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RESEARCH ARTICLE

Designing modules of system dynamics in decision support systems

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Abstract
Objectives. When creating models of system dynamics, the basic construct at the design stage is the representation of the process under study in terms of a causal relationship consisting of a positive feedback loop and a negative feedback loop. The construction of a model of a dynamic environment can experience a number of difficulties in using feedback. This work shows the possibility of designing modules of system dynamics for decision-making systems based on the situational-activity approach. The study proposes the gap in knowledge about models of system dynamics to be filled with a conceptual model of an act of activity, by means of which an expert system can be implemented based on production rules. In this context, conceptual models are applied to human reasoning with reference to certain types of activity. The objective of the study was to investigate the possibility of applying the situational-active approach to designing models of system dynamics of infectious diseases based on particular representations of the conceptual structure of the act of activity.
Methods. By synthesizing Bolotova's situational algorithm and Shchedrovitskiy's system-activity approach, the conceptual structure of the act of activity is presented as a methodology of the situational-activity approach. The analysis of this structure leads to the construction of a plan of processual structure and a plan of analytical relationships. The article proposed a hypothesis that the process representations describe the notation of flows and levels, and the analytical relationships implement differential equations. In order to prove this hypothesis, the subject area of infectious diseases was investigated.
Results. Based on the set of these plans, a graphic image was synthesized for constructing models of system dynamics, which is identical to the diagram of flows and levels of development of the SIR process. However, the problem of constructing conceptual structures is nontrivial, complex, and laborious. Therefore, the Designer–Solver–Interpreter software suite was implemented. The software tools enable a visualization of the conceptual structures and implementation of the knowledge bases for expert models of system dynamics. It also tests the completeness and viability of the model.
Conclusions. To date, there is no single conceptual structure for designing expert systems and situational and simulation dynamic models. The proposed method and software tools allow these problems to be resolved using the situational-activity method. Various types of dynamics in expert systems interact, thus confirming the reliability of knowledge in the models of system dynamics. The conceptual structures of the act of activity are the core part of designing expert systems, while he derivative process and analytical representations of the act of activity are the core part of developing modules of system dynamics.

Keywords: situational-activity approach, conceptual structure of an act of activity, process representations, analytical representations, models of system dynamics

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НАУЧНАЯ СТАТЬЯ

Проектирование модулей системной динамики в системах поддержки принятия решений

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Резюме
Цели. При проектировании моделей системной динамики базовым конструктом стадии проектирования является представление исследуемого процесса в терминах причинно-следственной связи, состоящей из петель положительной и отрицательной обратной связи. При построении модели динамической среды возникает ряд трудностей использования обратной связи. Настоящее исследование показывает возможность проектирования модулей системной динамики для систем поддержки принятия решений на основе ситуационно-деятельностного подхода. Предполагается восполнить нехватку знаний о моделях системной динамики концептуальной моделью акта деятельности, с помощью которой может реализоваться экспертная система на основе продукционных правил. Концептуальные модели при таком аспекте применяются к человеческим рассуждениям с привязкой к определенным видам деятельности. Целью работы является исследование возможности применения ситуационно-деятельностного подхода для проектирования моделей системной динамики инфекционных заболеваний на основе частных представлений разработанной концептуальной структуры акта деятельности.
Методы. На основе синтеза двух подходов – ситуационного, предложенного Л.С. Болотовой, и системно-деятельностного, предложенного Г.П. Щедровицким, представлена концептуальная структура акта деятельности как методика ситуационно-деятельностного подхода. Анализ данной структуры приводит к построению процессуального плана и плана аналитических закономерностей. Была проверена следующая гипотеза: процессные представления описывают нотацию потоков и уровней, а аналитические закономерности реализуют дифференциальные уравнения. Для доказательства гипотезы исследовалась предметная область инфекционных заболеваний.
Результаты. На совокупности данных планов синтезирован графический образ для построения моделей системной динамики, который идентичен диаграмме потоков и уровней развития SIR-процесса. Однако задачу построения концептуальных структур следует признать нетривиальной, сложной и трудоемкой. Поэтому реализован программный комплекс следующего состава: «Оформитель», «Решатель» и «Интерпретатор». Программный инструментарий позволил визуализировать концептуальные структуры и реализовать базы знаний для экспертных моделей системной динамики, а также провести исследования на полноту и адекватность модели.

Выводы. На сегодняшний день не существует единой концептуальной структуры для проектирования экспертных систем, ситуационных и имитационных динамических моделей. Предложенный в работе метод и программный инструментарий позволяет решить данные задачи на основе ситуационно-деятельностного метода. Таким образом, осуществляется взаимодействие различных видов деятельности в экспертных системах, тем самым подтверждается достоверность знаний в моделях системной динамики. Концептуальные структуры акта деятельности являются ядерной частью при проектировании экспертных систем, а производные процессные и аналитические представления акта деятельности являются ядерной частью при разработке модулей системной динамики.

Ключевые слова: ситуационно-деятельностный подход, концептуальная структура акта деятельности, процессные представления, аналитические представления, модели системной динамики

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PROBLEM STATEMENT

The value of the decisions made depends on the reliability and completeness of the data used. At the same time, the activity in a highly dynamic environment is intense and tends to independently choose its own state. Acts of activity also impose requirements on the decision-making system. The objects of acts of activity in situations of a dynamically changing environment and the need to make a managerial decision are controlled by their states. These states, in turn, are determined by the definition of objectives by the controlling object. If there are sufficient controlling actions in the system, then there is uncertainty in the dynamics of processes, favoring a simplified perception of reality and an emotional solution to a complex control problem [1]. A situation arises in which the sequence and relationships of actions in the decisions being made are impossible to identify. Therefore, the hypothesis of the behavior of a complex object controlled by several controlling actions needs to be defined, on this basis, the process of change in the object with various variants of solutions to be simulated [2].

A simulation model is defined by a logical-algorithmic description of the behavior of a complex object and includes continuous and discrete states. The discrete model consisting of conventional functional blocks, can be characterized by an average level of abstraction, and is implemented using the structured analysis and design technique (SADT) or function modeling (IDEF0) methodology. The continuous modeling supports all levels of abstraction and is written in the unified modeling language (UML), mainly, state and activity diagrams.

In the simulation model, there is a high level of abstraction, referred to as system dynamics. Real-world processes in the system dynamics are represented in terms of information and flows between levels and storages, while their formal basis is represented as flow rate equations using dynamic processes in the state space. The idea of changes by feedback loops is one of the most important in determining the structure of the system dynamics. This led to the creation of tools for constructing causal (feedback) loop diagrams (CLDs). The graphical model obtained by the modeling process is, in fact, a diagram of links, reflecting the relations between elements of the system modeled as a CLD. If a change in the cause entails a similar change in the effect, then such a relationship is called positive. However, if the change in the cause causes the opposite change in the effect, then the relationship is called negative, so the correctness of the model mainly depends on the correct definition of the role of the CLD. This process without a conceptual study is laborious [3].

Knowledge representation models are similar in expert and situational systems. A frequent tool for situational modeling is the use of simulation models. This means that the language of situational design must include certain tools of modeling languages.

INVESTIGATION OF THE STAGE OF DESIGNING MODELS OF SYSTEM DYNAMICS

Models of system dynamics comprise two main stages. The first of them is called “qualitative,” the implementation of which takes into account the relationships of elements of the system and also the structure of the problem itself. Here, the basic construct of the system is the process diagram, consisting of a positive feedback (“+”) and a negative feedback (“–”) with the corresponding notation of their polarities (Fig. 1).

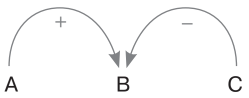

Fig. 1. Polarities of relationships

The second stage is called "quantitative." When it is implemented, the correctness and reliability of the model are checked, as are the scenarios of the behavior of the system under various conditions [4].

If two negative relationships are connected in series, they form a positive relationship. In turn, causal relationships (CRs) can form a loop that is unidirectional and closed. It can be either positive feedback (PF) or negative feedback (NF).

The rules for determining the polarity of a feedback loop in a generalized form state that the absence or an even number of CRs therein makes it a PF loop, while an odd number of negative CRs makes it an NF loop.

The dynamic nature of the modeled environment can give rise to difficulties. For example, if the system is sufficiently complex, then there may simultaneously be both several PFs and several NFs, while the causes of dynamic changes in the environment can be difficult to achieve in the model. Note also that only the CRs that are understandable without any additional actions need to be determined. An important role is also played by the objectification of the feedbacks that incorrectly reflect the objective reality of the problem [5].

The CRs of the model enable the quantitative stage of modeling the dynamic system to be determined, thus making them the main tool for designing flows and levels of systems. The elementary units of the system are levels, decisions (of a functional type), information flows, and material flows (Fig. 2).

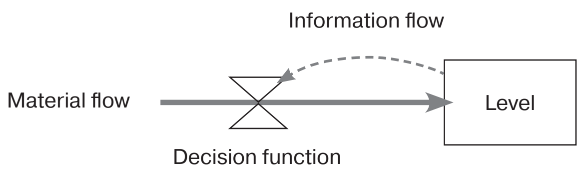

Fig. 2. Structure of the quantitative stage

Levels have a clear time dependence and denote a certain variable (at a particular point of time), while their content can be completely heterogeneous. Mathematically, the level value at a certain point of time is equal to the sum of the level value at the previous point of time, while the product of the rate of change in the level value and the increment of time. The rate of change in the level value is the difference between the rates of the incoming and outgoing flows. Figure 3 presents a model of the levels.

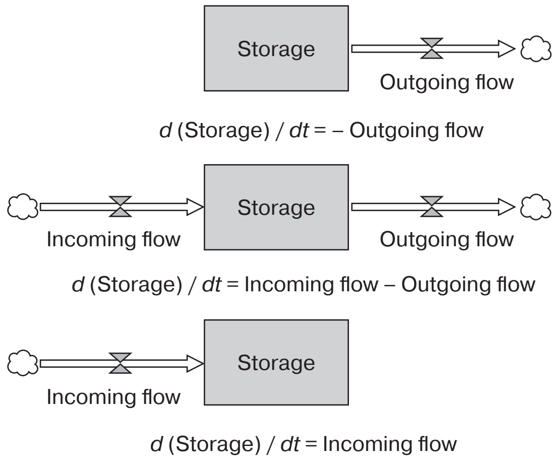

Fig. 3. Simulation dynamic model of the levels

If the equations of the levels allow the value of a certain level to be determined at the current point of time from its value at the previous point of time, then the rate equations are predictive, i.e., can predict the values at the next point of time [6].

In the problem of predicting the rates, it is important to take into account not only the direct, but also the indirect factors of influence, e.g., time, as well as the information flow.

A single experiment may be sufficient to obtain results from the decision space. However, a comprehensive study of the environment requires a certain set of experiments, which may ensure the variability of decisions for the decision maker.

DESIGNING MODELS OF SYSTEM DYNAMICS BASED ON THE SITUATION-ACTIVITY APPROACH

According to the methodology of the situational-activity approach, the types of activities that exist in the complex dynamic environment need to be determined, thereby defining the boundary of the validity of the selected subject area. Imagine, e.g., a dynamically complex environment "Combating infectious diseases," in which there are many activities (Fig. 4) [7].

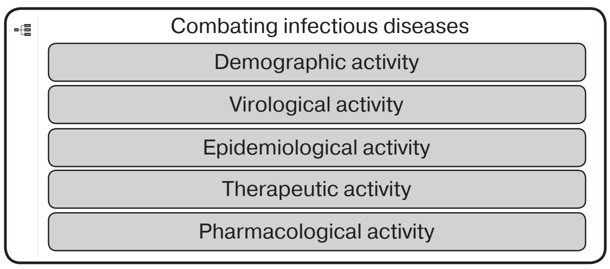

Fig. 4. Numerous activities in a dynamic environment

The structuring of an activity enables certain types of the activity to be identified. This in turn, makes it possible to transition to another activity within the selected type by a logical (formal) analysis. In the structure created,

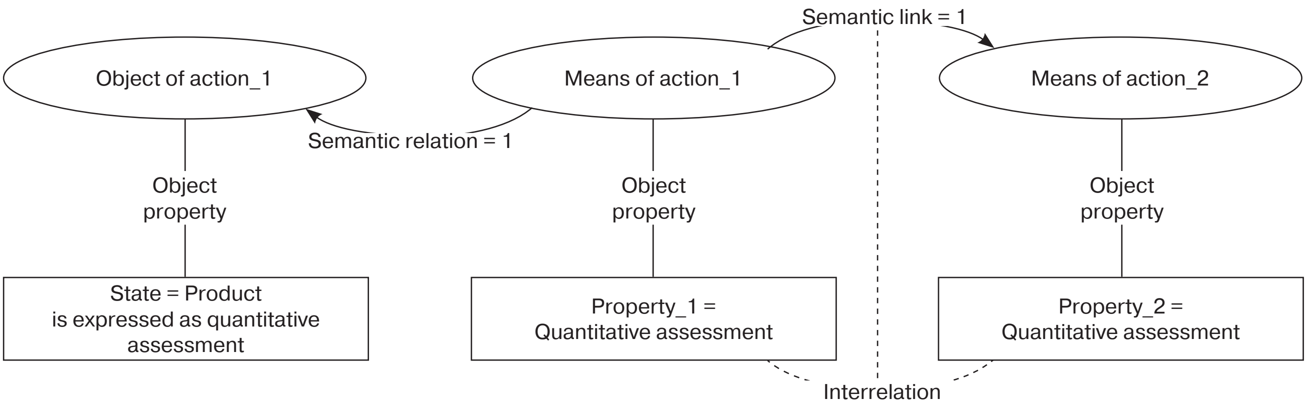

Fig. 5. Structure of the plan of relationships

the fundamental unit is an act of activity, which does not limit the researcher in identifying any other units that depend on the setting of objectives and problems [8, 9].

From the conceptual structures of acts of activity, four different contents of the act of activity can be defined: a plan of functional structure, a plan of processual structure, a plan of context, and a plan of analytical relationships [10]. These plans are expressed in a single structure which combines them into a single whole. Not only does not this create contradictions, but also it allows them to be applied both in parallel and in series [11, 12]. In view of the above, the main subject of this work is the plan of processes and relationships of the dynamic simulation model.

The planning of processes is determined by the processes themselves, the objects involved in them, the states of these objects, and the means by which the system reaches its objective state [13].

The planning of relationships is determined by the set of objects and the set of relations between them, and also by the properties of the objects and the relationships between them (Fig. 5).

The plan of relationships is implemented in accordance with the following rules:

- the state of the object of action is equal to the product (production element) expressed by the quantitative assessment and is associated with the decision;
- the properties of the means of action are equal to the quantitative assessment and are associated with the parameters defined in the structure of the equations;
- the relations must be unidirectional, and the relations of the type of “$a > b$ by x,” “$a < b$ by x,” “$a > b$ by a factor of x,” and “$a < b$ by a factor of x” (where x is a real number greater than one, and a and b are some signs of comparison of objects or relations of objects of the subject area) should be indicated using the corresponding arithmetic operations;
- objects of relationships of the “increase” type should be denoted by the plus sign; of the “decrease” type, by the minus sign; and “define,” by the equals sign.

A variety of representations of the sequence of arithmetic operations in the models of system dynamics is formed due to the plan for defining relationships for its further application in the differential equations of the corresponding models.

SOFTWARE SUITE FOR THE IMPLEMENTATION OF DYNAMIC MODELS OF DECISION SUPPORT SYSTEMS

The conceptual modeling of a subject area (SA) requires the specialist to understand the methods of analyzing situations, activities, and processes occurring in a given SA [14]. In particular, there is a range of assignments that can only be performed using software that can:

1) represent concepts (as elements of sign systems);
2) check the completeness and consistency of systems;
3) generate databases.

As part of the first assignment, we developed the Designer application, which performs the following tasks [15]:

- creates objects based on standard geometric shapes (primitives);
- implements links between objects;
- edits text of elements of the model;
- scales the model.

Tasks 2 and 3 are solved using the Small Problem Solver (SPS) application designed especially for situational analysis. SPS supports the following functions [15]:

- creation, storage, modification and testing of the model, and also verification of the correctness of production knowledge bases (KB) consisting of a working database (WDB) and a rule base (RB);
- logical conclusion;
- creation of reports on the analysis of problem situations and on the achievement of objective situations.

The functionality of the SPS is determined by its architecture (Fig. 6).

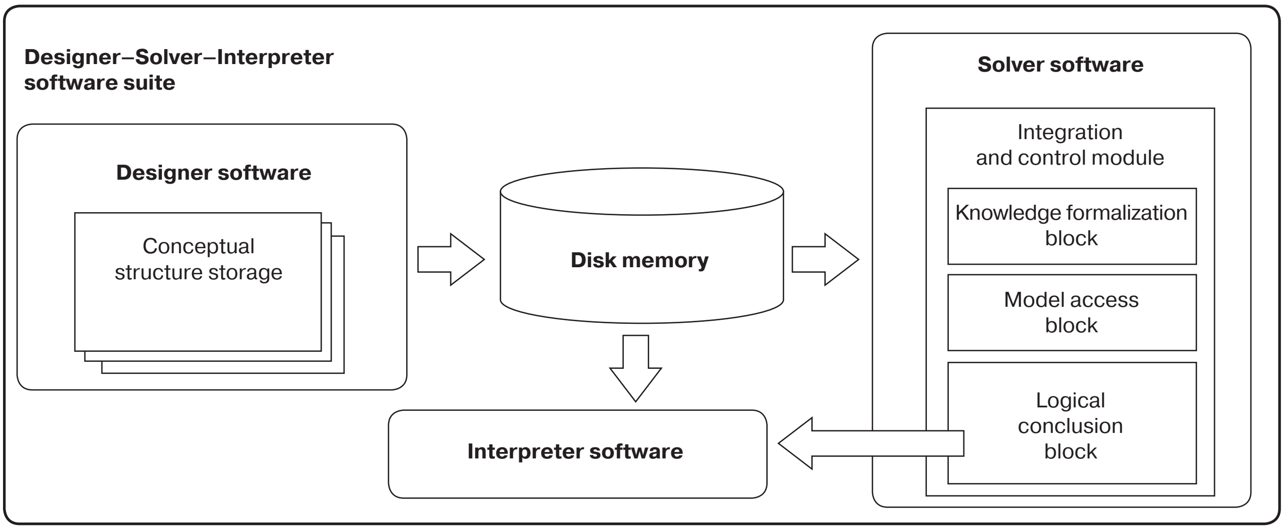

Fig. 6. Designer–Solver–Interpreter software suite and the SPS architecture

Thus, the following sequence in the operation of the Designer–Solver–Interpreter (DSI) software suite can be defined. When a file is saved in the Designer program, an XML file is created with the markup of a graphical model. Then this file is opened by the SPS, and the program using its own application programming interface (API) reads information from a file. It writes it to its knowledge base, checks the model for syntax errors, and informs the user about the loading result. The next step is to check the knowledge base for completeness and consistency. Initial values are set in the editors of objects, relationships, conflict resolutions, and objective situation, after which the situation is checked in the Description/Analysis section.

The knowledge base consists of WDB and RB, which contain the model elements and the names of rules and products.

Products have a left side (precondition), which is a set of the values of properties and relations that are required to activate the rule, and a right side (postcondition), which is a set of the values of properties and relations that that these properties and relations take after the rule is executed.

In essence, the Interpreter is an API receptor for the perception and translation of XML files of a graphical model of the concept of the subject area. Its structure includes:

- a parser which searches for data in the XML markup using certain pointers (tags);
- a lexer which translates the data located in the places labeled by the tags into a form understandable by the SPS.

Upon completion of the transformation and transmission of data by the lexer, the main stage of the operation of the SPS begins. After setting the initial conditions for the properties of objects and relations, the initial situation, and the conflict resolution strategies, a logical conclusion is attained from the RB in accordance with the production rules. The report obtained as a result of the operation of the SPS allows the researcher to understand the degree of correctness of the conceptual model of the subject area which he or she constructed. This is because the SPS not only can create a basic initial situation but it also allows the researcher to modify it by changing the initial objects, properties, relations, and rules and adding additional ones.

In the act of conflict situations in the modeled system, or if these conflicts were intentionally created by the researcher, there are two main ways of resolving them [16]:

- prioritization of production rules in the rule editor with subsequent assignment of top priority to a conflict resolution strategy;
- definition of conflict resolution strategies other than prioritization, e.g., "getting closer to the objective," "not creating cycles," etc.

The optimal solution for the conflicts created intentionally when designing the conceptual model is to set priorities. The highest priority should be defined by the rule which is related to the most important factor, e.g., human life. If the conflicts are related to errors made at the design stage, then the SPS user can manually change the products in the rule editor. This provides for the possible branching when the model is implemented under changed initial conditions.

In general, it is recommended that at least three problem situations be checked for:

(1) all the conditions of the problem situation should correspond to the initial logic of the graphical model (no changes are made to the initial conditions);
(2) for one (or several) key properties, the value of which changes during the actions of the model, the values to be reached in the course of the

operation (state changes in accordance with the knowledge base) of the model need to be set. Thus, the result of the operation of the SPS needs to be checked, in order to verify that it converges with the logic (which the researcher assumed) of the model;

(3) one (or several) properties need to be set to such values that the logic of the model is broken or does not work at all. This makes it possible for the correctness of the model to be verified under impracticable and contradictory conditions.

Thus, the main purposes of the DSI software suite are [16]:

- to construct a conceptual model of the subject area of the problem considered by the researcher;
- to convert the model from the graphical model to a software one, common for most actual applications;
- to analyze the program model for possible problem situations using a formal theory.

Summarizing all of the above, it can be stated that the DSI allows the researcher to create a conceptual model of the subject area under investigation and to understand how true and complete this model is, i.e., whether the logic embedded in the model works from the point of view of program logic (and from the point of view of formal theory), and whether the model provides for all kinds of situations and their consequences.

CONCLUSIONS

The experience and practice of creating decision support systems (DSSs) show that, to date, there is no single conceptual structure of a knowledge base for the implementation of intelligent modules, and also the software that supports the situational-activity approach. The absence of such a single structure indicates that, at present, there is at least one problem in decision support. The situational-activity approach allows systems that are complex in terms of dynamics to be studied efficiently, in order to create simulation models, models of expert systems, as well as other intelligent DSSs.[1]

A set of conceptual structures are defined as a certain elemental composition, which when synthesized enable the construction of intelligent DSSs. Given that the knowledge of a complex dynamic environment based on the conceptual structures of the situational-activity approach is the key to designing intelligent modules, there are several potential directions for development: as a language for understanding and modeling, as well as a tool for identifying a knowledge base.

Authors' contribution. All authors equally contributed to the research work.

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