]$ and V (=, >, <, etc.).

A universal relation is the equality of entities, which is defined recursively: two entities are equal if and only if the sets of attribute entities of these entities are equal.

Other relations can be inherited from the notion-types used in the notional model.

Example 8. The notional model of the staffing from Example 6 might have the following facts: Vacancy(Trainee) – Trainee is a vacancy; Staff(X) – X is an entity of the staffing; Vacancy[X] = Employee – the vacancy of the staff position X is an employee.

5.2 Inference rules

Schemas of notions set rules of inference, and the notional structure is a formal theory that preserves the truth of all the consequences deduced in it.

From the scheme of the notion-generalization follows the inference rule, according to which the entity E belongs to the notion N if and only if this entity belongs to at least one attributes of the notion N.

From the schema of the notion-association follows the inference rule, according to which if the entity E belongs to the notion N then attributes of the entity E are attributes of the notion N.

Example 9. The notional structure of the staffing from Example 6 provides the following inference rules:

$$\text{Vacancy}(E) \leftrightarrow \text{Trainee}(E) \vee \text{Employee}(E); \qquad (1)$$

$$\text{Staff}(E) \rightarrow \text{Division}\{E\} \wedge \text{Position}\{E\} \wedge \text{Vacancy}\{E\}, \qquad (2)$$

where $\rightarrow$ ($\leftrightarrow$) is the (bidirectional) logic consequence, $N\{E\}$ is a predicate of the presence of the attribute N of the entity E and the belonging of its entity to the notion N, $N\{E\} \leftrightarrow N(N[E])$.

5.3 Reasoning

The result of any query to the knowledge base is a search for notion entities that meet a given condition, expressed as a fact. In reasoning, rules of (1) define the notions to be processed, and rules of (2) allow you to extract private attributes from the entity to verify the condition.

6 Knowledge base

Any knowledge base is a database that contains the notional model, as well as an inference mechanism that allows you to perform queries and acquire new knowledge.

The knowledge base implements a model of an open world, since inference monotony is disturbed due to the appearance of new facts.

6.1 Database

Any entity in the notional model is a record in a database table with a unique global identifier. Notion-types are implemented as built-in data types of a database management system.

Notion-associations are implemented as tables with fields corresponding to associated notions, and notion-generalizations are implemented as views that select entities from tables (views) of generalized notions.

Any notion is itself a notion and the same means are used to describe it as for applied notions. For this reason, inference rules are entries in a database table and point to attributes of notions that are themselves notions.

The kernel diagram of the intelligent system database is shown in Fig. 1, where presents four notion-tables: Abstraction, Aspect, Notion and Attribute. Each record of the tables is an entity that has the following common fields: Entity – the global unique identifier of the entity[1], Title – the collective name of the entity. The links between tables are foreign keys [5, p. 163].

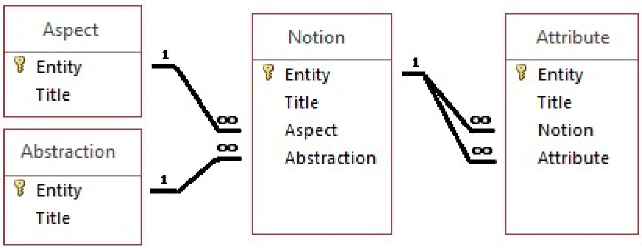

Fig 1. The kernel diagram of the intelligent system database

6.2 Queries

Any knowledge base query is a search for notion entities that match specified conditions for notion attributes. Queries are presented in the database query language.

[1] The global unique identifier consists of two parts: the first part is the record number in the current table; the second part is the number of the current notion in the notion table. This allows you to find out the notion of an entity by its identifier. In addition, the entity equality relation is quickly calculated by the equality operation of identifiers.

Note that the query execution time has a nice polynomial estimate, since the time to search for an entity depends asymptotically on the number n of records in the database table as n [5, p. 667]. Moreover, if the search is performed on indexed fields, the estimate is reduced to log n, where log is a logarithmic function [5, p. 601].

Fig. 2 shows a query form for searching for notion entities that meet the conditions set using the template on the right panel. The template is displayed after the pointer is set on the search node (the node with the binoculars icon). The template consists of a list of notion attributes with its searched entities. Note that these entities, separated by the # symbol, are the results of nested queries.

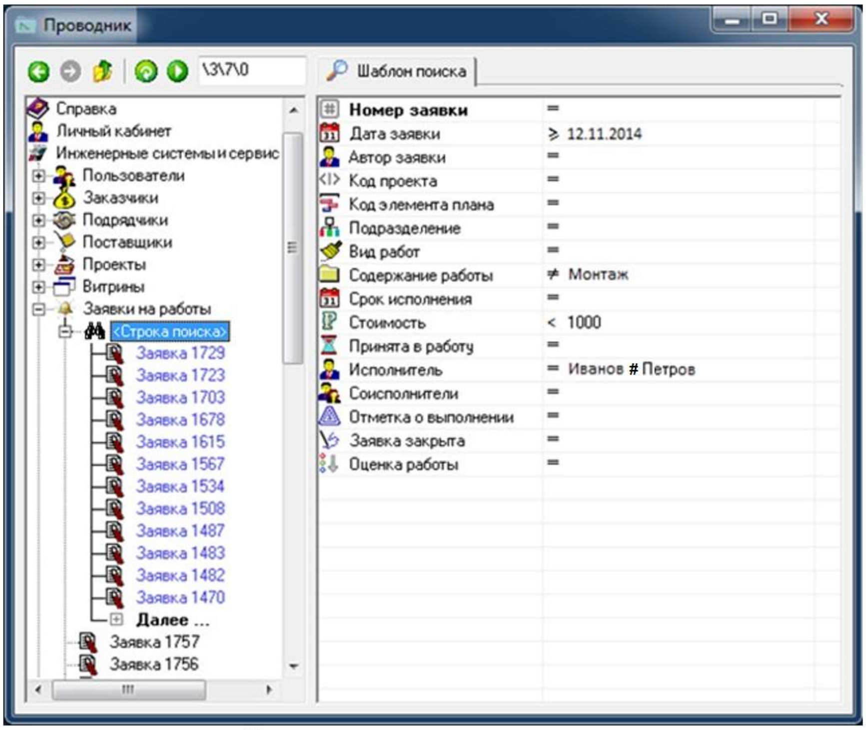

Fig 2. The query form of the intelligent system[1]

After setting the template, the intelligent system searches for entities that meet the specified conditions and displays as child nodes on the left panel (marked in blue). A simplified search for entities is performed after entering a string in the name of the

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[1] An example of intelligent system implementations is published with the permission of LANIT.

search node.

Trees on left panel (a forest) is a result of reasoning with some initial entity. Root nodes are notions that have the notion of initial entity as its attribute. Child nodes of the root node are entities that have the initial entity as the entity of the attribute. Then the procedure is repeated for each child entity of each displayed notion. In the process of reasoning, the user controls the display of notions and entities.

7 Conclusion

The fundamental difference between the considered approach for the representation and processing of knowledge is the use of another semantic invariant in addition to formal logic – the formal theory of notions. The refusal to describe associations as links between concepts makes the formal theory of notions semantically invariant (independent of subject domains).

The main difficulty in using notional models is the need to use a new methodology for analyzing the subject domain and a specific technology for representing and processing knowledge. However, the high efficiency, expressiveness and reliability of the implemented models of knowledge allow us to hope for their widespread implementation in the practice of creating and using modern intelligent systems.

The use of the intelligent system based on the notional model creates prerequisites for improving the transparency of business processes, reduces the risks of ownership of the intelligent system, and increases the company's investment attractiveness.

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