Designing a knowledge base for the development of intelligent models based on the conceptual structure of activity act

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Abstract. This article discusses the development of intelligent models based on the conceptual understanding of a dynamically complex environment. The method proposed in this work allows solving these problems based on a synthesis of the activity approach and situational analysis. As a result, the conceptual structure of the act of activity is realized. The combination of these structures leads to the construction of a decision matrix, which represents a knowledge base about a dynamically complex environment. An analysis of these interrelated aspects leads to the construction of four conceptual plans: the functional structure, processes, context and regularity. Conceptual plans make it possible to combine model ideas about the subject area, thereby simplifying the choice of intelligent modules for decision support systems. Recognition of the task of constructing conceptual structures as non-trivial, complex and time-consuming led to the idea of implementing the software system "Designer + Solver + Interpreter". The software toolkit allows not only visualization of conceptual structures and implementation of knowledge bases for intelligent models, but also the studies for completeness and adequacy.

1. Introduction

The objective reality of the modern world is such that decision-makers are forced to act in a dynamically complex environment, which is characterized by the following features [1]:

- to achieve this goal, it is necessary to take a number of decisions, each of which must be considered in the context of the other;
- decisions that are not only interdependent but also have stochastic and long relationships;
- the surrounding validity varies both by itself and as a consequence of the decisions taken.

In a dynamic complex environment there are many systems (economic, social, technogenic, etc.) in which the logic of human goals and actions plays a central role. Under such conditions, the environment is determined by the multidimensional composition and complexity of the organization, and knowledge about it is not structured and difficult to formalize. Obviously, to manage such an environment, it is necessary to use a set of interconnected decision support systems (DSS), which are based on synergistic combinations of knowledge-based models. Using methods of artificial intelligence (AI) for the implementation of DSS it is necessary to take into account that they do not have the means to deepen understanding of subject areas; they only mobilize existing knowledge [2].

2. Action approach

It is difficult to obtain a finite rational definition of the “activity” concept because it is a general scientific category of limited abstraction and is used in the form of an explanatory principle. The
activity is defined as a complex, multi-level, multi-dimensional and developing phenomenon and is a
complicated dynamic system with its own structure, its own internal transitions and its development [3].

In a dynamically complex environment, many activities can exist. Moreover, activity exists in the
cycles of reproduction, which divide it into private images: spheres, types and acts of activity. The act
is an element of activity and is built in accordance with certain rules, without which it does not exist.
These rules are of interest when used repeatedly in the construction of other activities, and it is
possible to allocate general rules that would represent a pattern. To build a diagram of the act of
activity, it is advisable to consider “... completely abstract, proper methodological representations of
activity in the form of a set of blocks” [4]. Then there is the opportunity to build a template of the act
of activity, which can describe any subject area activity. The pattern of activity must be a categorical
scheme of act activities, each element of which can “unfold” in a selected direction of activity (figure
1) [5].

![Diagram of the act of an activity](image)

**Figure 1.** Categorical scheme of the act of an activity.

Elements in the categorical pattern of activity are presented in the form of different processes of
transformation, sequences and mappings. However, the manager, faced with a problem, does not have
certain knowledge about the method and means of solving it, about the sequence of actions for
building his own activities, and can not confidently rely on the experience of past or similar solutions.
Then, in the categorical scheme of the act of activity, the links between the problem and the methods,
as well as between the problem and the means, break.

To solve the problem in the categorical scheme of the act of activity it is proposed [6]:
- to express in the form of requirements for the product an act of activity;
- to make up for the lack of knowledge on the elements of the categorical scheme from the results
  of other categorical schemes of acts of activity.

Accordingly, to solve problematic situations in a dynamically complex environment, the
participation of experts from various fields of knowledge is required, which must clearly interact with
each other, which in itself is not easy. At the same time, the activity-based approach can not support
these requirements, since it does not take into account the role of situationality in solving the problem;
as a result, an adequate base of feasible solutions can not be formed. Therefore, it is proposed to
explore the possibility of designing DSS through a situational context.

3. The method of situational analysis
In accordance with the principles of the situation analysis it is necessary to identify an action with a
certain single decision (d). A single decision is considered as a linked structure of the following
elements (X): action subject (X_as) – action (X_a) – action object (X_ao) – action components,
that influence to decision. At the same time, the action constitutes the structure of three possible types of links (L): AS (L_as) is the relationship between the action subject
X_as and the action X_a, AO (L_ao) is the relationship between the action object X_ao and the action
Two types of bidirectional binary semantic relations are distinguished: interaction is a vertical indirect relationship, and a horizontal relationship is an empirical identification of the relationship between objects. Result of such semantic expressions is either in true (1) or false (0) [7].

Each horizontal relationship or vertical interaction consequently of the virtual or real linked leads to the activity of interconnected elements, i.e., to the alteration of their properties. All elements, entering into a structural link through action, lose some of their properties, which they potentially have in a free state. It is therefore necessary to take into account the structural relationship between the elements and their properties (property – \( P \)), which is represented by two conduits: \( OS(L_{op}) \) – link between an object (subject or components) and its properties \( P_o(P_s,P_c) \) and \( OP(L_{ap}) \) – the relationship between action and his property \( (P_a) \). A property can have a string, boolean, or numeric values (figure 2).

\[ C(D) = \bigcup_{i=1}^{n} C(d_i) \]

We need to perform several operations similar to the theoretical multiple For unification \( C(d_i) \): intersection, difference, complement, inclusion, integration, etc. Thus, on the basis of a set of individual solutions, a knowledge base for expert modeling is implemented [8].

As a result of the studies, the following contradiction was revealed: on the one hand, the activity approach does not take into account the situational aspect; on the other hand, the situational analysis does not give a clear understanding of the result of the activity. To remove these shortcomings, it is proposed to synthesize these aspects into the conceptual structure of the act of activity.

4. Conceptual structure of the act of activity

For removal of the revealed contradiction it is offered to synthesize aspects of the activity approach and situational analysis into a uniform representation - conceptual structure of the activity act. To develop such a structure it is suggested [9]:

\[ (L_{ac_1},L_{ac_2},...L_{ac_N}) \] relationship between components of actions \( (X_{ac_1},X_{ac_2},...X_{ac_N}) \) and \( X_a \).
The conceptual model of a dynamically complex environment is presented by the acts of activity, consisting of a set of conceptual structures of single solutions.

The elements of the conceptual structure of a single solution are described by the terms of the activity approach.

For realization of the given requirements it is necessary to project tops of the scheme of the act of activity on tops of conceptual structures of the unit decision. It is necessary to take into account that the structure of the single solution exists in two states: before the action as a problem, after the action as a method of solving the problem. Proceeding from this, it is possible to assert that the projection of the tops of the categorical scheme of the act of activity on the tops of the conceptual structure of the unit solution is a objective mapping (mutual-uniform). This projection allows natural formation of the conceptual structure of the act of activity, which is presented in figure 3 in a simplified form (at the level of processes) [9].

**Figure 3.** Conceptual structure of the instrument of action.

According to the field of knowledge of crossing: on a process object, on a process subject, on a subject and object of process, on an object about a problem situation between conceptual structures are carried out at a level of processes of operation and process components. The revealed intersections lead to possibility of construction of integral conceptual model of decision-making, which is presented as a matrix of decisions (figure 4).

**Figure 4.** Decision matrix.

The decision matrix is considered as a knowledge base for the design of expert systems (ES), which can be checked for completeness (decisions on acts of activity) and adequacy (decisions on situations). Decisions on acts of activity form functional properties of the model, and decisions on situations are structural.
5. Conceptual plans of the activity act

The conceptual plan of the instrument of action is understood as a certain part of the conceptual structure of the instrument of action, which is regarded as a project to develop knowledge-based models.

It has been suggested that dynamic (function and process plans) and static (context and regularities plans) representations of the structure of the instrument of action should be distinguished for the construction of conceptual plans. As for the plans, a number of statements have been made:

- The functional plan allows designing discrete-event models.
- The plan of processes allows developing the diagram of streams and levels for imitating-dynamic models.
- The plan of regularities allows designing analytical models in the form of simple mathematical equations.
- The context plan allows the development of various models based on the ideas of cognitive approach.

5.1. Functional plan

The discrete event model is seen as a global request service scheme. This approach is used to describe the transition of system functioning from one state to another in a discrete way in the form of an event. This approach is used to describe the transition of system functioning from one state to another in a discrete way in the form of an event [10].

\[ F = \langle X_a, X_{ao} \rangle. \]

By analogy with Structured Analysis and Design Technique (SADT) the functional plan of the act of activity should be presented: input characteristics, which are defined by the initial material; output characteristics - by the product; management - by the requirement; mechanisms - by the instrument of the act of activity (figure 5).

![Functional Plan of the Act of Activity](image)

**Figure 5.** Functional plan of the act of action.

The plan of the functional structure of the act of activity in figure 5 describes the top level function, which is reduced to the private plans of the functional structures of single solutions. Typization of relationships between functions is introduced: intersection by source material (input state); intersection by product and source material; intersection by product and property of one of the components.

The functional plan can be used not only for development of discrete-event models, but also for design of architecture of hybrid intellectual systems.

5.2. Process plan

The methodology of simulation and dynamic modeling includes qualitative and quantitative stages. The basic structure of the quantitative stage contains four essential elements: level (accumulator), solution function, material and information flows [3].
For realization of the basic structure of the quantitative stage it is offered to use the process plan of the act of activity which is caused by: process as a set of actions, object of the act of activity, its states - initial materials and products, means of achievement of the purpose and their properties (figure 6). The activity act process plan describes the processes of the upper level, which can be reduced to private plans of single solutions. Typization of links between process plans of single solution structures: type of sequential and logical links has been introduced.

The process plan operates with a set of actions, determines what quantitative state the object will move in the future from the given current state. The level of the drive is represented as an object of action \( X_{ao} \), defined through a relationship \( L_p(OS) \) by one of the quantitative states of the source material or product. A flow is defined by a continuous activity \( X_o \) that is represented by an action that moves content between drives. Using the hydrodynamic metaphor, the function of solutions is a valve, which controls the flow, which is determined by means of the action of activity \( \{X_{ac,1}, X_{ac,2}, \ldots, X_{ac,N}\} \) and the connection \( L_p(OS) \) with its functional properties \( P \).

![Figure 6. Process plan for the act of action.](image)

The qualitative stage will be considered within the context plan as a study of the structure of cause-effect relationships. On the basis of the plan of processes the diagram of flows and levels for imitating dynamic models will be developed [10].

5.3. Plan of regularities
Static aspects describe the conceptual structure of the act of action at a given point in time (before or after the action). At the same time, relations and ratios are the main binding building elements of such conceptual structures.

The plan of regularities is determined by the multiplicity of manifested properties of objects of the conceptual structure, which are characterized by certain relations \( (R_{oc} = 1, R_{ac} = 1) \) and relations \( (R_p) \), thus the regularities of transformation of the initial material into a product are fixed.

The following rules should be taken into account when drawing up the plan of regularities of a single solution:

- The state of the action object (product) is associated with the solution, and means of action with the internal parameters of the equation.
- Relationships in terms of patterns are unidirectional and unitary, that is, from one element may leave or enter a single relationship (figure 7).
Figure 7. Plan for the patterns of a single solution.

- The relation between an object and a means of action \( R_{oc} \), and the relation between means \( R_{cc} \) are represented by relations of dependences and are caused by types “increases” or “decreases”, the relation \( R_{oc} \) – by type “defines”.

- Relationships are associations of relations of dependencies, which are defined by the following types of “more on”, “less on”, “more in” and “less in”. Relationships of associations, in turn, can be displayed as arithmetic actions. The relation \( R_{oc} \) defined by the type “defines” is displayed as an equal sign.

On the basis of the pattern plan, various analytical representations can be defined, including the solution functions (flow intensity) for the simulation-dynamic model [11].

5.4. Context plan

Cognitive modeling is focused on activation of intellectual processes of the subject and helping the manager to fix his idea of the problem situation in the form of a formal model. As such model is usually used so-called cognitive situation map, which presents basic laws and regularities of the observed situation known to the subject in the form of oriented sign graph.

Thus, the following elements should be defined in terms of context: the subject of the activity act \( X_{as} \), which interacts with the subject of the action \( R_{so} \) and various components of the action \( \{R_{sc,1}, R_{sc,2}, \ldots, R_{sc,N}\} \); the subject of the activity act \( X_{ao} \), which exists in interaction with the subject \( R_{oa} \) and with various relations of the components \( \{R_{oc,1}, R_{oc,2}, \ldots, R_{oc,N}\} \); action components in the form of requirements and means of the activity act \( \{X_{ac,1}, X_{ac,2}, \ldots, X_{ac,N}\} \), which interact with the subject \( \{R_{cs,1}, R_{cs,2}, \ldots, R_{cs,N}\} \) and exist in relations with each other \( R_{cs ja} \) (figure 8).

Figure 8. Context plan for the activity act.

In this case, the term “context” refers to the structure of the external environment, within which control factors are identified. Statistical representation of the context plan is defined by interactions and relations equal to 1 and “increases” or “decreases” types [3].

A context plan is intended not only to design cognitive models, but also to provide a better understanding of a particular activity and as a complement to other conceptual plans. For example, to determine the qualitative stage in simulation dynamic modeling.

6. Software package for designing decision support systems

Designing conceptional models is not a trivial problem which require an understanding of the activity approach methodology, situation analysis and system peculiarities of subject area. This creates
problems that can be only solved quickly and effectively at the software level: first of them – visualization conceptional structures, second – checking conceptional model for completeness and adequacy, third problem – generation knowledge base for expert modeling and the fourth problem is generation knowledge base for cognitive, imitation and analytical modeling supported by this approach.

To solve the first problem we have realized program software “Designer”, which is defined by the following tools: node tool allows creating different nodes; link tool allows constructing different links, relations between vertices conceptional structures; text tool allows changing text inside elements of conceptional structures; zoom tool allows zooming the node to full-screen zoom for detail research [11].

Conceptional structures shown in software “Designer” are represented as an XML-document, which contains node tree that allows accessing any element of conceptional structure. Thus, we can change and process their content at the software level.

To solve the second and the third problem we have program software “Solver” which consists of components of the integration and management modules: knowledge formalization module consists of issue condition editor, object editor, link editor, rule base editor, situation models base; access to situation model module consists of problem situation model, current situation model, target situation model and knowledge base module; organizing and conducting logical output module consists of rule management editor, conducting direct logical output module, situation analysis module.

So, in the software “Solver” the XML file saved by “Designer” is being read, selecting the necessary fragments from it and building a primary logical structure that describes the conceptual schemes as marked-up oriented graphs. If any syntax errors are detected in the conceptual structures, the user is given the appropriate messages.

Also, the knowledge base is also checked for completeness and adequacy. The analysis of the set of conceptional structures of individual solutions for adequacy begins with the establishment of the values of the facts of the problem and target situation. If the target situation is reached by logical conclusions, then based on the content of the generated text report, the fact about the adequacy and completeness of the recommendations for the relevant knowledge base is established. For a conceptual model of a dynamically complex environment research on completeness and adequacy is carried out by checking logical conclusions on acts of activity and on situations (figure 4). Completeness is checked by situation classes. However, if the logical output is interrupted because the rules can not be applied to the initial situation, the knowledge base is incomplete. Verification of adequacy is based on logical conclusions for classes of acts of activity. The resulting report on output results must correspond to the logic of the modeled process of the activity act. If incompleteness or inadequacy is detected, the knowledge base should be improved.

The product rules knowledge base is implemented in a text file that specifies: main conceptional model elements, rule name <entity, action, object>; the content of the rule in the form of the following construct: IF<Pre-action conditions >THEN PERFORM THE ACTION <post-action conditions>.

Production rules describe the preconditions that the states of participating objects must satisfy, and the rules for changing the state of objects at the end of the corresponding action [11].

To solve the fourth problem, we have program software “Interpretator” which divides into two blocks: dynamic and static knowledge.

The functional plan dynamic knowledge base report defines following elements: function – [Action_N Object_N]; function’s input property – [Object property_N before Action_N]; function’s output property – [Object property_N after Action_N]; function’s mechanisms – [Action tools_N]; instructions for managing the function – [Requirements for the action act_N].

The text file of the functional plan indicates the identified intersections and offers recommendations for its construction in the form of various constructs. For example: Input<Object property_N before Action_N> → Function<Action_N Object_N> → Output<Object property_N after Action_N>.

In the report, the main elements of the processing plan knowledge base are: level – [Object_N Number: = <Object property before Action>] and [Object_N number: = <Object property after Action>]; array – [Action_N].
The text file of the process plan specifies the identified intersections and offers recommendations for its construction in the form of the following construct: level_1<Object_N Number: = Object property_N before Action_N → Array<Action_N> → level_1<Object_N Number: = Object property_N after Action_N'.

In the report, the main elements of the pattern plan knowledge base are: equation – [Object_N]; argument – [Object_N Object property after Action_N]; mathematical sign – [Relation]; equal sign – [Relation<Determine>].

The text file of the pattern plan offers recommendations for its construction in the form of the following construct: Equation<Object_N>Equal sign<Relation>Determine>argument<Object_1 tool property_1 after action_1>Mathematical sign<Relation>argument<Object_2 tool property_2 after action_2>etc.

In the report the main elements of knowledge base of context plan are: the fact of interaction – [entity interaction Object_N], [Entity Interaction Tool_N] and [Entity Interaction Requirement_N]; the fact of relation – [tool_N-1 relation tool_N], [Requirement_N-1 Relation Requirement_N] and [Tool_N Relation Requirement_N]; the fact of the appearance of the product – [Object_N Object’s_N property after action_N].

The text file of the context plan specifies the detected intersections. Finding the fact is a guideline for developing cognitive models.

A set of interacting software creates a software package “Designer +Solver +Interpretator” which is positioned as an intelligent add-on for designing intelligent models.

7. Conclusion
The method proposed in the article allowed considering all kinds of problem situations through the prism of constructing conceptual structures of acts of activity and directs the transformation of a dynamically complex environment according to the goals of decisions. A set of conceptual structures acts and activities create a complete model of decision making for designing a knowledge base for expert systems. Thus, the expert’s knowledge is the basis for development decision support systems.

Splitting the conceptual structure of the act of activity into particular representations makes it possible to implement other aspects of knowledge bases for the development of an AI model. At the software level, a knowledge show case has been created for the design of smart DSS.

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