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PROBLEM OF CONSTRUCTING AN ONTOLOGICAL METAMODEL OF ITERATIVE GROUP METHOD OF DATA HANDLING ALGORITHMS

Introduction. *Data volumes are permanently increasing and some new approaches are needed for storage and processing them considering the development and improvement of modern computers. This puts forward new requirements to automatic data processing tools and intelligent systems for analyzing information with taking into account its semantics.*

The advantage of iterative group method of data handling (GMDH) algorithms is that they are able to work with a large number of arguments. The generalized iterative GMDH algorithm includes various former modifications of these algorithms. For example, algorithms of multilayer and relaxation types as well as varieties of iterative-combinatorial (hybrid) algorithms are diverse particular cases of the generalized one.

Metamodeling is the construction of generalized models of a certain group of objects (software tools, mathematical models, information systems). An ontological metamodel of the iterative GMDH algorithms was built using the Protege tools in order to structure knowledge in this subject area.

The purpose of the paper *is to analyze the developed iterative GMDH algorithms and propose an approach to structuring knowledge on iterative GMDH algorithms by building an ontological metamodel of this subject area.*

Results. *A retrospective analysis of the developed iterative GMDH algorithms is carried out in the paper, their advantages and disadvantages are indicated. It is shown that the generalized iterative algorithm, whose special cases are both known and new varieties of multilayer, relaxation and iterative-combinatorial GMDH algorithms, makes it possible to compare the effectiveness of various algorithms and solve real modeling problems. Based on the results of this study, an ontological metamodel of iterative GMDH algorithms has been developed.*

Conclusions. *Classic iterative GMDH algorithms allow processing large datasets. The generalized iterative algorithm allows forming typical architectures of previously developed modifications of these algorithms when setting up various operating modes of this algorithm. The construction of an ontological metamodel based on this one allows structuring knowledge on the available iterative algorithms making it possible to automate the design and use of specialized software tools for specific applied tasks.*

Keywords: *inductive modeling, GMDH, iterative algorithms, mathematical model, metamodeling, subject area, ontology.*

INTRODUCTION

The rapid development of modern systems and technologies puts forward new requirements for automatic data processing and intelligent systems for analyzing information taking into account its semantics.

Now there are new trends of supporting the processes of searching, processing and using knowledge for business: knowledge management, data management, data engineering, data mining, ontology building and many others.

The artificial intelligence technologies and intelligent computer systems are actively developing. The internal structure of such systems is a reflection of knowledge in the form of models of a subject area which are fed to the input of the system in a formal form.

Information semantic technologies based on ontologies make it possible to build applied systems for analyzing and modeling complex objects, systems and processes of various natures. To develop such systems, the results of structuring knowledge on a certain area of human activity are used helping to solve tasks of analysis and design of the structure of knowledge bases and functionality.

One of effective methods for constructing models of complex objects and systems based on observational data is the group method of data handling (GMDH) [1–3] built on the principles of induction, that is sequential generalization of partial phenomena (from specific to general ones). This method allows automatic finding unknown patterns of functioning of an object or process under study, information about which is implicitly contained in a data set.

An analysis of the subject area of inductive modeling will allow structuring knowledge on the main stages of this process, the data nature, applied methods and conditions of the effective use of the built models.

Ontological analysis explains the structure of knowledge and forms a conceptual dictionary as the basis of any knowledge representation system for a particular domain [4]. Such an analysis of the subject area is the first step towards the development of knowledge-based systems.

The purpose of the paper is to analyze the developed iterative GMDH algorithms, to propose an approach to structuring knowledge on these algorithms by building an ontology of this subject area, and to build an ontological metamodel of the algorithms.

THE TASK OF STRUCTURING KNOWLEDGE ON METHODS OF CONSTRACTING MODELS FROM EXPERIMENTAL DATA

Building models is one of prerequisites for creating artificial intelligence tools designed to identify knowledge in data for further analysis and processing, as well as forecasting and decision making.

Currently, hundreds of algorithms have been developed to obtain knowledge from data, but there are still many unsolved problems in the field of computer modeling and data analysis. Modern data mining packages contain numerous modules for collection and preprocessing, feature selection and construction, classification, approximation, optimization, pattern detection, clustering, visualization etc.

To identify knowledge that describes a particular subject area, their formalization is required. To do this, it is necessary to perform a detailed analysis of this area and to structure knowledge on the main stages of the processes which it is composed of, on the data nature, on methods used to process the data, and on the conditions of effective application of the resulting models.

In [4], the issues are considered on the role of ontology in the field of artificial intelligence research, the importance of their use for describing and structuring knowledge of a subject area. Ontological analysis clarifies the structure of knowledge, forms a conceptual dictionary as the basis of any knowledge representation system for a particular domain. The ontological analysis of the subject area is the first step to the development of efficient knowledge-based systems.

GMDH as a typical method of inductive modeling is an effective means of discovering knowledge from experimental data, which has proven itself over more than 50 years of application in various fields. One of fundamental varieties of GMDH is the class of iterative algorithms. The most known among them is the classical multilayer iterative GMDH algorithm. Nowday, a whole range of iterative algorithms have been developed, each of which has its own peculiarities. Based on these algorithms, a generalized iterative GMDH algorithm was developed [5, 6]. By adjusting its parameters, different special cases of iterative algorithms may be obtained. In order to structure knowledge on these algorithms and their tuning modes, it is planned to build an ontological metamodel of the iterative GMDH algorithms.

The design and development of intelligent computer technologies based on the creation of high-performance computing tools for inductive modeling in order to significantly expand the possibilities of building models of complex processes of various nature remains an important area of research [7]. The basis of it is the results of structuring knowledge of the subject area in order to design the appropriate structures of knowledge bases, functional support and intelligent interface tools. Therefore, it is necessary to analyze the subject area of inductive modeling, the main stages of the process of building models from data, the methods used and the conditions for their effective application, as well as the construction of ontological models of inductive modeling tools based on the performed analysis.

That is why the task was set in the paper to investigate the iterative GMDH algorithms and build their ontological metamodel to structure knowledge in this subject area.

METAMODELING. ONTOLOGY AS A METAMODEL OF A SUBJECT AREA

The prefix *meta* means a superstructure to some object. For example, metadata is data on data which is some additional generalized information about data. Metadata refers to data or information about information. Meta-knowledge in the field of artificial intelligence is a part of the knowledge base that defines the structure of data about the subject area. A meta-model in informatics is a model that describes another model i.e. transitive relations between models [8].

Metamodeling is the analysis of processes, the design and development of frames, decision rules, constraints, models and theories that can be applied to generalized models of intelligent software and information systems.

The term *metamodeling* is used to summarize the problems that arise in different areas at all stages: data collection, processing, object management for automation purposes, simplification and streamlining, in order to form a common structure that still has a certain level of flexibility and extensibility.

If we have a set of objects, we can build a model of each of them (objects of the same class, close to functions, but performing different operations), but it is better to build a generalized model or metamodel of this group of objects. Such a metamodel is a generalized model of this class, set or group of objects. When we modify this general model by some parameters, it will describe any particular object of this group.

The main question of metamodeling [9]: how to design the elements on which the metamodel is based? These features should combine characteristics of a data set and relevant aspects of the learning model. Such characteristics of a data set should not be limited to a simple enumeration of the number and type of attributes and the number of objects.

The concept of *metamodel* is closely related to the concept of *ontology* [10]. The purpose of modeling can be considered as an explicit description (in the form of structures and rules), that is as a model of a specific subject area.

Metamodels and ontologies are used to describe and analyze relationships between concepts, limit complexity, and structure information [11]. This is an explicit formalized description of how a domain-specific model is built. Typically, a metamodel is ontology but not every ontology can be explicitly presented as a metamodel. Ontologies are often distinguished by their level of generality from meta-ontologies (top-level ontologies) to the ontological domain and to applied ontologies.

The latter can describe a specific task, its structure, data types, restrictions etc., but they do not contain a specific implementation, they are not tied to software. This ensures the principle of interoperability which facilitates the use of formalized knowledge by many users in accordance with their goals.

In many areas, standard ontologies are being developed to formalize the basic concepts of the subject area and the relationships between them. They are used to analyze the subject area, define common dictionaries (thesauri) for sharing by specialists of specific domains and for annotating information in their area, facilitate its reuse, expansion by integrating several existing ontologies of one subject area [12].

In this article, we consider iterative GMDH algorithms in order to determine their general structure and constituent elements, describe rules of their application for the possibility of the automated use of this knowledge.

MAIN TYPES OF ARCHITECTURES OF ITERATIVE GMDH ALGORITHMS

A review and a comparative analysis of typical architectures of iterative GMDH algorithms are presented here. The classical multilayer iterative algorithm MIA [1] is the most widespread among them. As it is evident from the Fig. 1, it is of neural network type with some original features: parewise connections to nodes of any hidden layer; selection of best nodes on any layer; number of layers is not predefined.

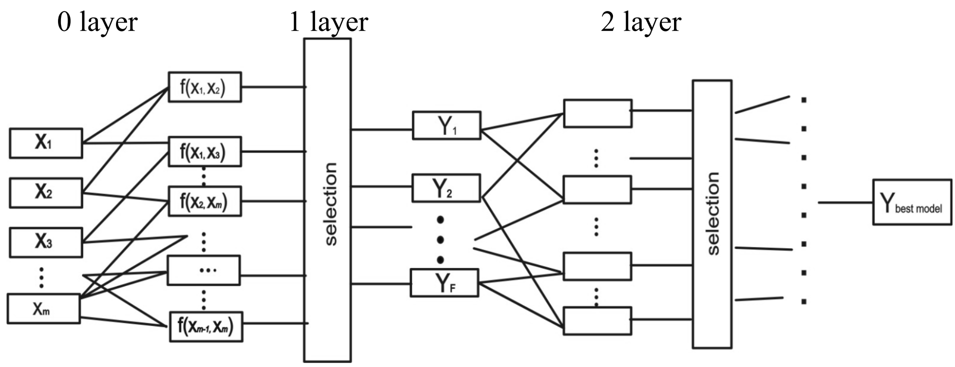

Fig. 1. Scheme of the classical multilayered algorithm (MIA)

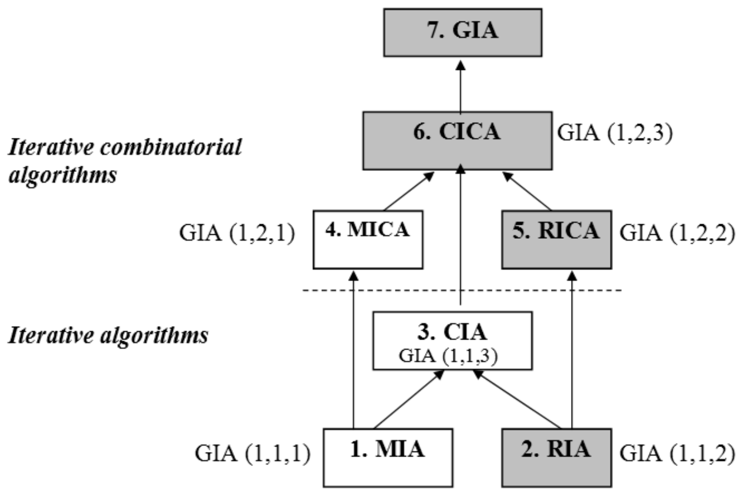

Fig. 2. Hierarchy of the developed iterative GMDH algorithms [13]

However, MIA has its own significant drawbacks: the possibility of losing informative and/or including non-informative arguments, exponential growth of the degree of the polynomial. To overcome these shortcomings, some modifications of MIA were implemented.

To date, seven standard implementations of iterative GMDH algorithms with different properties are known [13], schematically presented on the Fig. 2.

The first group of algorithms consists of the following iterative GMDH algorithms:

1) MIA – Multilayered Iterative Algorithm;
2) RIA – Relaxation Iterative Algorithm;
3) CIA – Combined Iterative Algorithm.

In each of the named algorithms, it is possible to apply combinatorial optimization of the complexity of transfer functions of the nodes; this can be abbreviated as *optimization of partial descriptions*. Then we get three new algorithms with the obvious common name *iterative-combinatorial* ones. Hence the second group of algorithms is iterative-combinatorial GMDH algorithms:

4) MICA – Multilayered Iterative-combinatorial Algorithm;
5) RICA – Relaxation Iterative-combinatorial Algorithm;
6) CICA – Combined Iterative-combinatorial Algorithm;
7) GIA – Generalized Iterative Algorithm.

Thus, the Generalized Iterative Algorithm (GIA) GMDH developed in [5] is a generalization of all six of the above algorithms.

In MIA GMDH, the problem of constructing an optimal model is solved inductively: models of a gradually complicated structure are built, and the process of complication has the character of iterations, when the best previous results are used in the next layer (iteration). The complication occurs according to a single rule, which allows building an arbitrarily complex model from a large number of variables (arguments) that characterize the modeling object.

RIA is a modification of the iterative algorithm MIA, in which pairs are formed from intermediate and initial arguments [14, 15]. Taking into account the primary arguments on each layer, this algorithm eliminates the possibility to lose informative arguments.

CIA is an iterative algorithm in which pairs are possible both from intermediate arguments and from intermediate and initial ones, so it combines the two previous ones, MIA and RIA.

To eliminate the disadvantage of the basic algorithm, namely the exponential growth of the polynomial degree, it was proposed in [16] to use an exhaustive search of variants of a partial model, the so-called MICA, described in detail in [3].

The RICA proposed in [17] makes it possible to improve the MIA GMDH generator of structures and obtain new variants that allow to not losing informative arguments that can be eliminated at previous stages of modeling.

CONSTRUCTION OF AN ONTOLOGICAL METAMODEL OF ITERATIVE GMDH ALGORITHMS

The complex developed in [18] can be called a metaprogram. It contains many variants of algorithms that generalize other algorithms and allow the author of the simulation to build his own algorithm from separately programmed modules of the complex, as well as compare the results with other algorithms and explore its properties.

It was shown in [19] that the successful solution of the problem of modeling complex objects, processes, and systems based on data significantly depends on the choice of an optimal method and, consequently, on familiarity with modeling methods. First of all, it is important for a data-driven modeling specialist who must decide which method will be most effective in a particular case, as well as for a user who wants to apply the available modeling methods.

Functional and interactive structures of an integrated set of tools for the study and application of modeling methods based on the observation data have been developed and implemented. Computer tools are designed for experimental discovery of knowledge about the comparative advantages and disadvantages of modeling methods and its components. The computer complex has the ability to use recurrent parameter estimates in order to increase the efficiency of modeling methods.

In [5], a generalized iterative algorithm for inductive modeling was developed. This is one software product, which in its structure contains seven different software products with various properties, and this product is a metamodel of the GMDH iterative algorithms.

The software structure described in [20] is built on the principle of metamodeling and is intended for the implementation and launch (execution) of several GMDH algorithms. A key component of the software structure that distinguishes it from libraries of aggregated functions/methods is the kernel, which is implemented in accordance with the object-oriented paradigm.

In [21], the problem of metamodeling is considered as one of the problems of artificial intelligence. The author used methods for solving such specific tasks as: estimation of parameters of nonlinear transfer functions by gradient methods; development of heterogeneous nodes using genetic algorithms with niching schemes; inductive choice of optimal models of the GMDH multilayer measure using external criteria based on partitioning a given data set; improving the ability to generalize the network system by combining multiple models; visualization of useful properties of multidimensional processes due to evolutionary search based on genetic algorithms with special fitness functions.

The study of the classical multilayer iterative GMDH algorithm and its modifications showed that if to structure the knowledge about these algorithms in one ontological metamodel, this will allow to implement such a metamodel once and get results using different algorithms, setting up its various parameters.

Let us first consider the architecture of the generalized iterative algorithm GIA GMDH [5] based on various modifications of the classical iterative GMDH algorithm. For further development of architectures of iterative algorithms, the following ideas are introduced here [22]: selection of primary arguments (addition on each layer of initial arguments) and implementation of combinatorial optimization of the structure of particular models. The idea of optimization [23] means that each neuron implements a sorting or other GMDH algorithm.

The hybrid architecture of the GIA algorithm developed in [24] provides its new properties: restoration of informative arguments sifted out at the first stages of the algorithm, elimination of non-informative arguments remaining at the first stages, avoidance of “degeneration” (repetition) of the structures of partial models. Thus, it is possible to generalize the main structures of the previously developed iterative GMDH algorithms and simultaneously obtain their new variants. Fig. 3 shows the scheme of operation of the GIA GMDH [5].

The general scheme of the GIA GMDH architecture and, accordingly, the hierarchy of the main types of iterative algorithms built using the Protégé ontoeditor is shown in Fig. 4.

Each of the algorithms has its own peculiarities in these components. It is necessary to have a description of different options in one general ontological structure in order to be able to obtain different types of algorithms by combining them.

The main principle of ontological analysis is the generalization of the task at the top level and its detailing at the lower levels of the hierarchy. That is, the upper level defines the basic principle of building a model, and the lower ones determine the procedures and methods of forming a model.

The purpose of developing an ontological metamodel of iterative algorithms is to build such a software tool that will allow to automatically configure this metaprogram as a metamodel of iterative algorithms with defining an algorithm that is most adequate to a specific object by adjusting the control parameters.

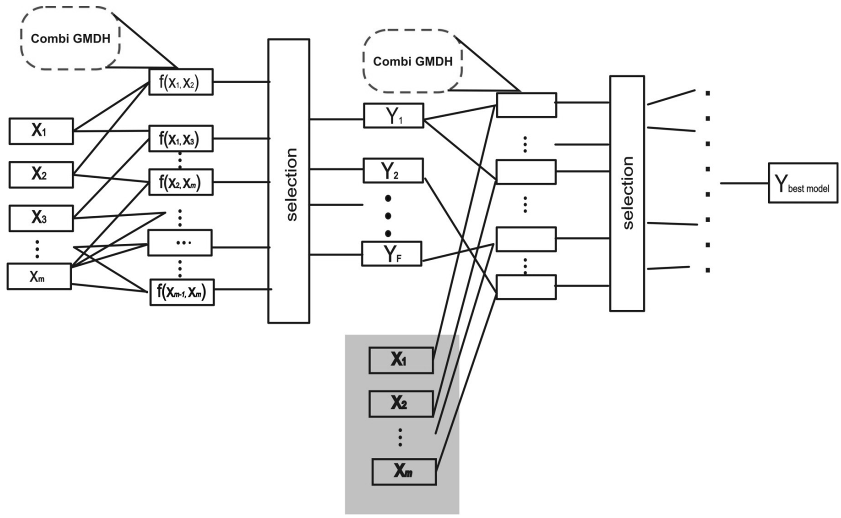

Fig. 3. Generalized iterative algorithm GIA GMDH [5]

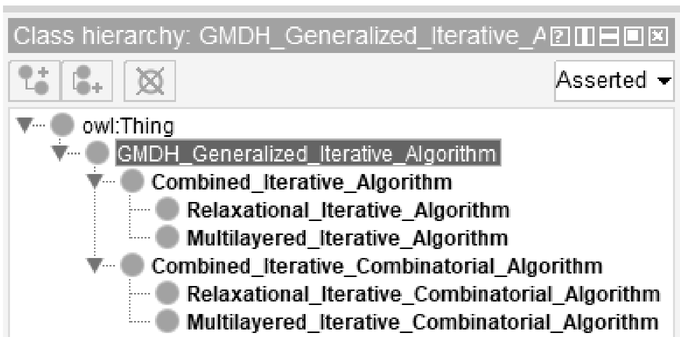

Fig. 4. Hierarchy of main types of the iterative GMDH algorithms

The software package that describes this generalized iterative GMDH algorithm can be called a metaprogram that generalizes many algorithms and allows the author of the simulation to build his own algorithm from the programmed modules of the complex, compare the results with other algorithms, and explore its properties. In fact, this is one software product, which in its structure contains seven different software products with different properties, i.e. this software product is a metamodel of iterative GMDH algorithms.

CONCLUSIONS

The article considers the problem of constructing the ontological metamodel of the iterative GMDH algorithms allowing to automatically discover dependencies in data with minimal user intervention.

In order to generalize the knowledge on iterative GMDH algorithms, a review of their typical variants was performed which showed that the advantage of these algorithms is that they allow working with large data samples, since their basic peculiarity is the pairwise consideration of input variables.

The review showed that the generalized iterative algorithm GIA GMDH can be called a metamodel of iterative ones since it includes all previously developed their variants. Building a metamodel of iterative algorithms allows generalizing knowledge on the main stages of the process of building models from data, the methods used and the conditions for their effective usage.

The formed knowledge on iterative GMDH algorithms is organized in the ontological metamodel built by means of the tool Protege.

It is planned to develop in future a concept and modeling tools based on the inductive approach which will allow transferring the principles have worked out in the field of inductive modeling to solving metamodeling problems. This will allow automating the process of designing software tools for efficient model building, taking into account in the form of an ontological metamodel the experience gained in the development and application of inductive modeling algorithms.

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ПОБУДОВА ОНТОЛОГІЧНОЇ МЕТАМОДЕЛІ ІТЕРАЦІЙНИХ АЛГОРИТМІВ МЕТОДУ ГРУПОВОГО УРАХУВАННЯ АРГУМЕНТІВ

Вступ. Обсяги даних постійно збільшуються і для їх зберігання та оброблення потрібні нові підходи з урахуванням розроблення та удосконалення сучасних комп’ютерів. Це висуває нові вимоги до засобів автоматичного оброблення даних та інтелектуальних систем аналізу інформації з урахуванням її семантики.

Перевагою ітераційних алгоритмів методу групового урахування аргументів (МГУА) є те, що вони працездатні за великої кількості аргументів. Узагальнений ітераційний алгоритм МГУА містить різні попередні модифікації цих алгоритмів. Наприклад, алгоритми багаторядного та релаксаційного типів, а також різновиди ітераційно-комбінаторних (гібридних) алгоритмів є різними окремими випадками цього узагальненого алгоритму.

Метамоделювання — це побудова узагальнених моделей певної групи об’єктів (програмних засобів, математичних моделей, інформаційних систем). Засобами Protégé побудовано онтологічну метамодель ітераційних алгоритмів МГУА з метою структурувати знання в цій предметній галузі.

Мета статті — проаналізувати розроблені ітераційні алгоритми МГУА, сформулювати завдання побудови онтологічної метамоделі ітераційних алгоритмів МГУА та запропонувати підхід до структуризації знань про ітераційні алгоритми МГУА шляхом побудови онтології цієї предметної галузі.

Результати. Виконано ретроспективний аналіз розроблених ітераційних алгоритмів МГУА, вказано їхні переваги та недоліки. Показано, що узагальнений ітераційний алгоритм МГУА, окремими випадками якого є як відомі, так і нові різновиди багаторядних, релаксаційних та ітераційно-комбінаторних алгоритмів, дає можливість порівняльного дослідження ефективності різних алгоритмів і розв’язання реальних завдань моделювання. На основі результатів цього дослідження розроблено онтологічну метамодель ітераційних алгоритмів МГУА.

Висновки. Класичні ітераційні алгоритми GMDH дають змогу обробляти великі набори вхідних даних. Узагальнений ітераційний алгоритм МГУА уможливлює формування типовіх архітектур попередньо розроблених модифікацій цих алгоритмів під час налаштування різних режимів роботи цього алгоритму. Побудова онтологічної метамоделі на його основі дає змогу структурувати знання про наявні ітераційні алгоритми, що забезпечує можливість автоматизувати конструювання та використання спеціалізованих програмних засобів для конкретних прикладних завдань.

Ключові слова: *індуктивне моделювання, МГУА, ітераційні алгоритми, математична модель, метамоделювання, предметна область, онтологія.*