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TEMPORAL-ORIENTED MODEL OF CAUSAL RELATIONSHIP FOR CONSTRUCTING EXPLANATIONS FOR DECISION-MAKING PROCESS

Abstract. The **subject** of research in the article is the decision-making process in intelligent systems. The goal is to develop a model of the causal relationship between the states of the decision-making process in an intelligent information system, taking into account the temporal aspect of this process, in order to build cause-and-effect relationships between the actions of the process and further use these dependencies to form explanations for the sequence of actions to obtain a decision. The formation of causal relations between the states of the decision-making process makes it possible to substantiate the sequence of actions of this process, considering incomplete information regarding external influences on this process. **Tasks**: structuring the decision-making process in an intelligent information system as a specialized business process; development of a three-element model of the causal relationship between the states of the decision-making process, considering the temporal aspect of this process; substantiation of the possibility of using three-element relationships to build causal dependencies for decision making in intelligent systems. **The approaches used are**: the set-theoretical approach used to describe the elements of the decision-making process in intelligent systems; a logical approach that provides a representation of the relationship between the states of the decision-making process; probabilistic approach to describe the probabilistic component of the decision-making process. The following **results** are obtained. The decision-making process in an intelligent information system was structured as a specialized business process that, using additional information from the user, turns the input data into a result that is valuable for this user; a three-element model of the causal relationship between the states of the decision-making process is proposed, which makes it possible to take into account external influences on the process; using a probabilistic approach, the possibility of using three-element causal relations to describe the decision-making process in intelligent systems is substantiated, taking into account uncontrolled external influences. **Conclusions**. The scientific novelty of the obtained results is as follows. A three-element model of the causal relationship between the states of the decision-making process is proposed, based on a model of a temporal rule of the "future" type, containing a state-cause, a state-effect and an intermediate state that reflects external influences. The model makes it possible to build a base of cause-and-effect dependencies for the decision-making process in an intelligent information system, considering external influences and use these dependencies to build explanations for this process.

Keywords: intellectual system; explanation; decision-making process; temporality; causality.

Introduction

The decision-making process in intelligent systems today, as a rule, is based on the use of complex, "non-transparent" for the user computational intelligence algorithms. The use of such algorithms does not always allow the user to establish causal relationships between input data, external influences and the decision obtained by the information system. As a result, the user's confidence in the received decision may decrease [1]. This makes it difficult to use such a solution in practice. In order to solve this problem, the user should receive an explanation of the decision process [2, 3]. Such an explanation is based on the use of a chain of causal dependencies. The latter establish a cause-and-effect relationship between the input data and the resulting decision, considering current external influences [4, 5].

The explanation can be a component of the decision-making process, and can also be used as a supplement to this process [6]. In the first case, the decision-making algorithm should provide for the formation of cause-and-effect dependencies. The advantage of this approach is that the explanation can contain complete information about the decision-making process.

The disadvantage of the approach is that it complicates the implementation of the decision-making process in an intelligent system.

In the second case, the explanation is constructed in parallel with the decision-making process based on data on the actions of the process and its state. This approach makes it possible to supplement the existing intelligent systems with the possibilities of explaining the obtained solutions.

For example, supplement recommendations in e-commerce systems with explanations. However, such an "external" explanation does not always have full access to data regarding the state of the decision-making process and external or internal events that affect the sequence of actions of the process. Therefore, the problem of forming causal relations for constructing an explanation is relevant. The latter represent knowledge about the decision-making process in conditions of incomplete information about external and internal influences on this process.

Existing approaches to the construction of explanations regarding the sequence of decision-making in intelligent systems were formed within the framework of the Explainable Artificial Intelligence program [7]. One approach is to formulate explanations based on causal relationships. Such dependencies can be obtained as statistical regularities, formalized to predict the results of external influences [8], and also generalized to construct explanations [9, 10].

The decision-making process has a temporal aspect and therefore statistical regularities can be represented in the form of weighted temporal rules [11, 12]. These rules specify the order in time for pairs of states of the decision-making process [13, 14]. Dependencies can be specified for successive states (next-rules), as well as for states between which there are intermediate states (future-rules).

These intermediate states reflect changes in the course of the decision-making process, which arise as a result of additional external or internal influences. The weight of temporal rules determines their importance. The weight of each rule is set taking into account the probability of execution of alternative implementations of the decision-making process that use this rule [15]. However, within the framework of the temporal approach, causal relationships are considered insufficiently [16].

Existing approaches to the selection of causal dependencies are based on the use of a probabilistic d-separation approach both for individual variables and for structured entities [8].

However, such approaches determine statistical regularities [17]. It is not assumed that the probability distribution of the values of the relevant variables can change over time.

Thus, the combination of probabilistic and temporal approaches makes it possible to build causal relationships that can be used to explain the decision-making process in an intelligent information system. This problem needs its solution.

The aim of the article is to develop a model of the causal relationship between the states of the decision-making process in an intelligent information system, taking into account the temporal aspect of this process in order to build cause-and-effect dependencies between the actions of the process and subsequently use these dependencies to form explanations about the sequence of actions with receiving a decision.

The formation of causal relationships between states of the decision-making process makes it possible to justify the sequence of actions of this process, taking into account incomplete information about external influences on this process.

To achieve this goal the following tasks are solved:

– structuring of the decision-making process in the intellectual information system as a specialized business process;

– development of a three-element model of the causal relationship between states of the decision-making process, taking into account the temporal aspect of this process;

– justification of the possibility of using three-element relations to build causal dependencies for the decision-making process in intelligent systems.

Structuring the decision-making process

The decision-making process in an intelligent system as an object of research has a number of properties that are essential for building causal relationships that explain the sequence of reaching the resulting decision. We highlight the following key properties of this process, which make it possible to determine probabilistic causal relationships between the states of the information system:

– the decision-making process of a given technology transforms input data into an output that is of value to the user;

– the decision-making process provides a result in interaction with the user, that is, this process has executors;

– information about the execution of the process is recorded in the form of a sequence of events reflecting the sequence of execution of its actions.

Thus, this process has inputs, outputs, contains an algorithm for obtaining a result and uses information resources provided by the user. The decision-making process, taking into account these characteristics, can be presented in the form of a graph that displays possible sequences of actions to achieve the result. Such a graph contains one or more initial vertices, which reflect the receipt of input (input) data sets, the final vertex, which reflects the fact of obtaining the result.

The key elements of this process are presented in the Table 1.

Table 1 – **Elements of the decision-making process**

Element	Properties	Use in the construction of causal dependencies
Input	The data sets that define the resulting solution; for example, in the recommender subsystem, records about the choice of goods and services by users are used as input data	They set the initial state of the decision-making process and make it possible to represent this process as a generalized cause-and-effect relationship "input data - resulting decision"
Output	The resulting decision; for example, a recommendation to the user on the selection of goods or services in the e-commerce system	Sets the final state of the decision-making process and makes it possible to build a causal relationship with the maximum degree of generalization "input data - resulting decision"
Sequence of actions	Contains alternative options for obtaining a solution and can be represented by a directed acyclic graph; each of the alternative options for obtaining a decision is given by a path on the graph of the decision-making process.	Makes it possible to determine causal relationships between the actions of the decision-making process, which are true for several alternative options for performing such a process
Resource	Additional data provided by the user in the process of forming a decision; for example, information about the user's navigation through the pages of the e-commerce site.	Such additional data are not always available when determining causal dependencies in the decision-making process, as they are the result of external influence from the user of the intelligent system

In conclusion, the decision-making process has algorithmic and probabilistic components. The algorithmic component sets the sequence of decision-making actions for different options of input data, as well as data received from the user. The algorithmic component can be displayed in the form of a directed acyclic graph.

The probabilistic component reflects external and internal influences on the decision-making process as a result of, for example, the actions of the user of the intelligent system. The probability component specifies a specific path along the process graph depending on the user's actions.

An important characteristic of this process is that it should provide a useful solution for the user, taking into account both algorithmic and probabilistic components.

In general, the decision-making process has features of a business process, which makes it possible to use the concept of building a process model based on its logs to determine causal dependencies that determine cause-and-effect relationships between the actions of this process. The process model in this case is presented in the form of a directed acyclic graph.

The log contains records about the sequence of process events, i.e. about the implemented paths around the process graph. Each sequence of events reflects the process of forming a decision under relevant external influences.

That is, different user actions lead to different options for implementing such a process.

Accordingly, the process log contains traces of possible alternative options for its execution. Each trace consists of a sequence of events. Each of the events is a reflection of a certain action of the process. That is, it is appropriate to consider the event as a "snapshot" of the state of the decision-making process in the intellectual system. Therefore, the task of building causal relationships between the actions of the decision-making process can be transformed into the task of identifying cause-and-effect relationships between the states of this process.

It should be noted that the log usually does not contain a complete description of the process states, which does not make it possible to build deterministic dependencies between states. Therefore, when forming causal dependencies, it is necessary to take into account the probabilistic aspect.

That is, the choice of one of the log traces is determined by external or internal influence. External influences are set by the user. Internal influence is a probabilistic generalization of incomplete information regarding the decision-making process.

For example, a process model does not contain all intermediate states.

Temporal-oriented model of causal relationship

The process combines several sequences of states

$$S_i = \left\langle s_{i,1}, s_{i,2}, ..., s_{i,|S_i|} \right\rangle .$$

Such sequences may reflect the same causal relationship y_n^j between j and $n-$ states of the decision-making process.

For example, joint dependence y_3^1, for pairs of states $\langle s_{1,1}, s_{1,3} \rangle$ from the sequence S_1 and $\langle s_{2,1}, s_{2,3} \rangle$ from the sequence S_2.

The difference between these sequences arises as a result of the influences θ_1 and θ_2, which arise as a result of interaction with the user in the process of obtaining a decision.

Sequences of process S_i execution states are ordered in time. The temporal aspect of each state $s_{i,j}$ is recorded in the log in the form of time stamps $t_{i,j}$. That is, the condition is fulfilled for each pair of states $\langle s_{i,j}, s_{i,n} \rangle$:

$$\left(\forall \left\langle s_{i,j}, s_{i,n} \right\rangle \right) t_{i,j} < t_{i,n}, \qquad (1)$$

where $t_{i,j}, t_{i,n} -$ the instants of time when the states $s_{i,j}, s_{i,n}$ occur, respectively.

Thus, on the set of sequences

$$S = \{ S_i \}$$

there are temporal dependensies r_n^j that express ordered by time pairs of states $s_{i,j}, s_{i,n}$ on one or multiple sequences S_i.

A set of such rules represents temporal knowledge about decision-making processes. The use of weighted rules r_n^j makes it possible to form new sequences of states and order the obtained sequences according to the probability of their use.

The temporal approach cannot be used to construct explanations, since temporal relationships between process states do not always reflect causal dependencies between these states.

For example, a user's choice of a certain product in an e-commerce system over time is not always related to a change in his preferences or product properties. Such a choice can be, for example, the result of fulfilling another person's order.

In this example, the sequence of product selection is displayed with the help of a temporal dependence r_2^1: the selection of product 2 after the selection of product 1. At the same time, the presence of dependence r_2^1 does not indicate the existence of causal dependence y_2^1, which reflects a cause-and-effect relationship between the choice of goods. In this case, there is an unforeseen external influence (execution of an order from another user).

Information about this influence is absent in the description of the decision-making process (in particular, it is not recorded in the log of this process).

Therefore, when moving from temporal knowledge to causal dependencies, it is necessary to take into account possible external influences and responses to changes in the sequences of states of the decision-making process in the intelligent information system.

The problem in this case is the lack of information about external influences. However, we can take into concideration the consequenses of such influenses under conditions of the existanse at least one intermediate state $s_{i,m}$ between states $s_{i,j}, s_{i,n}$, so the temporal rule r_n^j set the following sequanse of states:

$$r_n^j = \left\{ \left\langle s_{i,j}, s_{i,m}, s_{i,n} \right\rangle \right\} : \quad (\forall i) t_{i,j} < t_{i,m} < t_{i,n}, \tag{2}$$

Such a rule r_n^j is a type of temporal rule of the "future" type [13]. In the general case, for a temporal rule of this type, there can be an arbitrary number of intermediate states between the initial and final states $s_{i,m}$.

This work is devoted to the detection of causal relationships based on temporal rules, so we will consider only a simple version of the rule connecting three states. Future - a rule with several intermediate states can be represented as a combination of several temporal rules with three elements.

Each of the sequences of three states will be considered as a model of the causal relationship $y_{i,n}^{i,j}$ on the path S_i provided that the last state $s_{i,n}$ depends only on the two previous ones.

That is, if the probability of its occurrence $P\left(s_{i,n}\right)$ is a function of the probabilities of occurrence of previous states:

$$y_{i,n}^{i,j} = = \left\langle s_{i,j}, s_{i,m}, s_{i,n} \right\rangle \Big| P\left(s_{i,n}\right) = F\left(P\left(s_{i,j}\right), P\left(s_{i,m}\right)\right), \tag{3}$$

where $P\left(s_{i,j}\right), P\left(s_{i,m}\right)$ – probabilities of occurrence of conditions $s_{i,j}, s_{i,m}$ on the sequence S_i.

We substantiate the possibility of constructing a causal relationship (3) in conditions of incomplete information regarding external influences on the process of decision formation in an intelligent system.

The probability of this relationship depends on the probability of uncontrolled influence $P\left(\theta_i\right)$, as well as on the probability of successive occurrence of states $s_{i,j}, s_{i,m}, s_{i,n}$ on the sequences S_i:

$$P\left(y_{i,n}^{i,j}\right) = \sum_{i:\forall S_i \exists y_{i,m}^{i,j}} \left(P\left(\theta_i \,\middle|\, \exists\theta_i\right) P(s_{i,m} \,|\, \exists s_{i,j} : t_{i,m} > t_{i,j} \right) * \quad * P\left(s_{i,n} \,\middle|\, \exists s_{i,m} : t_{i,n} > t_{i,m}\right). \tag{4}$$

Since the intermediate state $s_{i,m}$ makes it possible to represent the future rule as two consecutive next rules [13].

We know the results of the first rule, so we will consider the uncontrolled external influence within the framework of the second rule, during the transition $\left\langle s_{i,m}, s_{i,n} \right\rangle$:

$$P(y_{i,n}^{i,j}) = P\left(s_{i,m} \,\middle|\, \exists s_{i,j} : t_{i,m} > t_{i,j}\right) * \sum_{i:\forall S_i \exists y_{i,m}^{i,j}} \left(P\left(\theta_i \,\middle|\, \exists\theta_i\right) P\left(s_{i,n} \,\middle|\, \exists s_{i,m} : t_{i,n} > t_{i,m}\right)\right). \tag{5}$$

In expression (5), we take into account the transition probabilities $\left\langle s_{i,m}, s_{i,n} \right\rangle$ for all possible influences θ_i, that is, on all trajectories known from the log along the directed acyclic graph of the decision-making process.

Therefore, the probability of dependence $P(y_{i,n}^{i,j})$ can be calculated as follows:

$$P\left(y_{i,n}^{i,j}\right) = P\left(s_{i,m} \,\middle|\, \exists s_{i,j} : t_{i,m} > t_{i,j}\right) P\left(s_{i,n} \,\middle|\, \exists s_{i,m} : t_{i,n} > t_{i,m}\right) \Big| \forall S_i \exists y_{i,n}^{i,j}. \tag{6}$$

According to expression (6), the three-element relationship $y_{i,n}^{i,j}$ is a causal relationship, since the probability of the resulting state $s_{i,n}$ depends only on the probability of the occurrence of two previous states $s_{i,j}, s_{i,m}$ and does not depend on the probability of uncontrolled influences.

Each state $s_{i,j}, s_{i,m}, s_{i,n}$ according to approach which was introduced in [5] is given by the set of the property values.

Such properties can reflect the objects with which the decision-making process operates, as well as the actions of this process.

Therefore, model (3) specifies a causal relationship between states that are described by heterogeneous variables. The distribution of variables differs. Also, the distribution may change over time [18].

Conclusions

The structuring of the decision-making process in the intelligent information system as a specialized business process, which, with the use of additional information from the user, transforms input data into a result that is valuable for this user.

The sequence of works of this process is represented by a time-ordered directed acyclic graph, each vertex of which reflects the state of the decision-making process after the corresponding action is performed.

The process graph combines possible variants of its implementation taking into account external influences from the user. The given structuring makes it possible to identify causal relationships between states of the decision-making process taking into account external influences based on existing temporal dependencies for pairs of states. Such temporal dependencies determine the ordering of process states in time, but do not always reflect the cause-and-effect relationships between states that arise as a result of the implementation of process actions.

A three-element model of the causal relationship between states of the decision-making process, based on the model of a temporal rule of the "future" type, is proposed.

The model contains a time-ordered sequence of three states. The first of the states reflects the cause, and the last - the effect.

The intermediate state makes it possible to take into account additional external influences, information about which is missing in the description of the decision-making process.

The proposed causal relationship model makes it possible to establish cause-and-effect relationships between states of the decision-making process on the basis of temporal relations between these states. Such relationships can later be combined into causal dependencies reflecting the connections between the actions of the decision-making process and used to build explanations in intelligent information systems.

The possibility of using three-element relationships to build causal dependencies for the decision-making process in intelligent systems is substantiated. The elements of the relation are the sequence of states of the decision-making process.

It is shown that this relationship makes it possible to take into account unknown external influences on the decision-making process.

That is, the probability of reaching the final state depends on the probability of the first and intermediate states of this process.

Thus, the proposed approach makes it possible to establish cause-and-effect relationships between the actions of the decision-making process in conditions of incomplete information regarding this process.

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Темпорально-орієнтована модель каузального відношення для побудови пояснень щодо процесу прийняття рішення

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Анотація. Предметом вивчення в статті є процес прийняття рішення в інтелектуальних системах. **Метою** є розробка моделі каузального відношення між станами процесу прийняття рішення в інтелектуальній інформаційній системі з урахуванням темпорального аспекту даного процесу з тим, щоб побудувати причинно-наслідкові залежності між діями процесу та в подальшому використати ці залежності для формування пояснень щодо послідовності дій з отримання рішення. Формування каузальних відношень між станами процесу прийняття рішення дає можливість обґрунтувати послідовність дій даного процесу з урахуванням неповної інформації щодо зовнішніх впливів на даний процес. **Завдання**: структуризація процесу прийняття рішень в інтелектуальній інформаційній системі як спеціалізованого бізнес-процесу; розробка трьохелементної моделі каузального відношення між станами процесу прийняття рішення з урахуванням темпорального аспекту даного процесу; обґрунтування можливості використання трьохелементних відношень для побудови каузальних залежностей для процесу прийняття рішення в інтелектуальних системах. Використовуваними **підходами** є: теоретико-множинний підхід, який застосовується для опису елементів процесу прийняття рішення в інтелектуальних системах; логічний підхід, який забезпечує представлення відношень між станами процесу прийняття рішення; ймовірнісний підхід для опису ймовірнісної складової процесу прийняття рішення. Отримані наступні **результати**. Виконано структуризацію процесу прийняття рішень в інтелектуальній інформаційній системі як спеціалізованого бізнес-процесу, який, з використанням додаткової інформації від користувача, перетворює вхідні дані у результат, що становлять цінність для цього користувача; запропоновано трьохелементну модель каузального відношення між станами процесу прийняття рішення, що дає можливість врахувати зовнішні впливи на процес; з використанням ймовірнісного підходу обґрунтовано можливість використання трьохелементних каузальних відношень для опису процесу прийняття рішення в інтелектуальних системах з урахуванням неконтрольованих зовнішніх впливів. **Висновки**. Наукова новизна отриманих результатів полягає в наступному. Запропоновано трьохелементну модель каузального відношення між станами процесу прийняття рішення, що базується на моделі темпорального правилу типу «future», містить стан-причину, стан-наслідок та проміжний стан, що відображає зовнішні впливи. Модель дає можливість побудувати базу причинно наслідкових залежностей для процесу прийняття рішення в інтелектуальній інформаційній системі з урахуванням зовнішніх впливів та використати ці залежності для побудови пояснень щодо даного процесу.

Ключові слова: інтелектуальна система; пояснення; процес прийняття рішення; темпоральність; причинно-наслідковий зв'язок.