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Stages of Knowledge Representation on the Example of the Typology of Interdisciplinarity: Philosophical Aspects

Rusyaeva E.Yu.*

* *V. A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences*
65 Profsoyuznaya street, Moscow 117997, Russia

(Tel: +79169358538; e-mail: rusyaeva@ ipu.ru, 1779624@mail.ru)

Abstract: It is suggested, when creating knowledge management mechanisms to avoid any extremes in their presentation: various "centrisms", hypertrophy in the use of both mathematical and verbal-meaningful knowledge. It is shown that it is important to observe the principle of "ethics of engagement ", which can be implemented on the basis of a productive interdisciplinary synthesis. The stages of knowledge presentation are considered on the basis of the typology of interdisciplinarity. It is argued that the stage of semantisation (conceptualization) of knowledge representation, when creating control systems, should be preceded by the stage of ontologization. It enhances the distinctiveness of knowledge representation. The stage of ontologization is necessary for the construction of more detailed explanatory constructions, due to the greater formalization of the ontological representation, in comparison with the stage of semantisation. It is assumed that the taxonomy stage can become the basis for the ontologization of knowledge representation, for example, in knowledge engineering.

Keywords: ethics of engagement, knowledge representation, typology of interdisciplinarity semantisation (conceptualization), ontologization and taxonomization stages

1. INTRODUCTION

The purpose of this work will be to substantiate the following thesis: when creating knowledge management mechanisms, it is necessary to adjust the sequence of stages of knowledge presentation. So, the stage of semantisation (conceptualization) of knowledge representation should be preceded by the stage of ontologization, since it increases the distinctive ability of knowledge representation. Therefore, for example, before developing the details of mathematical mechanisms and models, it is necessary to comprehend (semantise) ideas about this subject area and management situation. This will be a prerequisite for the development of effective governance mechanisms.

Indeed, a managerial effect that is optimal from the point of view of conceptually distorted ideas is unlikely to be optimal in reality. In a broad sense, the conceptualization of the subject area in general and the management situation in particular is reduced to the explication of ideas about them with varying degrees of formalization. If representations can already be considered as explicit, but the degree of their formalization is insufficient to transfer work with them to a computer program, then we can talk about conceptualization in the narrow sense of the subject area, or, in other words, about its semantisation. If the formalization is sufficient to convey the argumentation to the machine, then we can talk about the ontologization of the subject area.

Ontologization, in turn, can also be carried out with different depths. At a certain depth of conceptual research, taxonomization of the subject area plays a significant role - in other words, the study of key typologies of the subject area. We believe that the deeper the conceptual research was carried out on the line of semantisation (conceptualization in the narrow sense) - ontologization - taxonomization, the more effective - all other things being equal - will be the mathematical control mechanisms built "above" the system of representations formalized with such depth.

Now more than ever in science, the ethical principle of interaction is relevant, the basis of which is a constructive interdisciplinary synthesis, and not just a multidisciplinary joining of studies of one subject area. The typology of interdisciplinarity is given as an example of a hierarchical approach to the stages of knowledge representation, which is especially relevant when creating mechanisms for managing them.

2. CONCEPTUALISATION OF THE CONTROL SITUATION AND CONTROL MECHANISMS

It may seem that knowledge in control theory can be represented by a set of control models and/or mechanisms. However, it is possible to show that it is more correct to describe this knowledge in the form of conceptualized representations of a managerial situation, over which the models and mechanisms of control are built. This is quite consistent with the modern vision that has developed in the philosophy of science [1], when knowledge is semanticised, conceptualised representations, not just a set of models. Correctness of conceptualization is the basis, necessary (but not sufficient) condition for the development of effective control mechanisms.

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It is possible to show that knowledge is not reduced to a set of models, even nonmathematical models, as semantised, conceptualized representations are not reduced to models if models to understand in own, narrow meaning of this word. Distractedly philosophizing, it is possible to understand any idealized representation about something by model. But it seems to be an overly broad interpretation of this concept, because when a researcher uses the word "model" in his constructions, he often uses a narrower meaning, which is his own because of the frequency of use. Anyway, as the work [1] shows, the model is understood in practice as an isomorphism. Further, the work [1] convincingly shows that knowledge of any subject area will not be reduced to a set of isomorphisms, still there will be a significant "residue". In order to explicate knowledge about any subject area, in particular, about a managerial situation in its entirety, one should semantise and conceptualize representations about this subject area. And only a part of these formalized representations will be mathematical models.

3. FINITE AND INFINITE CONTROL MECHANISMS

The control mechanism can be represented as a function from a set of control objects in a set of control actions. Both these sets can be finite and infinite. The control mechanism, in which both the set of control objects and the set of control actions are finite we called finite control mechanisms. The rest of the mechanisms will be called infinite. For finite mechanisms a set of control objects and a set of managerial actions are more correctly interpreted as a set of classes of indistinguishability of control objects and a set of classes of indistinguishability of managerial actions respectively.

It is natural to assume that at the beginning of the design process of the control mechanism is the finite one: I.R. Prigozhin [2] wrote that the reality is seen by a man through the "window of finite width". Looking at the multitude of control objects and control actions through such a "window" will give us a small finite number of classes of indistinguishability of control objects and control actions, respectively. As additional information is attracted, the finite mechanism becomes infinite in its limit.

However, the disadvantage of infinite mechanisms is that their design and development will probably require an infinite amount of information, which is unrealistic. In spite of this, it is possible to assert that "traditional" control mechanisms are designed as infinite, and the scientific weight is given to them by the decision of the nontrivial problems of optimization establishing the best conformity between a control object and suitable for it control action.

Let's show that designing of infinite mechanisms is realistic only for simple control situations. By our definition, for simple control situations are known:

1. a significant characteristic of control objects, represented by the real number;

2. a significant characteristic of control action, represented by a real number;

3. a reasonable approach allowing to establish the law of correspondence between these two characteristics.

For complex control situations, one of the conditions is not met. For example, there is often a situation when we cannot collate the a significant characteristic represented by a real number of control objects with control action. In the conditions of current knowledge about the world, we can only set a small number of classes of indistinguishability of control objects and/or control actions. And between them to look for the law of correspondence.

Another variant of a complex control situation is that we think that we know the significant characteristics for both the object of control and the control action, represented by real numbers, but there are no reasonable considerations allowing us to directly establish the law of correspondence now and even in the foreseeable future. And the only way to establish a correspondence law is to link these characteristics indirectly. And those characteristics that act as intermediaries cannot be characterized by a real number, but can only be represented by a finite number of gradations.

For example, we want to manage the revenue of the innovation center through monetary incentives. Both revenue (object of control) and monetary motivation (control action) can be represented by real numbers. And it would seem that in order to get an optimal action (monetary motivation), we can extract roots, take logarithms or take any combination of known functions from the current and/or desired revenue of the innovation center. We can think up a mathematical puzzle here and solve it diligently. But in fact, there are no reasonable considerations as to which superposition of functions these two characteristics can be connected. It is not possible to link them directly. In order to feel the connection, we must determine the characteristics of the intermediaries. If we think about it, the revenue of the innovation center, depending on the motivational material incentives, is determined by the extent to which these incentives help to increase the readiness of developments for their practical application, to increase their maturity, firstly, and to increase the depth of interdisciplinary synthesis, and secondly. Apparently, higher values for a higher level of readiness of developments and greater depth of interdisciplinary synthesis will increase the revenue of the innovation center. These characteristics are intermediary characteristics between the two analyzed characteristics. But we already know that not only can we not evaluate these two intermediary characteristics by a real number, but even evaluate the number of gradations, 2-3 in number, is a serious scientific task. Consisting of nine parts Technology Readiness Level Scale [3] is a major breakthrough from NASA that has been in use for several decades [4].

4. THE PRINCIPLE OF ETHICS OF ENGAGAMENT AND INTERDISCIPLPNARY

The concept - ethics of engagement was taken by us from work [5] in the journal AI&, where it is applied in the sense of a rule for the study of a socio-philosophical plan. At its core, the very use of the word "engagement" denotes a deeper penetration, synthesis, than the usual notion of "interaction".

This reflects the tendencies of modern science and therefore, in the broader meaning of ethics as a general rule of application, it can be translated, in our opinion, to all types of research, not only the above-mentioned plan.

Following the understanding of the concept of a principle as a rule [6], we can consider the ethics of interaction as one of the leading principles in modern science. New knowledge is now obtained as a result of closer interaction between representatives of different disciplines in the subject field.

The very principle of ethics of interaction in science, its justification is the level of conceptualization in the representation of knowledge. So that it does not remain just a declaration, a call for the right action, a level of ontologization in the representation of knowledge is needed, which explains the concepts introduced and the sequence of "moves" in determining the systemic relationships between the components of the concept. That is, before the stage of semantisation (conceptualization) of knowledge representation, when creating control systems, there should be a stage of ontologization, which increases the distinctive ability of knowledge representation. On the basis of the order relation in the sequence, a typology is deduced, which is the level of taxonomization.

Let us demonstrate the indicated stages of knowledge representation using the example of the typology of interdisciplinary synthesis [7].

The relevance of an interdisciplinary approach in science today is obvious. But how to determine the level of interdisciplinary synthesis in research projects is far from a trivial question. Our task at the conceptual level is to increase the reproducibility and accuracy of determining the level of interdisciplinarity of research, which is proposed to be done in [7, 8] on the basis of a formal mathematical analysis of the interrelationships of the main components of the term under study.

The approach developed in [7, 8] allows us to draw conclusions about the level of interdisciplinarity of research: mono-, multi-, mezh- (we will indicate in transliteration, in order to avoid a similar name for the next level), inter-, trans- or cross- involved in a specific project. On the basis of formal mathematical analysis, it will be possible not only to more reasonably determine the levels of interdisciplinarity, but also to present a consistent typology of interdisciplinarity as a whole.

At the onlogical level, let us give the definitions of the introduced terms, as they are formulated in [7, 8]. Our approach allowed us to formalize the components that make up the semantic basis of the concept of “interdisciplinarity”. As the basic components, we have chosen quite conventional and / or unambiguously interpreted terms in science today: “well-established scientific discipline” (hereinafter “discipline”); The "subject" of the discipline; its "method", synthetic (generated) "new discipline", synthetic, "new method", "new subject"; A "project" that has a goal and objectives, for the solution of which it is precisely necessary to involve one or several scientific disciplines.

Discipline is an independent branch, a section of any science; branch of scientific knowledge; academic subject. Conventionally, we can assume that the discipline is determined by its subject and the methods used.

Method (synonym - method) is a way of achieving a goal, solving a specific problem; a set of techniques or operations of practical or theoretical assimilation of reality.

A project is a separate completed cycle of productive activity.

Next, we list the sequence of "moves" in defining the systemic relationships between the components of the concept of "* -disciplinarity":

1. Determine the relationship between method and subject within one established discipline. So, scientific research, for which one discipline is involved, determined by its subject and method, is monodisciplinary.

2. If several disciplines with their own subjects and methods are involved in solving some problems within the framework of the project, but the method of one established discipline does not apply to the subject of another well-established discipline, then we have a multidisciplinarity.

3. If during the interaction of disciplines in the course of a scientific project emergence arises between some components of both established and newly emerged synthesized disciplines, methods, subjects, then we have different levels of interdisciplinary synthesis of research.

In order to formalize the concept, consider four sets. Index t shows that the composition of the set changes, but the elements of the set do not chang.

Let us list the sequence of "moves" in defining the systemic relationships between the components of the concept of "* -disciplinarity" [8]:

1. The set of discipline methods $\mu_t = \{A, B, C, \ldots, N\}$.

2. The set of subjects of disciplines $\pi_t = \{a, b, c, \ldots, n\}$.

3. The set of scientific disciplines $\delta_t \subset \mu_t \times \pi_t$ (Cartesian product μ by π).

4. A set of scientific projects, each of which is: $\zeta_t = \{A_1a_1, A_2 a_2, A_3a_3 .., A_n a_n\}$.

$A_i \in \mu_t$; $a_i \in \pi_t$; $i \in N \{1, 2, 3, \ldots, n\}$.

Let's say: $\mu_t = \mu_{t-1} \cup m_1 \cup m_2 \cup \ldots \cup m_k$, where m_j - methods created during the project

$\pi_t = \pi_{t-1} \cup p_1 \cup p_2 \cup \ldots \cup p_l$, where p_j - items that appeared during the project

$\delta_t = \delta_{t-1} \cup d_1 \cup d_2 \cup \ldots \cup d_q$, where d_j - disciplines that have arisen in the course of the project.

Thus, the sets μ, π, δ can be characterized by a triple (k, l, q), and $q \geq \max(k, l)$.

Let's give definitions: q - the number of new disciplines; k is the number of new methods; l is the number of new synthesized research subjects; |ζ| - the number of disciplines in the project.

Table 1. Classification system of the concept of "interdisciplinarity".

	Number of disciplines used in the project> 1	Interaction of method and subject of different disciplines	Synthesis of a new subject	Synthesis of a new method
Monodisciplinarity	–	–	–	–
Multidisciplinary	+	–	–	–
Mezhdisciplinarity	+	+	–	–
Interdisciplinarity	+	+	+	–
Transcisciplinarity	+	+	–	+
Crossdisciplinarity	+	+	+	+

Let's define the order on such triples:

$(k_1, l_1, q_1)> (k_2, l_2, q_2)$ means by definition $(k_1> k_2) \vee (k_1 = k_2 \vee l_1> l_2) \vee (k_1 = k_2 \wedge l_1 = l_2 \wedge q_1> q_2)$, it represents is a lexicographic order.

For example: (2,1, q)> (1,2, q), (1,0, q)> (0,5, q)

If one discipline is involved in scientific research, then this level will be called monodisciplinary. :

Discipline Aa is determined by its subject and the method of monodisciplinarity, the only pair of method-subject belong to one discipline (and one project).

Here: $| \zeta_t | = 1, q = 0$. Formula of monodisciplinarity: $| \zeta_t | = 1, q = 0$

The level of research will be multidisciplinary, during which, to solve the problems of a certain scientific project ζ_t, scientific research of established disciplines that have their own objects and methods is involved. In the course of research, the methods of some well-established disciplines are not applied to the subjects of other well-established disciplines. Formula of multidisciplinarity: $| \zeta_t |> 1, q = 0$

We will consider the level of research in one project as mezhdisciplinary, while the method of one established discipline is applied to the subject of another established discipline, and a new synthetic discipline arises. Formula of mezhdisciplinarity: $q \geq 1, k = l = 0$.

An interdisciplinary (in a broad sense) method is the level of research when a new synthetic discipline B (a Bb) arises, and one established discipline to the subject a subject b of this new discipline. Formula of interdisciplinarity (in a broad sense): $l \geq 1, k = 0$.

The transdisciplinary level will mean that the method for solving problems is synthesized as a single one for the disciplines involved in the scientific project. That is, to solve the problems of the project, with the interaction of the established disciplines of the new synthetic field A⊙Ba (or B⊙Ab), a new method A⊙B arises, which is applied to the subject area of the established discipline Aa. Formula for transdisciplinarity: $l = 0, k \geq 1$.

The newly generated method can be applied to a new, emerging subject of Russian discipline, we will consider such a level of research, when a new synthetic method is applied to a new synthesized subject, they together form a new synthetic discipline. The formula of cross-disciplinarity: $l \geq 1, k \geq 1$.

The following levels of "interdisciplinary research" are obtained:

1. Monodisciplinarity $| \zeta | = 1, q = 0$

2. Multidisciplinarity $| \zeta | > 1, q = 0$

3. Mezhdisciplinarity ($q \geq 1, k = l = 0$

4. Interdisciplinarity $l \geq 1, k = 0$

5. Transdisciplinarity $k \geq 1, l = 0$

6. Crossdisciplinarity $l \geq 1, k \geq 1$

Therefore, it turns out that either the control situation is simple, or we need discrete mathematics and operation with a small number of classes of indistinguishability of both control objects and control actions.

The majority of control situations in the socio-economic sphere, as well as in the control of organizational systems, are complicated in the above sense, so the solution of optimization tasks for them should ideally not be separated from the identification of a small number of classes of indistinguishability. It is easy to show that these classes of indistinctness can also be called both taxons and concepts (in a broad sense). The necessary explication of the volume and content of such notions (or that the same thing - the volume and diagnosis of a taxon) when solving the problem of optimization of managerial action is the necessary conceptualization of a managerial situation, considered from a slightly different angle of view.

5. FROM CONCEPTUALIZATION AND SEMANTISATION TO ONTOLOGIZATION AND TAXONIZATION

In the first approximation, conceptualization and semantisation can be considered synonyms. The next step after conceptualization (semantisation) will be ontologization as a necessary stage of refining the representations of a managerial situation. By ontologization of a subject area in general and of a managerial situation in particular we will understand such degree of formalization of representations which is sufficient for work with this subject area to be transferred to the machine so that the computer program could carry out a deduction on knowledge in the given subject area either independently or in a human-machine mode. Similar approaches to ontologization of other subject areas were developed, for example, in [9]. Such an even greater degree of formalization of representations creates the necessary conditions to develop even more effective control mechanisms "over" these representations.

But where should the ontologization of the managerial situation begin? Ontology as a formalized system of representations is usually reduced to a set of frames, semantic networks and a set of taxonomies. Semantic network is, in fact, a set of concepts and relations between them. Therefore, we can assume that the study of semantic networks begins with the study of a set of concepts close to each other, their more accurate, explicit correspondence between themselves - and there is a taxonomy of the subject area, for which the semantic network is built. On the other hand, the frame as a set of slots (features) and values of these slots is also the result of taxonomy: it explicates a set of strict concepts, and the concept is defined by the volume and content - a set of features that distinguish it from another concept. This set of values of some features actually defines the frame. It turns out that the "locomotive" of ontologization is taxonomization. Taxonomies are created, less formally they can be called typologies.

Table 2. Conceptualization stages

Conceptualization stages	Ability to use data for machine learning	Explicability of the optimality criterion
Semantisation	–	–
Ontologization	+	–
Taxonomization	+	+
Note. The sign "-" means absence, the sign "+" means presence		

We draw the line between semantisation and ontologization through the ability to use the results of these processes by computers, particularly for machine learning. In other words, we call the semantisation of a managerial situation such a degree of formalization of the results of conceptualization of this managerial situation that a person (an expert) in principle understands what this or that notion refers to, but this knowledge cannot be transferred directly to the machine. On the contrary, ontologization of a managerial situation as a stage of conceptualization begins when the degree of formalization of the description of elements of the subject area of a managerial situation reaches the level necessary for the transfer of this knowledge to the machine. That is, it is already clear which of the elements of a managerial situation should be formalized by a frame and which one by a semantic network, and it is clear how to process these information structures.

However, both at the stage of semantisation and at the stage of ontologization, a managerial situation is "split" into a set of epistemes formalized in some way - concepts, frames, semantic networks, and sometimes even taxonomies, but in the overwhelming majority of cases it is not specified why the partition of representations about the subject area into components is exactly such, and not some other one. Is this partition of representations more preferable than all other possible partitions? And if so, by what criterion? In other words, the criterion of optimal partitioning of representations in most cases is not specified or explicit. Since the concept is, apparently, one of the "atomic" descriptive constructs, it makes sense to start with taxonomies as formalized representations of the systems of concepts. We will therefore call this stage of conceptualization of a managerial situation, at which the optimality criterion for canonical semantic partition is being explicated, taxonomization.

6. CONCLUSIONS

C. Pierce wrote that "conclusions are simple, concepts are complex" [10]. Indeed, the vast majority of practically significant control issues require a relatively simple deduction on the concepts. Edge cases when mathematical formalisms appear in all their beauty and power (for example, Gödel's theorems [11]) cover a much smaller share of cases. On the contrary, even a seemingly simple, "everyday" managerial situation is described by internally very complex, polysemic systems of concepts (or in other words, typologies, taxonomies). Unjustified simplification of these concepts leads to a significant decrease in control efficiency. In our opinion, this is what Ch. Pierce meant.

Thus, it is proposed to "focus" mathematics as a tool not only on the creation of models based on "large-block" representations of the managerial situation, but also, in particular, on the formalization and refining of the representations of managerial situations in order to improve the efficiency of control.

REFERENCES

1. Mauricio Suárez, *Francesca* Pero. (2018) *The Representational Semantic Conception* // Philosophy of science. The University of Chicago Press Books. V.86, No 3. pp. 344–365

2. Prigozhin I. (2001) *End of definition*. - Izhevsk: RHD, - 216 pages

3. Mihaly, Heder (2017). “From NASA to EU: the evolution of the TRL scale in Public Sector Innovation» *(PDF). The Innovation Journal.* 22: 1–23. https://core.ac.uk/download/pdf/94310086.pdf

4. Saltykov S.A., Rusyaeva E.Yu. (2018) *Integrated Scale of Research* 11th International Conference on Management of Large-Scale System Development (MLSD). Moscow: IEEE, https://ieeexplore.ieee.org/document/8551849.

5. Gill, K.S. (2020) *Ethics of engagement*. AI&Soc 35, 783–793. https://doi.org/10.1007/s00146-020-01079-8

6. Novikov D.A. (2013) *Control Methodology*. New York: Nova Science Publishers, - 101 p.

7. Saltykov S.A., Novikov D.A., Rusyaeva E.Yu. (2017) Typology of interdisciplinarity // *Philosophy of Science.* № 3(74). C. 3-16.

8. Patent: S.A. Saltykov, E. Yu. Rusyaeva A. G. Chkhartishvili, A. A. Burba. (2018) *A device for identifying the levels of interdisciplinary synthesis of research*: Patent for invention No. 2665278 RF; Registered. 28.08.2018.

9. Chernyak E., Mirkin B. (2015) *Refining a Taxonomy by Using Annotated Suffix Trees and Wikipedia Resources* // Springe Links / Annals of Data Science. Volume 2, Issue 1, pp 61–82 https://link.springer.com/article/10.1007/s40745-015-0032-1

10. Pierce C. (2000) *Selected philosophical works*. - M.: Logos, - 448 p.

11. Godel K. (1948) *Compatibility of the axiom of choice and the generalized continuum hypothesis with the axioms of set theory.* Uspekhi Matematicheskikh Nauk, 3: 1 (23), pp. 96–149.