UDC 004.051 : 004.451.35 : 519.683.4

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KNOWLEDGE DIAGNOSTICS BY SEARCH METHODS IN THE SEMANTIC SPACE

The article proposed the use of semantic space to describe of knowledge as a system object. The hypothesis of a threshold nature of knowledge is formulated. A bisection method is adapted to be used in border search problem in an answer space. It is marked a series of operations to improve the reliability of a remote knowledge diagnostics results.

Keywords*: distance education, semantic search, knowledge diagnostic*

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ОЦЕНИВАНИЕ ЗНАНИЙ МЕТОДАМИ ПОИСКА В СЕМАНТИЧЕСКОМ ПРОСТРАНСТВЕ

Предложено использование семантического пространства для описания знаний как системного объекта. Сформулирована гипотеза о пороговом характере знаний. Адаптирован метод деления пополам для использования в задачах поиска границ на поле ответов. Отмечен ряд операций для повышения надежности результатов дистанционной диагностики знаний.

Ключевые слова: *дистанционное образование, семантический поиск, оценка знаний.*

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ОЦІНЮВАННЯ ЗНАНЬ МЕТОДАМИ ПОШУКУ У СЕМАНТИЧНОМУ ПРОСТОРІ

Запропоновано використання семантичного простору для опису знань як системного об'єкта. Сформульовано гіпотезу про пороговий характер знань. Адаптовано метод поділу навпіл для використання в задачах пошуку границь на полі відповідей. Відзначено ряд операцій для підвищення надійності результатів дистанційного діагностування знань.

Ключові слова: *дистанційна освіта, семантичний пошук, оцінювання знань.*

Introduction The remote education acquires greater popularity in the modern fleeting world. The controlled from distance studies could save a time by excluding the personal contacts of teacher and student, diminishes costs for educational areas rent, allows to take exercises in suitable for a student time.

The process of studies can be conditionally divided into two stages: transfer of knowledge (mean teaching) and knowledge quality measuring (diagnostic or grading). Let's concentrate on second from the adopted stages.

Obtained knowledge quality diagnostics in remote education should be maximally automated, without experts (teachers) intervention in the process. In such process become actual the problem of evaluation methods unification for the different areas of knowledge, in that pulled out fundamentally different requirements to the evaluation criteria.

The problem of automated knowledge evaluation separates in a different direction of researches.

In the same time, one can meet the cases when knowledge diagnostics systems (or subsystems) could not be even distinguished as separate module of the educational complex. In such complexes the knowledge diagnostics bases on the answers for separate questions or problems solutions that are estimated by criterion "right / wrong". A final grading is folded as certain mean result of answers. General structure of knowledge, its integrity and inner bounds in the similar systems having not be analyzed.

Consequently, a problem could be found in a fact that for most remote education systems different approaches are used both for the criteria of evaluation and for the methods of result calculation. It could be posted that in such systems missed the analysis of inner knowledge structure and used only quality of answers for a separate questions.

The problem

In most modern information systems and especially in the remote education systems for the knowledge quality evaluation is used the analysis of answers for the questions set or tasks – by tests [e.g. 1–2].

A final result of knowledge quality estimation comes forward as a mark or grade. The simplest method of mark calculation is to take mean value of answers results [2–6]. The necessity of one resulting value for the mark stipulates different approaches to forming the value [7–8]. Concomitant problems consist of automations of evaluation process [9–10] and increase objectivity of mark [11–13].

The main feature of aforementioned methods of knowledge diagnostics is using in the mark calculation process answers for separate questions, but not knowledge as a system.

From one side, knowledge come forward as a form of existence and systematization of cognitive activity results, that allows them to be estimated by criteria "existence" and "systematizations". On the other hand, knowledge is the reflection of reality, Universe, so it is the system, with appropriated emergence.

Construction of mark as results of answers for separate questions is possible to consider a deductive method that only approximately gives the understanding of system by research of its separate constituents.

At the same time, more objective method for the system discovery will be inductive method, built on the analysis of the integral system.

In a present work it is shown the results of development a methodology of analysis of knowledge, as a certain system. It is carried out a way for construction of deductive methodology of knowledge quality analysis.

Definitions and hypothesis

In the work [1] semantic complexity for test questions were introduced. A few methods of final mark construction were offered taking into account the division of questions after semantic complexity.

For description of knowledge from certain thematic aspiration the semantic space will be used. Taking into account the use of developments in the education system, we will consider that knowledge is estimated from certain educational discipline that consists of a few thematic modules or themes. In underwritten without the loss of generality we will use term discipline for any area of knowledge, that is subject to diagnostics, term theme – for its semantic constituents term respondent – for a person which knowledge should be measured.

We will consider that themes, as separate discipline components, are semantically independent blocks that allow independent study, e.g., the component themes of discipline "mathematics" can be "algebra" and "geometry". Obviously, that independence of themes is relative. It is impossible to state that in geometry the conclusions of algebra are not absolutely used and vice versa. However, dividing of discipline into themes requires the introducing of relative independence criteria. In another case, dividing into themes seems to be at least inadvisable, from the semantic point of view.

The themes distinguished by such method form coordinate axes in the semantic space. Every point of the space $\vec{\xi}$ is determined by the set of coordinates

$$\vec{\xi} = (\xi_1, \xi_2, \ldots, \xi_n),$$

where n is an amount of coordinate axes. Coordinate ξ_i corresponds to projection of the point on a i-th axis and determines semantic complexity [1] of this point in a corresponding semantic theme.

Semantic space is description of certain educational discipline, as an independent field of knowledge, and fundamentally depends on character of discipline, its aspiration and thematic composition. Formally, it is possible to say about semantic space of certain field of knowledge or whole cognition, but such space will be enough multi-dimension so that, it produces the problems of co-ordinate axes selection, especially with the requirement of separate (independent) axes directions in the semantic understanding.

Every point of space is corresponds to a certain question, problem or task with certain semantic complexity. Completeness of task or answer for a question given by respondent is characterized by quality η [1]. Will consider an **answers field** to be a space a similar to semantic space in every point of which the quality of answer η is set.

Will consider a respondent **knowledge field** to be a part of answers field in that respondent gives the answers with necessary quality for a questions from this part of space ($\eta_{ans} \geq \eta_{\min}$).

Obviously, that the knowledge field depends on the minimal quality value as a parameter.

Will state **a basic hypothesis**: knowledge filed has a threshold character, i.e., has a sharp edge in the answer field. The hypothesis is equivalent to expression “it could be found a thing so that I know more simple things, but didn’t know more difficult things”.

The real answers field of respondent is, obviously, will not fully correspond to the terms of hypothesis. A respondent can give a high quality answer for the question with high complexity due to presence of separate knowledge exactly about this question. Sometimes occasional right answer could be passed without knowledge about it. In analogical cases, an incorrect answer is possible for the question with small complexity.

Right answers for single difficult questions should not be considered as a fact of presence of thorough and systematic knowledge in the corresponding part of semantic space. Similarly as single incorrect answers for simple questions should not be considered as a "free-space" in knowledge. Such points, in the terms of metrology, are the “appreciable errors” and must be eliminated from analysis. Some recommendations for eliminating of such points will be considered farther.

It is possible to consider that the task of knowledge quality diagnostics can be replaced by the task of border determination in answers field (or semantic space) using conclusion of the expounded hypothesis. It allows applying of the mathematical search methods in the knowledge quality diagnostics.

Semantic space metrics

For presentation of semantic space of certain discipline it is possible to use the Cartesian or polar (spherical, hyper-spherical) system of coordinates.

The Cartesian system envisages certain independence of co-ordinate axes and simplifies understanding of results treatment process. However for the author (authors) of the testing system process of question decomposition for thematic axes can be complicated. Also, for the question of maximal complexity ($\xi = 1$), that identically belongs to two themes the normalized vector will be $\vec{\xi}_{\max} = (1;1)$. Its module will be greater than 1: $\left|\vec{\xi}_{\max}\right| = \sqrt{2} > 1$, that complicates understanding of vector length as complexity measure.

The polar system of coordinates simplifies the questions preparation process because radial coordinate is considered to be a question complexity $\left|\vec{\xi}\right|$ and the polar angle (angles) is considered to be a semantic themes correlation degree. Vector length simply determines semantic complexity and exceeding of the rationed value 1 will not happen. Despite some difficulties dealt with vector processing, the polar system of coordinates is seems to be more convenient for knowledge quality diagnostics.

Will consider the semantic space to be either opened or closed. The **open space** envisages existence of points with arbitrary semantic complexity. The **close space** provides limits for semantic complexity of points.

Close space can testify to logical extremity of discipline content. Such space is expedient for "classic" disciplines with historically formed and relatively stable programs like algebra or mechanics.

Disciplines that correspond to actively developed sciences with frequently changed content require an open semantic space. In such cases a preference of open space allows to make operative changes in the semantic space follow the process of scientific search.

In any case open and close spaces are equivalent from the point of view of knowledge diagnostic procedure. In the moment of start of diagnostic programs semantic space, obviously, is formed, i.e., closed. In the process of scientific evolution this space can be changed (extended), but at the moment of next start it is possible to say about closed space.

On Fig. 1 two-dimensional semantic space is schematically presented in the polar system of coordinates. In shown space it is presented the edges of knowledge fields for different value of minimal quality $\eta_{\min}$. The minimal quality $\eta_{\min} = 0.9$ corresponds to mark "A" (or "perfect"), the value $\eta_{\min} = 0.75$ - "C" (or "good").

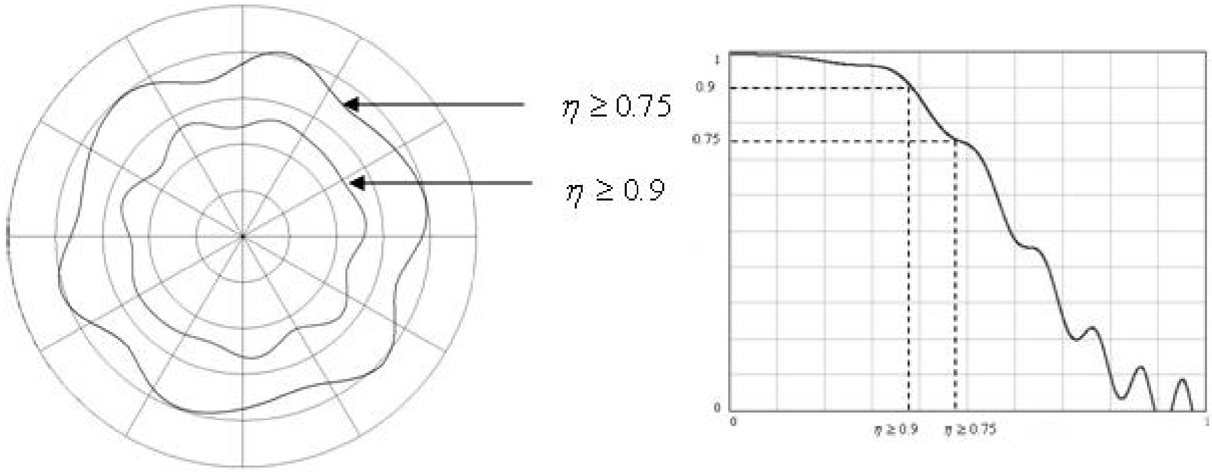

Fig. 1. Knowledge field edges for different value of minimal quality $\eta_{\min}$

Obviously, that knowledge field for higher $\eta_{\min}$ will be smaller. Because "perfect" knowledge includes "good" knowledge, it is possible to say that a difference of these fields is the area of "good" mark.

According to the entered determination for answers field for its forming it is necessary to ask a question (task or problem) to the respondent in every point of semantic space. For one-dimensional space it is relatively easy and could be limited by N=20-40 questions depending on final result desirable precise. The methods of work in one-dimensional space are described in [1].

In case of two-dimensional space it is necessary about $N^2 \approx 500$ questions. In spaces of higher dimension the number of answers exceeds all logical limits so knowledge diagnostics could not be realized for normative time that is taken on testing.

The main contradiction consists in that than higher dimension of space, the more integrity of knowledge shows up in it, the greater amount of points corresponds to cross-thematic questions that describe more real situations, than model questions with concrete (one-thematic) aspiration. On the other hand, than greater dimension of space, the greater amount of questions must be executed for filling answers field. From this side of view for a dimension of 3–4 number of questions will exceed the real limitations at times for the educational systems.

One of decisions of the marked contradiction follows from the basic hypothesis. It allows to avoid whole (point-by point) field filling, instead of answers field filling it is enough to define the knowledge field edge.

The methods of edge detection are actively investigated within the "computer sight" problem framework [e.g. 14–16]. In [14] it is considered a few search methods for shadow border detection at noise presence. In [15] the usage of wavelets for edge detection is shown. In [16] it is described one of the most widespread edge detection methods used in computer sight.

The marked methods have one fundamental defect from the point of view of the educational systems - they restricted by the used models and require own tuning - stable work parameters selection. Mainly, the described methods are used for concrete situations the change of that requires the repeated re-selection of parameters with experts' involvement. The use of such expert models within the educational systems requires additional researches and experiments with their tuning.

Alternatively, for the selected problem it is possible to use the methods of optimization and search [17]. In a mathematics they are developed for the search of extreme value of function, but can be used and for the search of other values.

Subsequently we will consider two groups of search methods: coverage methods and adaptive methods.

The coverage methods envisage the answers field filling in a few certain points.

Points can be inflicted by the certain method (linear or nonlinear) or randomly. A search consists in the analysis of values in these points and selection of necessary value. As it seems, exactly the coverage methods are used in most knowledge diagnostic systems in testing form. Both methods of points set forming are used as well [2–13].

We will discover the adaptive methods taking for basis the dichotomy as a method of optimization.

Consider that on the certain stage a respondent gave the answer of necessary quality. This fact testifies to belonging of semantic space point $\vec{\xi}_0$ that corresponds to the question to the knowledge field. Accordingly, points with less semantic complexity $\left|\vec{\xi}\right| \le \left|\vec{\xi}_0\right|$, due to basic hypothesis, also belong to the knowledge field. It is not necessary in future to choose such points.

In case of unsatisfactory quality of respondent's answer in a point $\vec{\xi}_0$ draws the conclusion about exiting outside the knowledge field and withdraw from further consideration an area with greater semantic complexity $\left|\vec{\xi}\right| \ge \left|\vec{\xi}_0\right|$. Correlation of areas with different complexity is illustrated on Fig. 2.

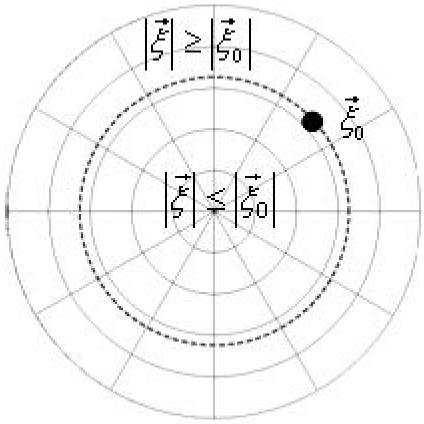

Fig. 2. Correlation of areas with different complexity related to point $\vec{\xi}_0$

After the analysis of each answer a part of space eliminates from consideration. A fragment that can be considered a knowledge field edge remains after multiple reductions of space. Edge thickness will be determined by the number of division procedures.

The maximal assured coefficient of semantic space radial reduction equal to ½ in a case when the $\vec{\xi}_0$ point is choose in the center of discovered space. Accordingly, after n iterations semantic space radial reduction will be equal to 2^n, that at $n = 10$ will be over 1000 times. It means that faithful usage of the described methodology with only ten questions (tasks) could estimate a respondent knowledge on a 1000-ball mark scale. If such precision is not necessary, the number of questions (tasks) can be diminished.

Features

For real systems additional attention should be devoted to the reliability of respondents' answers. As be marked higher, it is possible cases of faithful answer for the question of higher complexity (in comparison to the real knowledge level) and incorrect answer for a simple question. In such cases space reduction will result in irreversible distortions of the real knowledge field.

Some methods of the marked effect detection are shown below.

Firstly, the choice of point $\vec{\xi}_0$ can be substituted by the choice of several points that lie on a circle passed through the $\vec{\xi}_0$ point (dashed circle on Fig. 2). Knowledge quality should be controlled in a few points that belong to this circle. In a case of equal (identical) answers for two questions from a select circle it is possible to draw conclusion about inclusion $\vec{\xi}_0$ point into knowledge field. If answers for two questions are different an additional question (from the same circle) should be asked. As a result should be taken the result similar for pair of answers. In a case of large variation of quality values for three answers it is possible to draw conclusion about un-serious relation of respondent or about presence of auto-answered system. In any case selected point should consider to be excluded from knowledge field.

Secondly, it is possible to change the algorithm of space reduction. Elimination line, normally passed through the $\vec{\xi}_0$ point, could be passed behind or below this point. In a case of right answer in the $\vec{\xi}_0$ point from further decision eliminates a part of space in accordance with expression $\left|\vec{\xi}\right| \le (1-k)\cdot\left|\vec{\xi}_0\right|$ where k is a scale constant. If the answer is wrong, the expression will look like $\left|\vec{\xi}\right| \ge (1+k)\cdot\left|\vec{\xi}_0\right|$. A graphic analogy for described algorithm could be shown with a circle drawn with "fat line". Scale coefficient k describes a fatness of a line. Withdrawn space should be selected outside the line border.

In a case when line passes through withdrawn space the part of space could be returned to consideration. Such return will remove the effect of irreversibility caused by taking into account some error-points. A fatness of line could be adaptively changed with increase of result precision. Otherwise, the precision of edge detection could be limited by the constant line fatness.

Thirdly, it is necessary to pay additional attention to the process of question preparation. For example, it is recommended to avoid questions, quality of answers for that can acquire only two values (right / wrong). Exactly for such questions it is the easiest way to get a random answer. The detailed analysis and recommendations in relation to the process of question preparation require additional research.

Results

Basic hypothesis formulated in terms of semantic complexity allows resolving a contradiction related to high-dimension semantic spaces. The usage non-single dimension spaces allow to estimate knowledge integrity - the ability to solve problems of combined type, maximally closed to reality. In contradiction, the questions that belong to one theme, as a rule, are modeled and specially adapted for verification of knowledge exactly from a select theme.

The problem related to the necessity of plenty of questions is removed by questions sequence forming methodology. Instead of changes in results processing methods, the sequence of questions is varied, that allows consider the described methodology to be adaptive.

In an ideal case usage of described methodic allows exceeding a factor of 1000 in radial space reduction (edge detection) by a 10 questions sequence without dependence from space dimension. Taking into account the methods of results reliability increasing the number of questions in the sequence will not exceed value of 30. Described sequence could be simply realized without serious requirements to hardware and software of information system.

Conclusions

Introduction of semantic space is offered for knowledge description, as a system object. It is assumed that the high-dimension spaces allow estimating knowledge by its integrity and ability of respondent to decide the problems, maximally close to reality.

It is formulated a hypothesis about threshold character of knowledge in a semantic space. Knowledge diagnostic procedure is reduced to the edge detection problem.

The bisection method is adapted for the use in the edge detection problem in the answers field. Some methods of results reliability increasing are carried out. Discovered methods are indifferent to knowledge features and could be freely used for any educational discipline.

The prospects of further researches are seen in the comparative analysis of different edge detection methods and different semantic space metrics.

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Received 30.03.2012

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