Intelligent information systems

UDC 004.891.3 DOI: https://doi.org/10.20998/2522-9052.2022.2.08

Serhii Chalyi, Volodymyr Leshchynskyi

Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

TEMPORAL REPRESENTATION OF THE ESSENCES OF THE SUBJECT AREA FOR THE CONSTRUCTION OF EXPLANATIONS IN INTELLIGENT SYSTEMS

Abstract. The **subject** of research in the article is is the processes of constructing explanations in intelligent systems using causal relationships. The aim is to develop a representation of the entities of the subject area, taking into account the temporal aspect in order to represent the binary relations in time between the properties of the same entity. The construction of temporal relations between the properties of entities makes it possible to determine the probabilistic causal relationships between the states of these entities and use these dependencies to form explanations for the implemented decision-making process in the intelligent system, taking into account possible alternatives. **Tasks**: structuring the objects of the subject area, taking into account their essential properties for the decision-making process, including temporal; definition of classes of essences of subject area; determination of equivalence classes of entities of the subject area taking into account changes in the properties of these entities over time; development of a temporal model of representation of essences of subject area for construction of explanations in intellectual systems on the basis of definition of dependences in time between properties of essences. **The approaches used** are: set-theoretic approach, which is used to describe the classes of entities and classes of equivalence of entities of the subject area; linear temporal logic, which provides a representation of the relationship between entities in the temporal aspect. The following **results** were obtained. The structuring of the objects of the subject area is performed taking into account their properties, which are used in the decision-making process in the intellectual system; defined classes of entities; the classes of equivalence of entities of the subject area are defined as a kind of class of entities with the same values of key attributes, which makes it possible to take into account changes in these values over time; a temporal model of representation of the essences of the subject area is developed, which takes into account their static, dynamic properties and properties of time. **Conclusions**. The scientific novelty of the results is as follows. An equivalence class for entities is distinguished, which contains entities with the same key static properties and different dynamic properties considering the time of their change, which allows to reflect changes in the state of the entity in the decision-making process in the intelligent system. The temporal model of representation of essences of subject area which contains classes of equivalence of essences, and also temporal communications between properties of elements of these classes is offered. The selection of classes of equivalence of entities makes it possible to present the decision-making process in the intellectual system in the form of a sequence of temporal connections between the properties of entities of the subject area, and to form on this basis casual relationships between states of entities.

Keywords: intellectual system; explanation; essence; causality; causation; temporality.

Introduction

Today, intelligent systems use sophisticated decision-making algorithms that are not "transparent" to users of such systems. The user usually uses only those solutions that match his requirements and that he trusts. Therefore, it is important to ensure user confidence in the results of the intelligent system, making "transparent" causal dependencies that justify the decision [1].

For example, the choice of items offered by the recommendation system (goods, films, conferences, etc.) largely depends on the user's trust in the proposals received [2]. If the user believes that the proposed items are not in his interests, but the interests of the owners of the recommendation system, he will not take into account the recommended items in his choice.

Explanations in the form of a sequence of causal relationships that make the decision-making process "transparent" and the intelligent system, allow the user to understand why such a decision was made [3]. Presentation of the explanation in the form of a set of causal dependencies makes it possible to compare the obtained and alternative solutions. Decisions to be made on the basis of counterfeits are considered as alternatives. The latter are facts of possible actions that have not yet been implemented in practice [4]. As a result, a comparison of the solution obtained by the intelligent system and alternative solutions can be used as an explanation [5]. This comparison allows the user to make sure that the solution is the most effective given the requirements. Therefore, the use of explanations based on causal relationships makes it possible to increase user confidence in the results of the intelligent system.

To obtain causal dependencies that explain the results of the intelligent system, it is necessary to take into account the relationships between objects (entities) of the subject area used in the decision-making process. Dependencies between entities can be static or dynamic. The first reflect the constant properties of the subject area. They act as restrictions when performing actions in the intelligent system. The second reflects changes in the state of entities in the decision-making process and is based on the temporal relationship between the properties of such entities.

The relevance of the topic of this work is due to the fact that the formal description of the essence of the subject area, taking into account the temporal aspect makes it possible to build temporal and then causal relationships that reflect the relationship between input and intelligent solutions. Such dependencies make it possible to explain the reasons for the decision and, accordingly, increase user confidence [6, 7].

Modern approaches to building causal relationships to obtain explanations are being developed according to the XAI (Explanable Artificial Intelligence) program [8]. These approaches are based on a three-level hierarchy of causality [9].

The first level reflects the existing statistical patterns, the second - the impact of causal relationships on new results, and the third is the level of explanation of causal relationships [10].

In [11, 12] relational models of the set of entities of the subject area are substantiated and proposed and the importance of using such models to build causal dependencies using d-separation for connections of entities that are not identically distributed is substantiated. However, this approach focuses mainly on static relationships between entities and does not take into account the change of such relationships over time when performing the process of decision making in an intelligent system.

Temporal relationships between the states of the decision support process were considered in [13-15]. Such dependencies make it possible to order states that occur directly after each other [14], or have intermediate states [15]. The proposed approaches to the construction of temporal dependences [16, 17] make it possible to build statistical relationships between states. However, in the selection of such states, insufficient attention is paid to the relationship between the properties of the entities of the subject area. These connections directly affect the decision-making process, as well as reflect the results of this process. Taking into account such relationships makes it possible to justify the sequence of actions of the decision-making process in the intelligent system.

Thus, the construction and use of the temporal representation of entities makes it possible to build causal relationships based on the relationships between the properties of entities that change over time. Such dynamic dependencies create conditions for adaptation of the explanation in the decision-making process taking into account current requirements of the user and external influences.

The aim of the article is to develop a representation of the entities of the subject area, considering the temporal aspect in order to present binary relationships in time between the properties of the same entity.

The construction of temporal relationships between the properties of entities makes it possible to determine the probabilistic causal relationships between the states of these entities and use these relationships to form explanations for the implemented decision-making process in the intelligent system, taking into account possible alternatives based on counterfeits.

To achieve this goal the following tasks are solved:

– structuring the essences of the subject area, taking into account their essential properties for the decision-making process, including temporal;

– definition of classes of entities of the subject area;

– determination of equivalence classes of entities of the subject area, considering changes in the properties of these entities over time;

– development of a temporal model of representation of essences of subject area for construction of explanations in intellectual systems on the basis of definition of dependences in time between properties of essences.

Temporal representation of the essences of the subject area as objects of the decision-making process in the intellectual system

The essences of the subject area used in the decision-making process are characterized by many properties.

A structured description of these properties is given in the Table 1.

Table 1 – **Structuring the properties of entities used in the decision-making process**

Properties	Differences	Use in constructing explanations
Key (static)	Define the essence throughout the decision-making process	Set limits on possible actions with entities
Dynamic	Determine the state of the entities in the decision-making process	Reflect the temporal relationships between the actions of the decision-making process
Temporal	Moments of time or time intervals	Determine the periods of relevance of the dynamic properties of the entity

Entity properties can be static or dynamic. The first are key to the essence and characterize it throughout the decision-making process. The second characterizes the current state of the essence, i.e. changes over time. To compare entities and select classes of similar entities, it is necessary to take into account their static properties. The sequence of actions of the decision-making process in the intelligent system is reflected through the sequence of states of entities in time. Therefore, the dynamic properties of entities make it possible to reflect the temporal relationships between the actions of the decision-making process. Since temporal connections reflect causal relationships between the actions of the decision-making process, their generalization makes it possible to build probabilistic causal relationships for the decision-making process.

Formally define the essence of the subject area from the standpoint of their use in the decision-making process. Each entity e_j is characterized by properties (attributes) $b_j^{(k)}$ that are essential to the decision-making process, forming a subset: $B_j \subseteq B$:

$$B_j = \left\{ b_j^{(k)} \right\}, k = \overline{1, K}. \quad (1)$$

Properties (1) determine the differences of the entity, its state, the operations performed by the entity, the time intervals in which these properties are valid.

For example, for the object "Contractor" such properties may be:

$b_1^{(1)}$ – role that determines the competencies of the employee,

$b_1^{(2)}$ – salary,

$b_1^{(3)}$ – date from which the contractor receives this salary.

The attributes of the "Goods" object in the recommendation system, for example, are:

$b_2^{(1)}$ – cost,

$b_2^{(2)}$ – time for which the value was determined,

$b_2^{(3)},...,b_2^{(K)}$ – user properties that are of value to the consumer and which were used in the construction of recommendations.

A set of domain objects consists of subsets of similar entities that have the same set of properties. Such subsets represent classes of entities.

Definition 1. The entity class E_i of the domain є is a set of entities $e_{i,j}$ with the same finite set of properties - attributes:

$$E_i = \left\{ e_{i,j} : (\forall j) \exists B_i = \left\{ b_i^{(k)} \right\} \right\}. \quad (2)$$

Each of the attributes $b_i^{(k)}$ has a finite set of values $C_i^{(k)}$, and the values $c^{(q,l)}$, $c^{(k,l)}$ of the different attributes $b_i^{(q)}$ та $b_i^{(k)}$ do not match:

$$C_i^{(k)} = \left\{ c^{(k,l)} : (\forall q \neq k)\; c^{(q,l)} \neq c^{(k,l)} \right\}. \quad (3)$$

According to (3), the set of attributes B_i determines the set of possible values of the properties of the entities included in the class E_i. That is, each class is defined by a set of valid attribute values:

$$E_i = \left\{ e_{i,j} \,\middle|\, (\forall j \forall k) c_{i,j}^{(k,l)} \in C_i^{(k)} \right\}. \quad (4)$$

Note that subsets $C_i^{(k)}$ differ for entities of different classes, ie for classes E_h and E_i with sets of values k – attribute $C_h^{(k)}$ and $C_i^{(k)}$ accordingly the condition is satisfied:

$$(\forall E_i) \exists h \neq i : C_h^{(k)} \neq C_i^{(k)}. \quad (5)$$

For example, for the “Performer” and “Unit Manager” classes, the possible values for the “Role” attribute will be different.

According to (4) and (5), each instance $e_{i,j}$ of a class entity E_i s completely specified by a set of values of its attributes $\left\{ c_{i,j}^{(k,l)} \right\}$:

$$e_{i,j} = \left\{ c_{i,j}^{(k,l)} \right\}. \quad (6)$$

Information about the essence can be obtained at different times in the formation of decisions in the intelligent system. Therefore, elements of a class E_i can represent one entity in different states. Each state is determined by the current attribute values $b_i^{(k)}$. The state of the decision-making process in the intellectual system contains a set of states of entities with which this process operates.

Changing the state of entities is associated with the implementation of actions in the decision-making process.

Therefore, the study of transitions between states makes it possible to identify causal links between these actions.

According to the performed structuring, the set of attributes B_i of each entity $e_{i,j}$ contains subsets of key attributes B_i^{key}, attributes with variable values $B_i^{dynamic}$, and time attributes: B_i^{time}:

$$B_i = B_i^{key} \cup B_i^{dynamic} \cup B_i^{time}. \quad (7)$$

Key attributes distinguish between entities. These attributes do not change in the decision-making process in the intelligent system, they are static. Attributes with variable values characterize the state of the entity and change over time.

Time attributes define the time points or time interval for which the values of the attributes in the subset $B_i^{dynamic}$ are valid.

Selecting a subset of key properties B_i^{key} makes it possible to compare entities and combine identical entities into equivalence classes. We consider entities to be equivalent when they have the same values of key attributes. That is, equivalent entities differ only in their state.

Based on the definition of the set of attributes (7), we introduce the equivalence relation of entities.

Definition 2. The equivalence relation of entities $e_{i,j} \sim e_{i,m}$ from one class E_i is a binary relation that is satisfied in case of coincidence of values $c_{i,j}^{k,l}$ and $c_{i,m}^{k,l}$ of the key attributes of these entities:

$$e_{i,j} \sim e_{i,m} : (\forall k \forall l) c_{i,j}^{k,l} = c_{i,m}^{k,l} \,\middle|\, (\forall k) b_i^{(k)} \in B_i^{key}. \quad (8)$$

This relationship makes it possible to determine the equivalence of instances of the same entity at different times

Therefore, expression (8) considers only the attributes of the subset B_i^{key} and does not consider the variable properties and attributes of time.

The equivalence relation has the properties of symmetry, reflectivity and transitivity.

The first property specifies the equivalence of entity $e_{i,j}$ and $e_{i,m}$ from class E_i instances if attribute values were fixed at different times t_m and t_j:

$$(\forall j \forall m)\left(e_{i,j} \sim e_{i,m}\right) \Rightarrow \left(e_{i,m} \sim e_{i,j}\right), t_m \neq t_j. \quad (9)$$

The property of reflectivity determines the equivalence of the same entity in different decision-making processes in an intelligent system that run simultaneously:

$$(\forall j \forall i)\left(e_{i,j} \sim e_{i,j}\right). \quad (10)$$

The property of transitivity for entities of one class is defined as follows:

$$(\forall j \forall g \forall m)\left(e_{i,j} \sim e_{i,g}\right) \wedge \left(e_{i,g} \sim e_{i,m}\right). \quad (11)$$

In accordance with (11), the set of equivalent entities can be supplemented at each implementation of the decision-making process in the intelligent system. In addition, information about new entities is compared with known entities $e_{i,j}$.

Thus, it is possible to compare equivalent instances of the entity that were involved in the decision-making process at different points in time. Such entities constitute a class of equivalence.

Definition 3. The equivalence class $[e_i]$ contains instances of the entity $e_{i,j}$, that are related by the equivalence relationship (ie have identical values of the key attributes:

$$[e_i] = \left\{e_{i,j} : (\forall i) e_i \sim e_{i,j}\right\}. \quad (12)$$

Thus, an entity class E_i is an equivalence class $[e_i]$ if its elements $e_{i,m} \neq e_{i,j}$ contain the same attribute values $c_{i,m}^{k,l} = c_{i,j}^{k,l}$ from the set: B_i^{key} :

$$E_i \equiv$$
$$\equiv [e_i] \Big| \left(\forall k : b_i^{(k)} \in B_i^{key}\right)\left(\forall e_{i,m} \neq e_{i,j}\right) c_{i,m}^{k,l} = c_{i,j}^{k,l}. \quad (13)$$

The practical significance of expression (13) is the ability to combine in one class of equivalence all records of the use of essence $e_{i,j}$ in different implementations of the decision-making process in the intelligent system.

For example, for a recommendation system, information about the nature of the product "Painting" may contain attributes of the name and author of the painting. These attributes belong to the set B_i^{key} . The attribute "Price" belongs to the set $B_i^{dynamic}$. The set B_i^{time} contains the attribute “Date”, which indicates the date the price changed.

The elements $e_{i,j}$ of each equivalence class differ only in the values of the properties from the subset $B_i^{dynamic}$ indicating the time when this value was set. This makes it possible to set binary temporal relationships $r_{i,j}^{i,s}$ (for a pair of elements) between an attribute $b_{i,j}^{(k)}$ and в $b_{i,m}^{(k)}$ for an entity from class $[e_i]$ at time points $t_m > t_j$.

Temporal dependence is set by the temporal operator O :

$$r_{j,m}^{i,k} = b_{i,j}^{(k)} O b_{i,m}^{(k)} \quad (13)$$

Equation (12) specifies the binary temporal relationship between the elements of the class $[e_i]$. This relationship, depending on the temporal operator, sets the following sequence of changes in the value of the k – attribute of the e_i entity:

– the value of the attribute changes to the next discrete point in time t_m after the current moment t_j ;

the value of the attribute changes at one of the following time points, ie there may be intermediate time points between t_j and t_m ;

– the value of the attribute changes when a certain condition is met.

The temporal entity set model includes entity equivalence classes and binary temporal relationships between entity instance attributes within a single equivalence class $[e_i]$:

$$E = \left\{[e_i], \left\{r_{i,m}^{i,j}\right\}\right\}. \quad (14)$$

Consider an example of the implementation of such a model to describe the entities with which the recommendation system operates when building a recommended list of goods and services.

An example of recording five instances of the "4 PURPLE FLOCK DINNER CANDLES" entity is shown in the Fig. 1.

StockCode	Description	Quantity	InvoiceDate	UnitPrice
72800B	4 PURPLE FLOCK DINNER CANDLES	2	01.12.2010 12:49	2,55
72800B	4 PURPLE FLOCK DINNER CANDLES	12	05.12.2010 10:52	2,55
72800B	4 PURPLE FLOCK DINNER CANDLES	2	20.12.2010 13:43	5,06
72800B	4 PURPLE FLOCK DINNER CANDLES	1	05.01.2011 15:56	2,55

Fig. 1. Description of instances of entities

Static properties are StockCode, Description. Dynamic properties are Quantity, InvoiceDate, UnitPrice. Temporal dependencies, in particular, for the attribute UnitPrice are

$$(UnitPrice = 2{,}55)\,O\,(UnitPrice = 5{,}06),$$

for the Quantity attribute are

$$(Quantity = 2)\,O\,(Quantity = 12).$$

Conclusions

The structuring of the essences of the subject area is performed taking into account their properties, which are used in the decision-making process in the intellectual system.

Structuring has shown that the construction of causal dependencies on the decision-making process is based on the formation of temporal relationships between the properties of these entities.

Binary temporal connections are typical of entity equivalence classes. They reflect the change in the value of one of the attributes of the entity over time.

The set of temporal connections reflects the decision-making process in the intelligent system. Therefore, the comparison of current, implemented dependencies with possible alternatives provides an opportunity to build explanations for this process.

An equivalence class for entities that contains instances with the same key static properties and different dynamic properties, taking into account the time of their change, which allows to reflect changes in the state of the entity in the decision-making process in the intelligent system.

The temporal model of representation of essences of subject area which contains classes of equivalence of essences, and also temporal communications between properties of elements of these classes is offered. The selection of classes of equivalence of entities makes it possible to present the decision-making process in the intellectual system in the form of a sequence of temporal connections between the properties of entities of the subject area, to form on this basis casual relationships between states of entities and construct explanations.

REFERENCES

1. Tintarev N., Masthoff J. (2007) A survey of explanations in recommender systems. _The 3rd international workshop on web personalisation, recommender systems and intelligent user interfaces (WPRSIUI'07)._. P. 801-810.
2. Tintarev N., Masthoff J. (2012), “Evaluating the effectiveness of explanations for recommender systems”, User Model User-Adap Inter., Vol. 22, pp. 399– 439, https://doi.org/10.1007/s11257-011-9117-5.
3. Halpern J. Y. and Pearl J. (2005), “Causes and explanations: A structural-model approach. Part I: Causes”, The British Journal for the Philosophy of Science, Vol. 56 (4), pp. 843-887.
4. Чалий С. Ф., Лещинський В. О., Лещинська І. О. (2021) Контрфактуальна темпоральна модель причинно-наслідкових зв'язків для побудови пояснень в інтелектуальних системах,/ Вісник Національного технічного університету "ХПІ". Сер. : Системний аналіз, управління та інформаційні технології = Bulletin of the National Technical University "KhPI". Ser. : System analysis, control and information technology : зб. наук. пр. – Харків : НТУ "ХПІ", № 2 (6), С. 41-46.
5. . Miller T. (2019), “Explanation in artificial intelligence: Insights from the social sciences”, Artificial Intelligence, vol. 267, pp.1-38, DOI: https://doi.org/10.1016/j.artint.2018.07.007
6. Левикін В. М., Чала О. В. (2018), Підтримка прийняття рішень в інформаційно-управляючих системах з використанням темпоральної бази знань. Сучасні інформаційні системи. Том 2, № 4. С. 101-107. DOI: 10.20998/2522-9052.2018.4.17.
7. Castelvecchi D. (2016), “Can we open the black box of AI?” Nature, Vol. 538 (7623), pp. 20-23.
8. D. Gunning i D. Aha, (2019) “DARPA’s Explainable Artificial Intelligence (XAI) Program”, AI Magazine, Vol. 40(2), pp.44-58, doi: 10.1609/aimag.v40i2.2850.
9. Pearl J (2009) Causality: Models, Reasoning and Inference, 2nd ed. Cambridge University Press, USA.
10. Halpern J. Y., Pearl J. (2005), Causes and explanations: A structural-model approach. Part II: Explanations. The British Journal for the Philosophy of Science. Vol.56 (4). P. 889-911.
11. . Maier M, Marazopoulou K, Jensen D (2014) Reasoning about Independence in Probabilistic Models of Relational Data. arXiv
12. Marazopoulou, Katerina, Maier, Marc, and Jensen, David. Learning the structure of causal models with relational and temporal dependence. In Proceedings of the Thirty-First Conference on Uncertainty in Articial Intelligence (2015).
13. Chalyi, S., & Leshchynskyi, V. (2020). Temporal representation of causality in the construction of explanations in intelligent systems. Advanced Information Systems, 4(3), 113–117. https://doi.org/10.20998/2522-9052.2020.3.16
14. Chala O. (2018) Models of temporal dependencies for a probabilistic knowledge base. Econtechmod. An International Quarterly Journal. Vol. 7, No. 3. P. 53 – 58.
15. Чала О. В. (2020) Модель узагальненого представлення темпоральних знань для задач підтримки управлінських рішень. Вісник Національного технічного університету «ХПІ». Системний аналіз, управління та інформаційні технології. № 1(3). С. 14-18. DOI: 10.20998/2079-0023.2020.01.03.
16. Chalyi S., Leshchynskyi V. and Leshchynska I. (2019), Modeling explanations for the recommended list of items based on the temporal dimension of user choice. Control, navigation and communication systems, Vol. 6 (58), pp. 97-101. doi:https://doi.org/10.26906/SUNZ.2019.6.097.
17. Chala O. (2019), Development of information technology for the automated construction and expansion of the temporal knowledge base in the tasks of supporting management decisions. *Technology audit and production reserves*. Vol. 1/2(45). P. 9-14. DOI: 10.15587/2312-8372.2019.160205.

Received (Надійшла) 22.02.2022
Accepted for publication (Прийнята до друку) 28.04.2022

ВІДОМОСТІ ПРО АВТОРІВ / ABOUT THE AUTHORS

Чалий Сергій Федорович – доктор технічних наук, професор, професор кафедри інформаційних управляючих систем, Харківський національний університет радіоелектроніки, Харків, Україна;
Serhii Chalyi – Doctor of Technical Sciences, Professor, Professor of Professor of Information Control Systems Department, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: serhii.chalyi@nure.ua; ORCID ID: http://orcid.org/0000-0002-9982-9091.

Лещинський Володимир Олександрович – кандидат технічних наук, доцент, доцент кафедри програмної інженерії, Харківський національний університет радіоелектроніки, Харків, Україна;
Volodymyr Leshchynskyi – Candidate of Technical Sciences, Associate Professor, Associate Professor of Software Engineering Department, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: volodymyr.leshchynskyi@nure.ua; ORCID ID: http://orcid.org/0000-0002-8690-5702.

Темпоральне представлення сутностей предметної області для побудови пояснень в інтелектуальних системах

С. Ф. Чалий, В. О. Лещинський

Анотація. **Предметом** вивчення в статті є процеси побудови пояснень в інтелектуальних системах з використанням причинно-наслідкових залежностей. **Метою** є розробка представлення сутностей предметної області з урахуванням темпорального аспекту з тим, щоб представити бінарні відношення у часі між властивостями однієї й тієї ж сутності. Побудова темпоральних відношень між властивостями сутностей дає можливість визначити ймовірнісні каузальні залежності між станами цих сутностей і використати ці залежності для формування пояснень щодо реалізованого процесу прийняття рішення в інтелектуальній системі з урахуванням можливих альтернатив такого процесу. **Завдання**: структуризація об'єктів предметної області з урахуванням їх суттєвих для процесу прийняття рішень властивостей, в тому числі темпоральних; визначення класів сутностей предметної області; визначення класів еквівалентності сутностей предметної області з урахуванням змін властивостей цих сутностей з часом; розробка темпоральної моделі представлення сутностей предметної області для побудови пояснень в інтелектуальних системах на основі визначення залежностей у часі між властивостями сутностей. Використовуваними **підходами** є: теоретико-множинний підхід, який застосовується для опису класів сутностей та класів еквівалентності сутностей предметної області; лінійна темпоральна логіка, яка забезпечує представлення відношень між сутностями у темпоральному аспекті. Отримані наступні **результати**. Виконано структуризацію об'єктів предметної області з урахуванням їх властивостей, які використовуються у процесі прийняття рішень в інтелектуальній системі; визначено класи сутностей; визначено класи еквівалентності сутностей предметної області як різновид класу сутностей з однаковими значеннями ключових атрибутів, що дає можливість врахувати зміни цих значень з часом; розроблено темпоральну модель представлення сутностей предметної області, яка враховує їх статичні, динамічні властивості та властивості часу. **Висновки**. Наукова новизна отриманих результатів полягає в наступному. Виділено клас еквівалентності для сутностей, який містить сутності із однаковими ключовими статичними властивостями й різними динамічними властивостями з урахуванням часу їх зміни, що дає можливість відобразити зміни стану сутності у процесі прийняття рішення в інтелектуальній системі. Запропоновано темпоральну модель представлення сутностей предметної області, яка містить класи еквівалентності сутностей, а також темпоральні зв'язки між властивостями елементів цих класів. Виділення класів еквівалентності сутностей дає можливість представити процес прийняття рішення в інтелектуальній системі у вигляді послідовності темпоральних зв'язків між властивостями сутностей предметної області, та сформувати на цій основі казуальні залежності між станами сутностей з подальшою побудовою пояснень як ланцюжка каузальних залежностей.

Ключові слова: інтелектуальна система; пояснення; сутність; каузальність; причинно-наслідковий зв'язок; темпоральність.

Темпоральное представление сущностей предметной области для построения пояснений в интеллектуальных системах

С. Ф. Чалый, В. А. Лещинский

Аннотация. **Предметом** исследования в статье являются процессы построения объяснений в интеллектуальных системах с внедрением причинно-следственных зависимостей. **Целью** является разработка представления сущностей предметной области с учетом темпорального аспекта с тем, чтобы представить бинарные отношения во времени между свойствами одной и той же сущности. Построение темпоральных отношений между свойствами сущностей позволяет определить вероятные каузальные зависимости между состояниями этих сущностей и использовать эти зависимости для формирования объяснений относительно реализованного процесса принятия решения в интеллектуальной системе с учетом возможных альтернатив такого процесса. **Задания**: структуризация объектов предметной области с учетом их существенных для процесса принятия решений свойств, в том числе темпоральных; определение классов сущностей предметной области; определение классов эквивалентности сущностей предметной области с учетом конфигураций параметров этих сущностей со временем; разработка темпоральной модели представления сущностей предметной области для построения объяснений в интеллектуальных системах на основе определения зависимостей во времени между свойствами сущностей. Используемыми **подходами** являются: теоретико-множественный подход, применяемый для описания классов сущностей и классов эквивалентности сущностей предметной области; линейная темпоральная логика, обеспечивающая представление отношений между сущностями в темпоральном аспекте. Получены следующие **результаты**. Выполнена структуризация объектов предметной области с учетом их свойств, используемых в процессе принятия решений в интеллектуальной системе; определены классы сущностей; определены классы эквивалентности сущностей предметной области как разновидность класса сущностей с одинаковыми значениями ключевых атрибутов, что позволяет учесть изменения этих значений со временем; разработана темпоральная модель представления сущностей предметной области, учитывающая их статические, динамические свойства и свойства времени. **Выводы**. Научная новизна полученных результатов состоит в следующем. Выделен класс эквивалентности для сущностей, содержащий сущности с одинаковыми ключевыми статическими свойствами и разными динамическими свойствами с учетом времени их изменения, что позволяет отразить изменения состояния сущности в процессе принятия решения в интеллектуальной системе. Предложена темпоральная модель представления сущностей предметной области, содержащая классы эквивалентности сущностей, а также темпоральные связи между свойствами элементов этих классов. Выделение классов эквивалентности сущностей дает возможность представить процесс принятия решения в интеллектуальной системе посредством последовательности темпоральных связей между свойствами сущностей предметной области, и сформировать на этой основе казуальные зависимости между состояниями сущностей с последующим построением объяснений как цепочки каузальных зависимостей.

Ключевые слова: интеллектуальная система; объяснение; сущность; каузальность; причинно-следственная связь; темпоральность.