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CONSTRUCTION OF PATTERNS
OF USER PREFERENCES DYNAMICS
FOR EXPLANATIONS IN THE RECOMMENDER SYSTEM

Abstract. **The subject** of study in the article is the processes of constructing explanations in recommendation systems. **Objectives.** The goal is to develop a method of constructing patterns that reflect the dynamics of user preferences and provide an opportunity to form an explanation of the recommended list of items, taking into account changes in the user's requirements of the recommendation system. Construction of explanations taking into account the dynamics of changes in consumer preferences makes it possible to increase user confidence in the results of the intelligent system. **Tasks:** structuring models of temporal patterns of parallel-alternative and sequential-alternative users' choice of the recommendation system; development of a method for constructing patterns of changing user preferences using process mining technology; experimental verification of the method for constructing patterns of changing consumer preferences. **The approaches used are**: temporal logics, which determine the approaches to the description of the temporal ordering of a set of events. The following results are obtained. The structuring of models of temporal patterns of parallel-alternative and sequential-alternative users' choice of the recommendation system is performed; developed and performed an experimental test of the method of constructing patterns of user preferences dynamics. **Conclusions.** The scientific novelty of the results is as follows. The method of dynamics patterns construction of users' preferences for the formation of explanations concerning the recommended list of subjects is offered. The method sequentially generates a set of ordered events, each of which reflects the choice of the subject by a group of users at a certain time interval, and also builds a graph representation of the patterns of user preferences through intellectual analysis of processes. The patterns obtained as a result of the method consist of time-ordered pairs of events that reflect the knowledge of changing user preferences over time. Further use of such dependencies as elements of the knowledge base makes it possible based on probabilistic inference to build a set of alternative explanations for the received recommendation, and then arrange these explanations according to the probability of their implementation for the recommended list of subjects.

Keywords: recommendation system; recommendation; explanations; the process of explanations formation; temporal dependence.

Introduction

Recommendation systems offer consumers a list of items that may interest them, i.e. correspond to their preferences.

Such systems [1 - 3] are commonly used in conjunction with e-commerce systems. Thanks to the received recommendation, the consumer has the opportunity to choose from a limited list of items of interest to him, which greatly simplifies the purchase of goods and services in e-commerce systems.

Recommendations for target users are formed based on information about the choice of goods and services by similar users, as well as information about product ratings. Ratings reflect the degree of popularity of users, but they can be falsified as a result of attacks [4, 5] by virtual users, or shilling attacks.

The post-shilling recommendation is distorted because it reflects the requirements of both the target and attacking users. The user does not know how the recommendation construction algorithm works, has no information about the shilling attack, and therefore distorted recommendations ultimately force the user to abandon the use of the recommendation system.

In order for the user to trust the received recommendations and be able to take them into account even in the case of shilling attacks, the recommendation is combined with an explanation [6-8].

The explanation reveals the reasons and methods of obtaining a recommendation and sets the associative links between the recommendation and knowledge of the subject area. Combining a recommendation with an explanation increases the chances [7, 9-10] that the user will purchase the recommended product or service.

However, both recommendations and explanations must be relevant as the user's preferences change [11-15].

Such changes can occur cyclically or evolutionarily. Therefore, when constructing explanations to the recommendations, it is important to take into account the dynamics of changes in user requirements over time, i.e. to describe the process of user selection using temporal knowledge.

The latter set the order in time for each pair of events [16, 18], when the user selects items, puts ratings, etc. The set of this knowledge forms the patterns of the dynamics of user preferences at the selected time interval. Automated formation of patterns based on temporal knowledge is performed by the method presented in [17].

Thus, the problem of constructing explanations to the recommendations using temporal knowledge of user preferences is relevant.

The solution to this problem requires the selection of typical elements of temporal knowledge, the construction of patterns from such elements based on the analysis of the sequence of user actions. The rules set the order in time for a pair of events. The probability of implementation of the rule is determined by its weight [18, 19].

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To date, methods have been developed to construct explanations using temporal rules [20, 21].

The first method uses a set of temporal rules that determine changes in user preferences at a given time interval, such as a month, year. Explanations in the form of a numerical indicator are calculated using the weights of these rules.

Method [21] forms a description of the process of choosing a particular product by consumers in the form of a sequence of temporal rules. The explanation is formed as a numerical assessment of the user selection process. A common feature of these methods is that they explain to the user of the recommendation system the reason for the recommendation using the sign and the value of the numerical indicator of the explanation. The sign indicates an increase (+) or decreases (-) in demand for this item. The value of the explanation indicator reflects the rate of increase or decrease in sales for a certain period of time. The disadvantage of these methods is their dependence on the choice of basic temporal rules, as well as the time interval used in the construction of the indicator of explanation. To make an informed choice of the latter, it is necessary to identify typical patterns of user group behavior. These patterns are limited to a certain time interval and consist of sequences of temporal dependencies.

The definition of such patterns will allow, first, to select the basic temporal dependencies for the construction of explanations by methods [22-24]. Secondly, the information about the duration of the pattern makes it possible to determine the intervals of detailing the time for constructing explanations.

Thus, the solution to the problem of constructing patterns of the dynamics of changing consumer interests creates the conditions for constructing explanations for recommendations for users whose interests change over time.

The article aims to develop a method of constructing patterns that reflect the dynamics of user preferences and provide an opportunity to form an explanation of the recommended list of items, taking into account changes in the requirements of the user of the recommendation system.

Construction of explanations taking into account the dynamics of changes in consumer preferences makes it possible to increase user confidence in the results of the intelligent system.

To achieve this goal the following tasks are solved:

– experimental verification of the method of constructing patterns of changing consumer preferences.

– structuring of temporal patterns of parallel-alternative and sequential-alternative choice of users of the recommendation system;

– development of a method for constructing patterns of changing user preferences using process mining technology.

The method of constructing patterns

The pattern of consumer choice dynamics reflects the typical changes in the preferences of the group of users of the recommendation system over time. It combines several sequences of selection by different users of the same subset of items.

The pattern is determined by the events set of selection $E = \{e_i\}$.

Such events are recorded by the recommendation system or e-commerce system in the form of a sales log, user action log, etc.

For each event in the log, the time of its occurrence t_i, the code of the selected item, the user code u_n, as well as the number of selected items w_i are set.

Events are ordered in time.

This ordering according to the approach proposed in [19] can be described by temporal rules of two types.

Rules of the Next type, or X-rules, determine the temporal order for pairs of events (e_i, e_{i+1}) when the second event occurs immediately after the first.

That is, there are no intermediate events between two choices of a referral system or e-commerce system that record other purchases of goods or services.

Rules such as Future, or F-rules, determine the temporal order for pairs of events (e_i, e_l) between which other events occur.

This rule specifies that an event e_i must occur after a future event e_l.

Sequential selection by users of several items is represented by a sequence of X-rules. If one of the users selects the first item, and then skips the selection of several items and selects the final item, its actions are described by the F-rule.

Because users can either sequentially select the same items at a given time interval, or select different items, their behavior is described by patterns of parallel-alternative $N1$ and sequential-alternative choices $N2$.

The structure of such patterns is shown in Table 1.

Table 1 – **The structure of the patterns of the dynamics of user preferences**

Pattern	Alternatives	Representation by temporal rules
$N1$ – parallel-alternative choice	Consistent selection of a set of several subjects or select the first and last items from the set	An F-type rule or a sequence of X-type rules
$N2$ – consistently - alternative choice	Consecutive selection of several subjects, for which a parallel-alternative choice is implemented	A sequence of X-type rules followed by several alternatives between an F-type rule or a sequence of X-type rules

The parallel-alternative choice pattern $N1$ describes a local situation where users implement only alternative behaviors.

If the behavior of users of the recommendation system partially coincides, it is advisable to use a pattern $N2$ of a sequential -alternative choice.

The combination of these patterns makes it possible to describe the choice of several alternatives within one period of time.

The developed method of constructing patterns uses the event log of the recommendation system or e-commerce system as input data.

The method of constructing patterns consists of the following phases and stages.

Phase 1. Construction of an ordered events set for the purchase of an items subset for a given level of time granulation.

Stage 1.1. Select and organize a subset of shopping events for a given product group.

At this stage, events that reflect the work with a given group of objects A are selected from the input dataset.

The resulting dataset has the following form

$$E = \{e_i : \forall i \exists a_m \in A\}. \tag{1}$$

Each event e_i in this dataset a_m is associated with the selection of an object from a given set A.

The dataset is ordered in time, i.e. the condition is fulfilled:

$$\forall (e_i, e_{i+1}) t_i < t_{i+1}, \tag{2}$$

where t_i, t_{i+1} – moments of events occurrence e_i, e_{i+1}.

Stage 1.2. Forming a set of events for a given level of time granulation.

At this stage, events that occur e_i at a specified time interval Δt_s are combined into one event y_j. The resulting dataset Y is:

$$Y = \{y_j : \\ \{\forall j \exists E_k = \{e_i, e_{i+1}, ... : (\forall i) t_i \in \Delta t_s\}, \tag{3} \\ u_n \in U\},$$

where Δt_s – time detail interval, for instance a week.

The number of purchases q_j of a new event y_j is the sum of the number of purchases w_i for the incoming events e_i that generated it:

$$q_j = \sum_{i:e_i \in E_k} w_i. \tag{4}$$

Stage 1.3. Preparation of input data for intellectual analysis.

At this stage, a new ordered sequence of events is formed, which reflects X and F – the temporal relationship between the consumer's choice for a given level of time granulation.

Phase 2. Construction of patterns.

Stage 2.1. Forming a graph of changing user preferences for a given level of time detail.

At this stage, using the fuzzy miner, a graph is formed containing the patterns of the dynamics of user selection.

The task of this stage is to determine the duration of the patterns T on the basis of visual analysis of the obtained graph.

Stage 2.2. Construction of sets of temporal rules of X and F – types for a pattern $N1$.

At this stage, the rules that are part of the pattern are selected in the dataset Y using a sliding window for a duration T.

Step 2.2.1. Selection of events for the pattern $N1$.

In this step, a subset of events $Y_{k,l}^{(1)}$ on the time interval T is selected, for the elements of which the condition is fulfilled:

$$Y_{k,l}^{(1)} = \Big\{ y_k, y_j, ..., y_l : \\ (\forall k \forall l) \exists a_m \wedge \exists a_p, \tag{5} \\ (\forall j) \exists a_m \vee \exists a_p \Big\},$$

where a_m, a_p – items from the set A.

Each of the events y_k and y_l is associated with the choice of different subjects a_m, a_p, and intermediate events y_j – with the choice of only one of these subjects. Therefore, condition (5) specifies the temporal relation F – type for extreme events y_k and y_l, and the relation X – type for intermediate events y_j. The set of such relations corresponds to the pattern $N1$.

Step 2.2.2. Formation of a set of temporal rules using the approaches presented in [20, 21].

Steps 2.2.1 and 2.2.2 repeated for all patterns in the dataset.

Stage 2.3. Construction of sets of temporal rules of X and F – types for a pattern $N2$.

At this stage, on the initial dataset Y, events and rules are selected from the pattern $N2$ using the sliding window for the duration T using the sliding window.

Step 2.3.1. Selection of events for the pattern $N2$.

In this step, a subset of events $Y_{k,l}^{(2)}$ is selected, for the elements of which the condition is fulfilled:

$$Y_{k,l}^{(2)} = \Big\{ y_k, ..., y_{k+o}, ..., y_j, ..., y_l : \\ (\forall k \forall l : k + o < j) \exists a_m \wedge \exists a_p, \tag{6} \\ (\forall j) \exists a_m \vee \exists a_p \Big\}.$$

where a_m, a_p – items from the set A.

Each of the events y_k, y_{k+o} is associated with the choice of different subjects a_m, a_p, and intermediate events y_j – with the choice of only one of these subjects.

Therefore, the set $y_k,...,y_{k+o}$ specifies the sequential, and $y_j,...,y_l$ – the alternative parts of the pattern $N2$.

Step 2.3.2. Formation of a set of temporal rules F – type and X – type.

Steps 2.3.1 and 2.3.2. repeated for all detected patterns $N2$.

The result of this method is a set of rules that reflect the knowledge of changes in consumer requirements for recommended goods and services over time. The received rules are intended for construction of explanations concerning recommendations.

Experimental verification of this method was performed using a set of data on wholesale sales of gifts in a supermarket chain. The choice of data set is due to the significant number of sales over short periods of time, which makes it possible to identify patterns for different levels of time detail.

The 1-day interval was selected as the base level of time detail in step 1.2.

Identifying the values of the duration of patterns and temporal rules are presented in Table 2.

Table 2 – **Temporal patterns characteristics**

Type of dependence	Duration, time intervals	Percentage in the dataset
X	1-2	69
F	4-5	37
N1	5	–
N2	5-6	–

According to the results of the experiment, it was found that the duration of both patterns is about 5-time intervals. *X*-type temporal rules in both patterns last 1-2 intervals.

F - the rules for the pattern of parallel selection are 5 intervals, and sequential-alternative - 4 intervals. The patterns have common *X*-type rule rules. This indicates that the duration of the pattern in 5 intervals is typical for different groups of buyers and does not depend on calendar dates.

Also from Table 2, it is seen that only 69% of *X*-dependencies and 37% of *F*-dependencies can be used to construct explanations because they are part of the obtained patterns and reflect changes in user preferences.

The percentage of patterns in the sample was not calculated because they have common rules, and the number of common rules differs for different pairs of patterns.

The conducted experimental check showed that the results of the formation of patterns can determine the duration of intervals of change of interests of consumers, and also a subset of rules which will be used for the construction of explanations.

Conclusions

The problem of constructing patterns of user's preferences dynamics the recommendation system for formation of explanations concerning the offered list of subjects is considered.

This problem arises in the case of periodic and evolutionary changes in user requirements. A method for identifying patterns of alternative and sequential-alternative choices that reflect cyclical changes in consumer preferences due to changes in the seasons of the year, in fashion trends, etc. is proposed. Patterns are based on the temporal ordering of events pairs of the type "current event - next event", "current event - next event sometime in the future". Patterns describe a parallel alternative or sequential alternative consumer choice.

Each pattern consists of many pairs of events, and each pair is ordered in time.

The parallel selection pattern contains an alternative between a sequential selection of several products or a selection of only the first and last item in the pattern. The pattern of sequential-alternative choice complements the sequence of choices of goods with the pattern of an alternative choice.

The proposed method of constructing patterns of user preferences dynamics to form explanations for the recommended list of items includes phases of constructing a set of ordered events for purchasing a selected item for a given level of time granulation, as well as constructing patterns by process mining.

The implementation of the method of constructing patterns based on the analysis of the sequence of data on the choice of items by the consumer makes it possible to form sets of time-ordered pairs of events that are part of the explanations.

Such explanations take into account the temporal dynamics of consumer preferences. Experimental verification of the method showed that the method distinguishes patterns for popular items in wholesale sales, even in the case of short datasets. The results of the method largely depend on the number of consumers who chose the target items. The sets of temporal dependences obtained as a result of the method are elements of knowledge and therefore can be used to construct explanations by probabilistic inference in the knowledge base.

Further improvement of the developed method will involve determining the weights of temporal dependences in the composition of patterns. Such weights should correspond to the probability of realization of dependence in known patterns. The conclusion on the weighted rules will allow to arrange some possible alternatives of explanations on the value of the probability of their realization and then to offer to the user of the recommendation system the most probable explanation.

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Побудова патернів динаміки вподобань користувачів для пояснень в рекомендаційній системі

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Анотація. **Предметом** вивчення в статті є процеси побудови пояснень в рекомендаційних системах. **Метою** є розробка методу побудови патернів, що відображають динаміку вподобань користувачів і дають можливість сформувати пояснення щодо рекомендованого переліку предметів з урахуванням змін вимог користувача рекомендаційної системи. Побудова пояснень з урахуванням динаміки змін вподобань споживачів дає можливість підвищити довіру користувачів до результатів роботи інтелектуальної системи. **Завдання**: структуризація темпоральних патернів паралельно-альтернативного та послідовно-альтернативного вибору користувачів рекомендаційної системи; розробка методу побудови патернів зміни вподобань користувача з використанням технології process mining; експериментальна перевірка методу побудови патернів зміни вподобань споживачів. Використовуваними **підходами** є: темпоральні логіки, що визначають підходи до опису темпоральної упорядкованості множини подій. Отримані наступні **результати**. Виконано структуризацію темпоральних патернів паралельно-альтернативного та послідовно-альтернативного вибору користувачів рекомендаційної системи; розроблено та виконано експериментальну перевірку методу побудови патернів динаміки вподобань користувача. **Висновки**. Наукова новизна отриманих результатів полягає в наступному. Запропоновано метод побудови патернів динаміки вподобань користувачів для формування пояснень щодо рекомендованого переліку предметів. Метод послідовно формує множину упорядкованих подій, кожна з яких відображає вибір предмету групою користувачів на визначеному інтервалі часу, а також передбачає побудову графового представлення патернів динаміки вподобань користувачів засобами інтелектуального аналізу процесів. Патерни, отримані в результаті роботи методу, складаються із упорядкованих у часі пар подій, що відображають знання щодо зміни вподобань користувачів з часом. Подальше використання таких залежностей як елементів бази знань дає можливість на основі ймовірнісного виводу побудувати набір альтернативних пояснень щодо отриманої рекомендації, а потім упорядкувати ці пояснення за ймовірністю їх реалізації для рекомендованого переліку предметів.

Ключові слова: рекомендаційна система; рекомендація; пояснення; процес формування пояснень; темпоральна залежність.

Построение паттернов динамики предпочтений пользователей для объяснений в рекомендательной системе

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Аннотация. **Предметом изучения** в статье являются процессы построения пояснений в рекомендационных системах. **Целью** является разработка метода построения паттернов, которые отображают динамику предпоследний пользователей и дают возможность сформировать объяснение касательно рекомендованного перечня предметов с учетом изменений требований пользователя рекомендационной системы. Построение объяснений с учетом динамики изменений предпочтений пользователей дает возможность повысить доверие пользователей к результатам работы интеллектуальной системы. **Задачи**: структуризация темпоральных паттерном параллельно-альтернативного и последовательно-альтернативного выбора пользователей рекомендационной системы; разработка метода построения паттернов изменения предпочтений пользователя с использованием технологии process mining; экспериментальная проверка метода построения паттернов изменения предпочтений потребителей. Используемыми **подходами** являются: темпоральные логики, определяющих подходы к описанию темпоральной упорядоченности множества событий. Получены следующие **результаты**. Выполнено структурирование темпоральных паттернов параллельно-альтернативного и последовательно-альтернативного выбора пользователей рекомендательной системы; разработано и выполнено экспериментальную проверку метода построения паттернов динамики предпочтений пользователя. **Выводы**. Научная новизна полученных результатов заключается в следующем. Предложен метод построения паттернов динамики предпочтений пользователей для формирования объяснений рекомендованного перечня предметов. Метод последовательно формирует множество упорядоченных событий, каждое из которых отображает выбор предмета группой пользователей на определенном интервале времени, а также предусматривает построение графового представления паттернов динамики предпочтений пользователей средствами интеллектуального анализа процессов. Паттерны, полученные в результате работы метода, состоят из упорядоченных во времени пар событий, отражающих знания по изменению предпочтений пользователей со временем. Дальнейшее использование таких зависимостей как элементов базы знаний дает возможность на основе вероятностного вывода построить набор альтернативных объяснений по полученной рекомендации, а затем упорядочить эти объяснения по вероятности их реализации для рекомендуемого перечня предметов.

Ключевые слова: рекомендационная система; рекомендация; объяснение; процесс формирования объяснений; темпоральная зависимость.