Technique for development and organization of background information-analytical processes in cyber-physical systems based on neural-fuzzy Petri nets

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Abstract
The article is devoted to the organization of background information-analytical processes in cyber-physical systems, which are necessary for preparing information for the foreground processes, diagnosing a cyber-physical system, performing planned operations, etc. The technique for development information-analytical processes based on the variety of neuro-fuzzy Petri nets, which includes generalized stages of formalization, modeling, analysis and modification of information-analytical processes is proposed. This technique allows to diagnose and determine the attainability of various events of information-analytical processes, their cyclical nature, as well as eliminating the "bottlenecks" of the processes. This, in turn, makes it possible to identify and avoid complicating processes, create unnecessary processes, reduce the number of false messages about the inadmissibility of their implementation, and, as a result, prevent possible errors in the development of information-analytical processes.

Keywords 1
Ontology, Cyber-physical systems, Information-analytical processes, background processes, Neuro-fuzzy Petri nets

1. Introduction

Modern cyber-physical systems operate in conditions of uncertainty and steady growth of the volume of structured and semi-structured information coming from heterogeneous sources. The prerequisites for such growth are, first of all, the growing possibilities for hardware data acquisition, as well as the widespread use of personal devices that are used, on the one hand, as a data acquisition channel, and on the other, as a tool for analyzing and managing information-analytical processes.

A characteristic feature of cyber-physical systems is the close interaction of the main technological and information-analytical processes. Technological processes are subject to the influence of various external factors, therefore, the information-analytical processes associated with them must adapt to such changes. In this regard, there is an acute problem of increasing the efficiency and speed of development and modification of information-analytical processes, which include the processes of collection, processing, generalization, assessment and forecasting of the state of systems, the development of valid decisions and assessment of their feasibility.

Various approaches are used to develop information-analytical processes in cyber-physical systems. Thus, the traditional approach is that, even at the development stage, the requirements for the basic and information-analytical processes of the system are set rather rigidly [5]. At the same time, information-analytical processes are “embedded” into the main processes of cyber-physical systems in the form of a program code.

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The advantages of this approach include the high efficiency of process development. However, keeping these processes up to date requires significant financial costs. This is due to the fact that their correction with changes in systemic and external factors must be carried out quite often, and, over time, the intensity and complexity of such changes only grows. And often a decision is made to abandon the modifications and advance to a new version. The “semantic gap” between experts, architects and developers of information-analytical processes can also be attributed to significant disadvantages. In addition, seamless migration between versions is generally not possible (Figure 1).

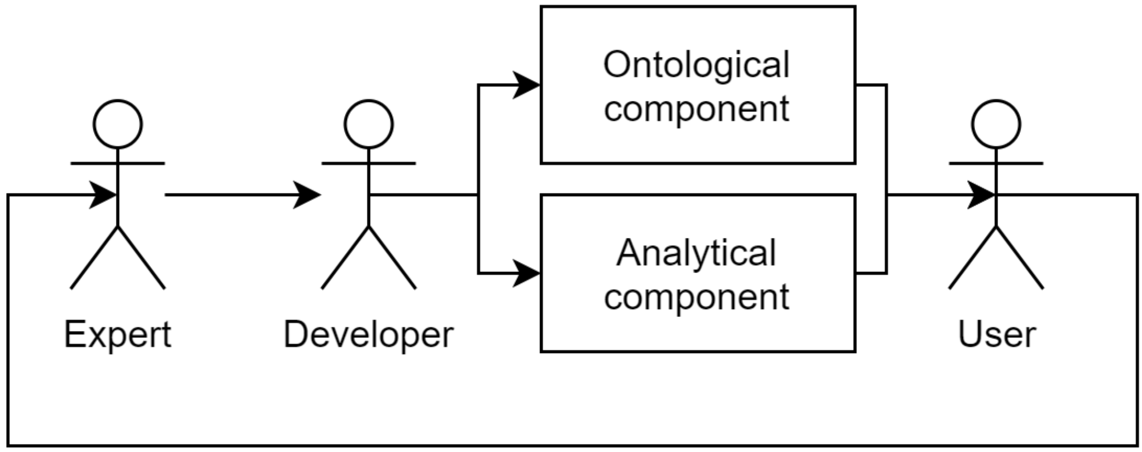

Figure 1: The traditional approach to the development of information-analytical processes

The constant change in external factors and requirements for the implementation of the main processes and a steady growth in the volume of information of different quality from heterogeneous sources, dictate increased requirements for the quality and efficiency of adaptation, primarily of information-analytical processes.

A promising approach to the development of information-analytical processes in these conditions is their creation without the involvement of program code developers. Developers create a software-instrumental environment based on an ontological approach (the tools of such an environment can directly operate on information entities of information-analytical processes), and experts, using the capabilities of the environment, implement basic algorithmic constructs and develop information-analytical processes themselves [7].

The advantage of this approach is the eliminating of the "semantic gap" between experts, architects and developers of information-analytical processes. At the same time, the involvement of developers is necessary only in the situations when it is required to develop new or adjust existing environmental tools. Experts, on the other hand, for the implementation of information-analytical processes must have only basic skills in process development.

Despite the fact that the financial and time costs for the implementation of the software-instrumental environment are much higher than for the implementation of heterogeneous "in the code", however, the life cycle of the software-instrumental environment can be several times larger, and the costs of developing new and existing information-analytical processes are lower, and, as a rule, "migration" between their versions is feasible.

All processes in cyber-physical systems are divided into foreground and background processes. Foreground processes provide support for dialogue in real time, while the tasks of background processes are to prepare information necessary for foreground processes, diagnose a cyber-physical system, perform planned operations, etc.

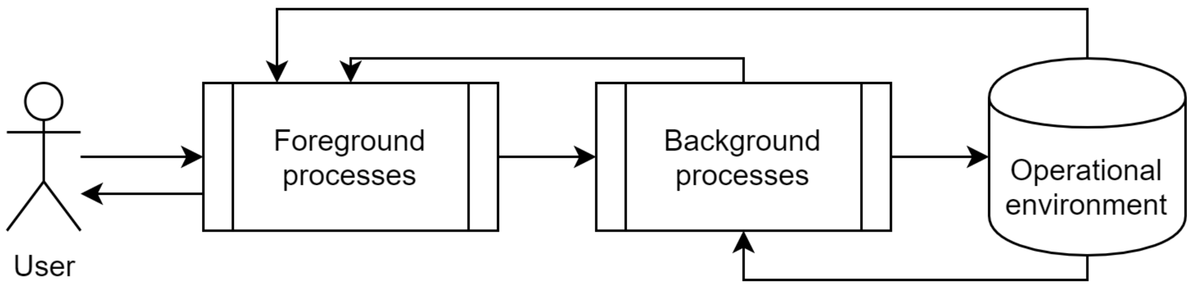

Figure 2: Foreground and background processes in cyber-physical system

The article implements an approach that consists in the coordinated use of ontological and analytical components that form a software-instrumental environment for the development of information-analytical processes in a cyber-physical system.

Petri nets [8] [10], [11], which have good graphic and expressive capabilities, have proven themselves well for formalizing, modeling and developing information-analytical processes focused on a discrete-event nature. from a mathematical point of view.

To formalize and develop information-analytical processes in cyber-physical systems, the paper proposes a kind of neuro-fuzzy Petri nets, which adequately reflects the structure and dynamics of changes in the state of these systems, the nodes and transition rules of which are formed on the basis of the neuro-fuzzy basis of operations, and also provides adaptive structural and parametric tuning when changing system and external factors based on machine learning algorithms.

The features of developing background information-analytical processes are considered.

2. Approach to the development of information-analytical processes in cyber-physical systems

To eliminate the “semantic gap” between analysts and developer, when developing information-analytical processes in cyber-physical systems, it is proposed to implement an approach consisting in the coordinated use of ontological and analytical components that unite in a software-instrumental environment for the development of information-analytical processes (Figure 3).

The ontological component should include tools for creating a quasi-hierarchical data structure of arbitrary nesting with the necessary additional relationships between hierarchy levels. Using this approach, an expert using the functionality of the soft-ware and instrumental environment, without involving programmers, is able to form the data structure himself and configure the necessary connections.

As a basis for organizing data storage, it is proposed to use an object-oriented approach, within which the subsystem "Class Tree" is formed.

The class, in accordance with the object-oriented approach, is a description of objects through their common attributes. Each attribute of a class has a name that is unique within this class, and is also characterized by the type of data that will be used to store the attribute value. In addition to attributes, the required number of methods that implement the actions and events characteristic of this class can be associated with a class to provide support for the system's response to information changes.

The analytical component should include tools for the development and modification of information-analytical processes, as well as tools that control both the data entering the system and the data produced by the system during its operation.

In cyber-physical systems, for their full functioning, there is not enough opportunity for input and output of information. A feature of systems oriented to use by engineering and technical personnel is the need to provide the user with analytical data obtained as a result of the functioning of information-analytical processes.

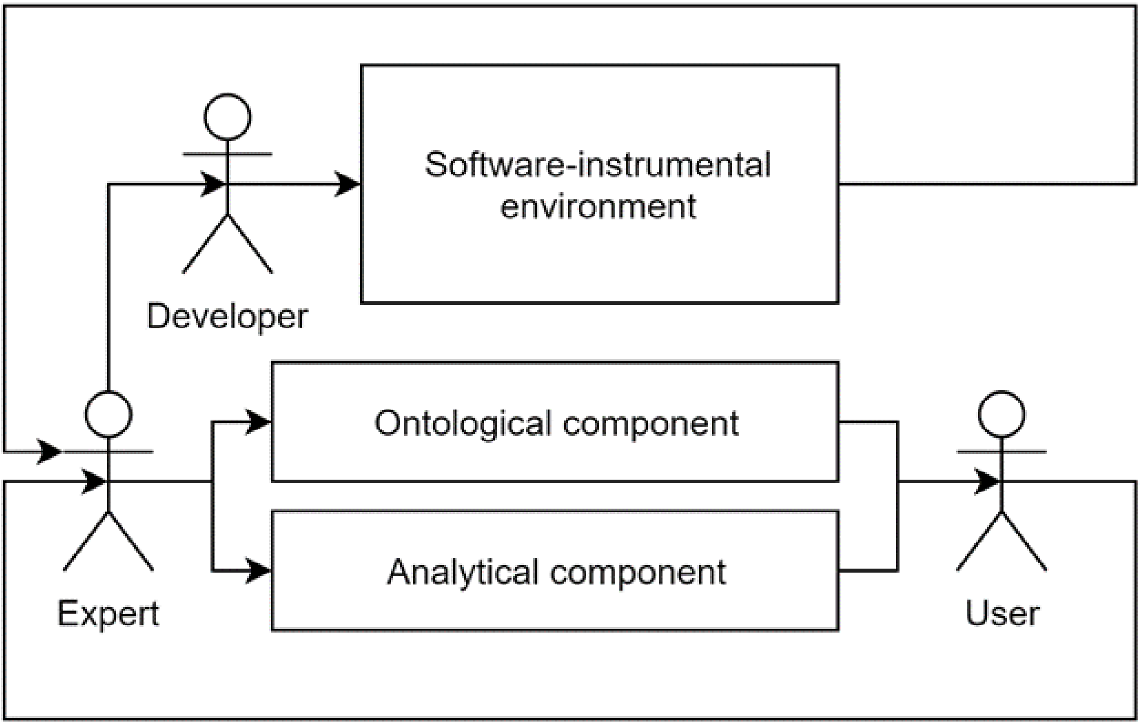

Figure 3: Illustration of the proposed approach to the development of information-analytical processes in the cyber-physical system

One of the possible solutions to the quality problem of source and analytical data in cyber-physical systems is the use of a neural network supervisor module that is able to verify data in real time. If there is a possibility of incorrect data entry or the appearance of incorrect analytical data, the supervisor reports this to the user involved in the information-analytical process. For additional training, the "Neural Network Supervisor" monitors the response of users to messages sent to them about possible errors. Also, training can take place under the supervision of a trained system user. Using the "Neural Network Supervisor" allows to improve the quality of the input data and strengthen control over the results of analytical processes.

3. The technique of developing information-analytical processes based on neuro-fuzzy Petri nets

In a situation then information-analytical processes for a cyber-physical system are developed by a group of experts, difficulties arise in unifying the intrasystem description of these processes. Experts, solving the same problem, can be guided by different logic, use a different sequence of steps.

As a result, when one expert needs to modify a process developed by another expert, he needs to spend time studying the code of process completely, and finding out all the details of the process, so that his modification does not break the algorithm of its work.

To accelerate the development of a new information-analytical process or reduce the time spent on familiarization with the process, it is necessary to transform the program code that implements the information-analytical process into a perceivable scheme. Using a schematic interface, expert can significantly speed up the development or modification of the structure of the information-analytical process.

As an example of the implementation of such a tool, we can consider the automatic construction of a process flowchart. The advantages of this approach include fast implementation, the ability to modify the information-analytical process right on the diagram. The disadvantages include too cumbersome representation of any large information-analytical process.

One of the successful and popular approaches for modeling and development is the use of a Petri net. However, classical Petri nets have a static flat structure, which is a significant drawback in the modeling and development of information-analytical processes, which use other information-analytical processes for their functioning.

As an effective approach to solving this problem, a method is proposed for modeling and developing information-analytical processes in cyber-physical systems based on fuzzy hierarchical Petri nets. Nested Petri nets are an extension of Petri nets, in which the tokens that define the net marking are themselves Petri nets.

The proposed method includes generalized stages of development, modeling, analysis and modification of information-analytical processes, which are iteratively repeated until the results meet the established criteria [2],[3],[4].

Modeling the information-analytical process is an important stage for analyzing the constructed process. The use of modeling helps to detect obvious defects and bottlenecks in the process.

Another important tool for analyzing a process modeled using a Petri net is the reachability graph. Having a reachability graph of the model, it is possible to check important behavioral properties - liveliness, fairness, safety - using automatic analysis, and detect such defects of behavior as dead ends, active locks, divergences, violations of mutual exclusion conditions, and others. To analyze all possible implementations of the model, it is necessary to build a complete reachability graph, which is possible for models with a finite state space. For systems that have a large number of states, or their number is not defined, it is possible to construct fragments of the state space. Such fragments can be limited by the maximum execution depth, the maximum time for building a fragment, the number of arcs selected for traversal in the branch nodes, or simply by the amount of memory available to the analysis system. Despite the incompleteness of the results obtained in the case of models with a large or infinite state space, the analysis of such fragments can reveal a large number of model defects [6].

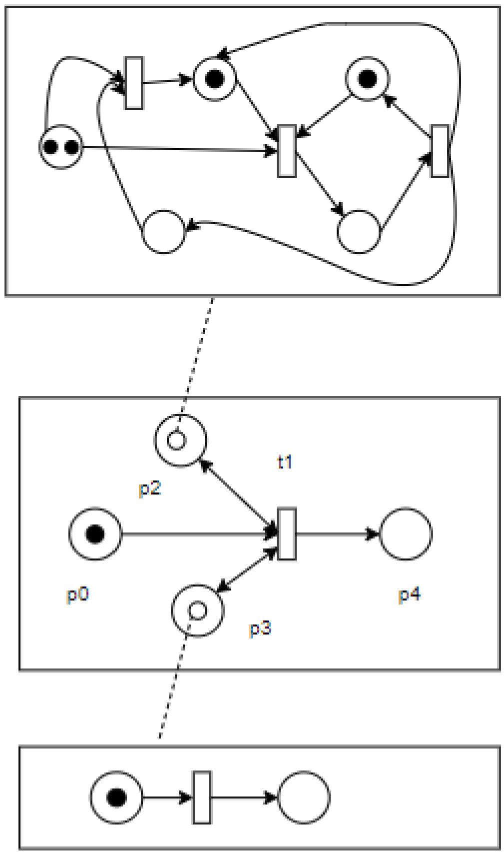

Figure 4: Illustration of the proposed approach to the development of information-analytical processes in the cyber-physical system

The use of hierarchical Petri nets in the development of information-analytical processes allows expert to break the process into sub-processes, and entrust their process to other experts. This approach allows expert to reduce the development time of the process, simplify its debugging and analysis, reduce the time for adjusting the process, and reduce the number of duplications when creating processes.

Using the apparatus of neuro-fuzzy Petri nets, it is possible to identify cyclical information-analytical processes - when information-analytical processes use the results of each other, perhaps not directly, but indirectly. This allows expert to avoid the creation of unnecessary processes in the system, and prevent possible errors in the development of information-analytical processes.

Petri nets can be used to analyze the current state of the process, as well as to identify the necessary conditions (for example, the presence of specific data) to complete the process.

Figure 4 shows the process of buying a new car using borrowed funds from a bank using the TRADE-IN system. The client arrives at the car dealership in his old car, in p2 - the bank on the basis of its own sources of information, information about the client takes out the maximum possible amount that the bank is able to borrow, and in p3 - the car dealership evaluates the client's old car in monetary terms. The p2 and p3 processes run in parallel, which reduces the client waiting time.

4. Organization of background information-analytical processes using a neuro-fuzzy hierarchical Petri net considering for example a queue of calculations

For the timely provision of the results of information-analytical processes, a subsystem is needed that will provide the results to user processes in a timely manner, and at the same time must use all the hardware capabilities of the system only when other subsystems do not need them.

Information-analytical processes can be divided into two groups:

- Processes that require obtaining the result of their functioning in real time. For example, the process of obtaining residual funds on the customer's balance before making a payment transaction.
- Processes that can provide a delayed result. For example, a process that receives information about user requests for the current month.

Information-analytical processes that take place in the system must respond to events (triggers) in order to provide relevant information. For example, a process that counts the number of child-objects should only be executed when child-objects are added / removed, but not every time the system state changes. The following triggers are proposed for organizing background information-analytical processes:

- Manual trigger is a way of performing an information-analytical process at the user's request.
- Automatic trigger is a method in which the moment of execution of an information-analytical process is determined by the system itself. For this trigger to work, a subsystem is needed that monitors changes in the system, and, if necessary, calculates the information-analytical process instantly, or puts it in a queue to obtain a result. The user has the opportunity to correct the parameters that were obtained as a result of the analysis by the subsystem of the information-analytical process, the changes of which must be monitored by the subsystem.
- A time trigger is a way of performing an information-analytical process after a given period of time. For example, once an hour, month, year, etc. The user enters the required interval, or intervals, and the subsystem, when the time comes, calculates the information-analytical process instantly, or puts it in a queue to obtain a result.
- Trigger on creation - a way to perform an information-analytical process when creating an object in the system. For example, when creating a child object. The user selects classes, when creating objects of which, the subsystem calculates the information-analytical process instantly, or puts it in a queue to obtain a result.
- Trigger on change — execution of an information-analytical process when the attributes of an object in the system change.
- Trigger on deletion — execution of an information-analytical process when an object is deleted from the system.

The use of a large number of triggers helps to better tune the information-analytical process, to minimize the number of “false” operations of the process, thereby reducing the “parasitic” load on the server on which the system is installed.

A subsystem has been developed for calculating information-analytical processes in the queue, built using the apparatus of hierarchical neuro-fuzzy Petri nets using fuzzy Kwan and Cai neurons [1]. By analyzing the parameters that will participate in the information-analytical process, the analytical parameters that await the calculation, the complexity of the calculation (the total estimate of the complexity of the functions used in the calculation) and the time the calculation is in the queue, the network redistributes the order of processes in the queue, setting them the appropriate priority.

The use of this approach shows its effectiveness in comparison with the calculation approaches, which were based only on the complexity of the calculation, or on the FIFO principle (English First In, First Out – “First in - first out”).

Figure 5 shows a fragment of a hierarchical neuro-fuzzy Petri net using Kwan and Cai neurons. Position p1 corresponds to a subnet that collects information about the parameters that will be used in the process, and also looks at their completeness and relevance, position p2 corresponds to a subnet that analyzes the current state of the system hardware (CPU load, amount of free resources), position p3 and p4 correspond information about the processes occurring on the input of information using various mechanisms, p3- processes of user import of information occurring in the system, p4- processes of obtaining information from other systems.

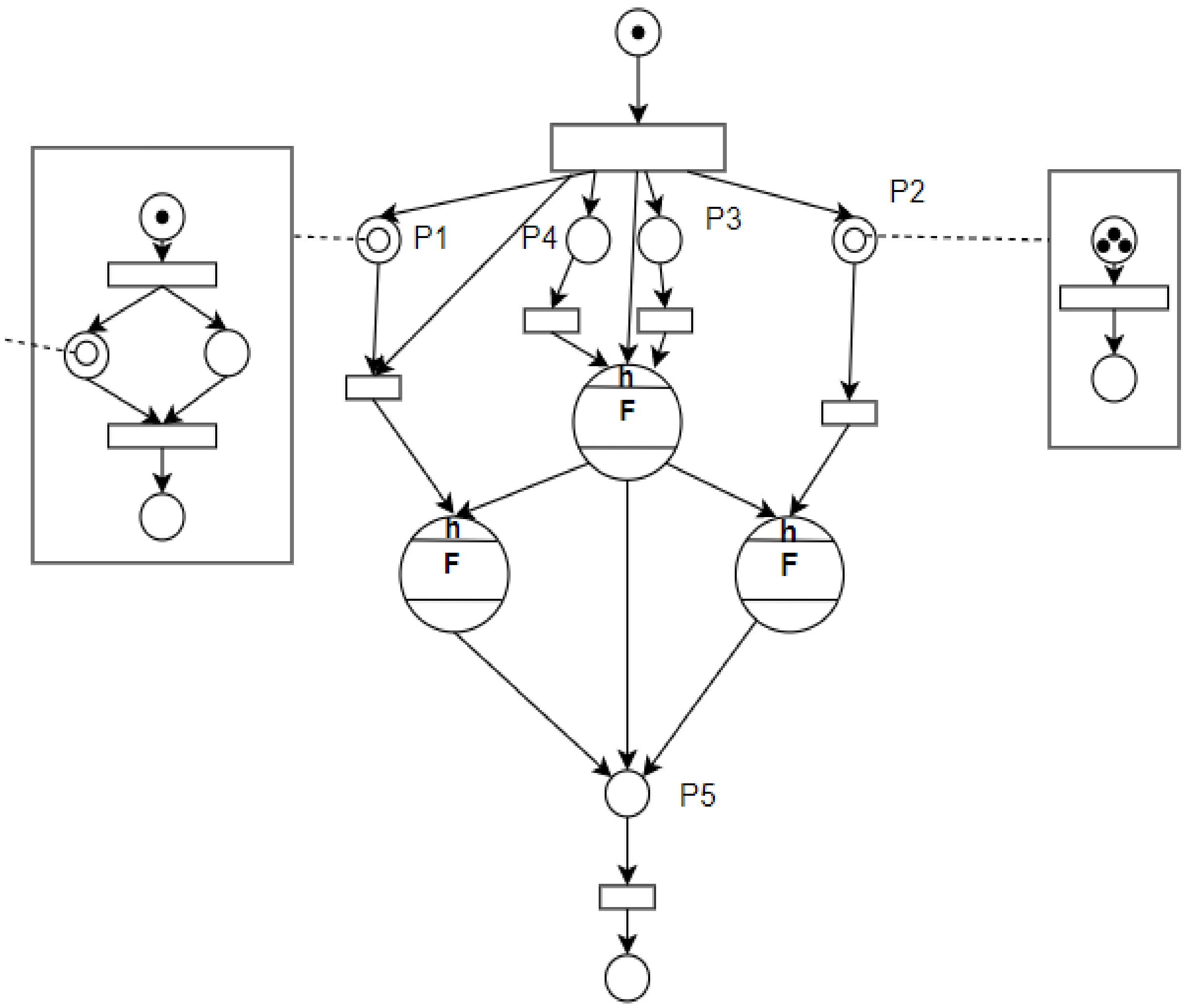

Figure 5: Fragment of a Petri net for the subsystem calculations queue

5. Conclusion

To eliminate the “semantic gap” between experts, architects and developers in the development of information-analytical processes in cyber-physical systems, an approach is proposed that consists in the coordinated use of ontological and analytical components that form a software-instrumental environment.

A system has been developed that is capable of:

- Store and process information.

- Possesses adaptability, and allows expert to work on devices with access to the internal network or the Internet.

- To build an information-analytical process, uses the mechanisms of constructors (WIZARD).

- Create, flexibly configure and promptly implement changes in information-analytical processes.

The "Class Tree" subsystem is responsible for building and modifying the data structure. The appearance of the subsystem is shown in Figure 6. For its work, this subsystem uses a subsystem to create information-analytical processes.

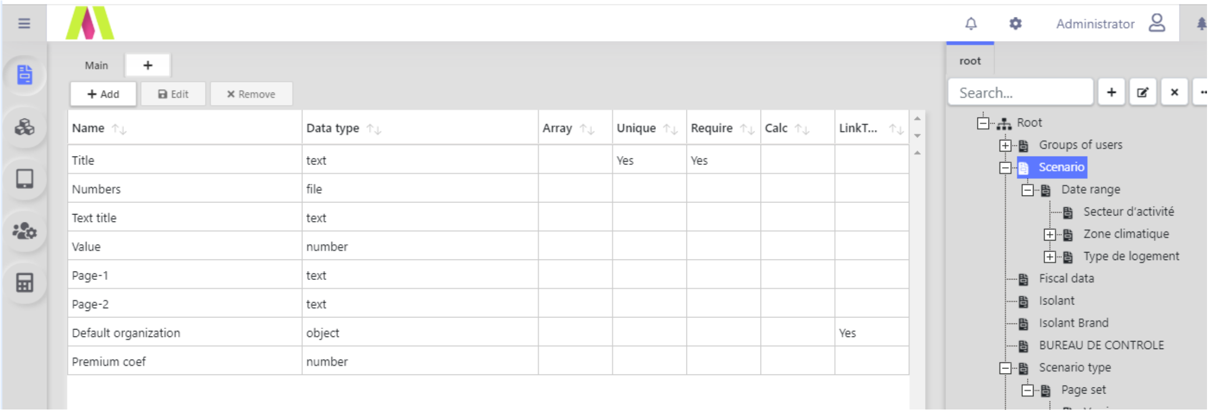

Figure 6: Screen form of the “Class tree” subsystem

For the formalization and development of information-analytical processes in cyber-physical systems, a variety of hierarchical neuro-fuzzy Petri nets is proposed, which adequately represents the structure and dynamics of changes in the state of these systems, the nodes and transition rules of which are formed on the basis of a neuro-fuzzy basis of operations, as well as providing an adaptive structural and parametric adjustment when changing system and external factors based on machine learning algorithms.

Figure 7 shows a screen form for developing information-analytical processes.

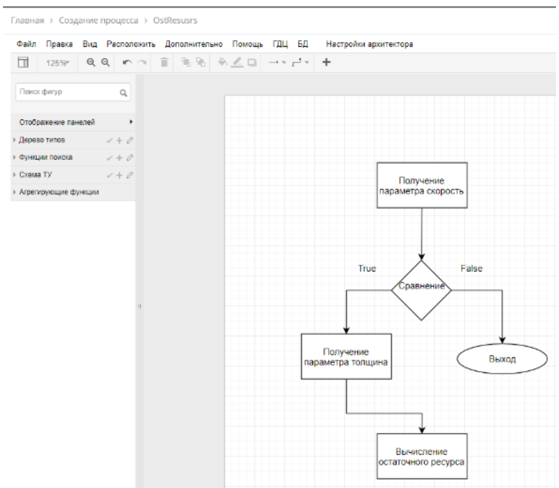

Figure 7: Screen form for developing information-analytical processes

A method is proposed for developing information-analytical processes in cyber-physical systems based on the proposed variety of hierarchical neuro-fuzzy Petri nets, which includes generalized stages of formalization, modeling, analysis and modification of information-analytical processes, which are iteratively repeated until the results are will meet the established criteria.

The proposed method allows diagnosing, determining the attainability of various events of information-analytical processes, their cyclical nature, as well as eliminating the "bottlenecks" of the processes. This, in turn, makes it possible to identify, avoid complicating processes, create unnecessary processes, reduce the number of false messages about the inadmissibility of their implementation, and, as a result, prevent possible errors in the development of information-analytical processes. The proposed method can also be used to monitor the state and control information-analytical processes in cyber-physical systems.

6. References

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