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MULTILEVEL PERSONALIZATION OF EXPLANATIONS IN RECOMMENDER SYSTEMS

Abstract. The **subject** matter of the article is the process of building a personalized list of objects in recommendation systems. The goal is to develop a generalized formal description of the multi-level presentation of explanations in recommendation systems to personalize these explanations, taking into account the features of the use of recommended subjects. Such a description provides a formal framework for constructing a multi-level model of explanation, taking into account the static and dynamic characteristics of the subject area. **Tasks:** structuring the multi-level presentation of explanations in recommendation systems taking into account differences in the possibilities of personalizing explanations using data and knowledge; development of a formal presentation of explanations at the levels of data, information, knowledge and metacognition, taking into account the relationships between these levels. **The approaches used** are: approaches to the construction of explanations based on the similarity of user interests and properties of user demand items. The following **results** are obtained. The levels of explanation description are structured taking into account knowledge about the context of consumer choice. A formal description of the multi-level presentation of explanations in recommendation systems is proposed. **Conclusions.** The scientific novelty of the results is as follows. A formal description of the explanations of the recommended personal list of objects in the form of a hierarchy of levels of data, information, knowledge and meta-knowledge about user behavior and characteristics of objects is proposed. At the data level, a description of the variables and their values is given, taking into account the instant of occurrence of these values. Information at the next level is represented by the relationships between individual facts. Knowledge is represented by causal or temporal explanatory rules that generalize the relationship of the information level to a subset of facts. Meta-knowledge sets the key patterns that determine the benefits and relevance of the proposed choice for the user of the recommendation system. In a practical aspect, the proposed formalization of explanations determines the typical sequence of constructing and personalizing multilevel explanations regarding recommendations, taking into account the characteristics of the subject area.

Keywords: recommender systems; representation of knowledge; recommendations; formation of explanations; knowledge; meta-knowledge; temporal rules.

Introduction

Recommender systems provide personalized support for the selection of goods, services, information and are widespread in e-commerce, finance, health and education [1-4].

Such systems form the recommended list of items taking into account interests of the user. The received recommendation reduces time spent on search of necessary goods and services among set of subjects with similar characteristics, increases trust of the user of the recommendation system and simplifies online sales of the goods and services [5].

Recommendations are formed on the basis of information about the past choice of the user and users with similar preferences. The characteristics of goods and services are also taken into account [6].

However, the dependencies used in the formulation of the recommendations are not always clear and understandable to the user. Therefore, the user considers the recommendation system as a "black box". The lack of justification for the proposed list of items reduces the credibility of the recommendation, which may lead to a refusal to choose a product or service [7].

To maintain user confidence in addition to the recommendations in such systems use explanations [8]. The explanation allows the user to understand the logic of the recommendation and, as a consequence, simplifies the choice of items by the consumer, which increases his satisfaction with the received personal recommendations [9].

The possibility of justifying the user's choice based on explanations depends on the chosen approach to calculating the value of the explanation and the appropriate form of presentation of the explanation. The chosen method and form of presentation must meet the criteria for evaluating explanations [8]. The following criteria make it possible to assess the results of interaction with the user before and after the use of explanations. In particular, the criteria for evaluating explanations include transparency and trust. The first criterion actually shows whether the logic of selection of recommendations was presented to the user. The confidence criterion makes it possible to determine whether the user has used the explanation to select a product or service.

Thus, the explanation should represent both the general patterns or conditions of the recommendation, and personalized relationships that take into account the interests of the user. This determines the relevance of the formation of a multilevel presentation of explanations, with varying degrees of personalization at each level.

Existing approaches to constructing explanations are based on methods used in precedent and expert systems [10]. A number of studies in recent years have considered the problem of automated knowledge formation for explanations, as well as the use of knowledge to adjust the recommendations. Changes in the interests of users over time have been considered in [11 - 13]. Temporal rules [14] were used to form such explanations.

However, the existing approaches to the formation of explanations are focused only on covering one of the aspects of the recommendation. The problem of developing a comprehensive, multi-level formal description of the explanation, which provides step-by-step personalization, needs to be solved.

The aim of the article is to develop a generalized formal description of the multilevel presentation of explanations in the recommender system in order to provide personalization of interpretations taking into account the method and conditions of use of the recommended subjects.

This description provides a formal framework for constructing a multilevel model of explanation, taking into account the static or dynamic characteristics of the subject area.

To achieve this goal the following tasks are solved:

- structuring of multilevel presentation of explanations in recommendation systems taking into account differences in possibilities of personalization of interpretations on the basis of use of data and knowledge;

- development of a formal presentation of explanations at the levels of data, information, knowledge and meta-knowledge, taking into account the links between these levels.

Multilevel representation of explanations in recommender systems

The proposed representation of explanations is based on the traditional DIKW hierarchy [15], which establishes a link between data, information and

knowledge. The data is a sequence of “raw” signals or symbols that are the result of observations. The key difference between information and raw data is the contextual links between the first level elements. The level of knowledge adds to the information ways to use it. The level of wisdom determines the conditions for the application of knowledge.

Generalized information about the proposed multilevel structure of personalized explanations is given in table. 1.

The first level of the proposed presentation of explanations contains a time-ordered sequence of data on the selection of the user of the recommendation system. Selection information is established on the basis of both explicit and implicit feedback. Explicit feedback is provided by product ratings from the user. Implicit feedback is more objective and is determined by the user's purchases. Additionally, data on the movement of the user on the pages of the site that uses the referral system can also be used.

The first level data contains implicit links that reflect the reasons for consumer choice. Such relationships can characterize the static or dynamic characteristics of consumer choice, which are essential for the formation of explanations. Static characteristics establish relationships between the properties of goods and services that a user or group of similar users chooses. Dynamic characteristics set the preferences of users over time.

These implicit connections determine the conditions and possibly the reasons for the consumer's personal choice. However, at this level they are not reflected formally.

Table 1– Multilevel structure of personalized explanations to recommendations

Level	Presentation of explanations	Presentation of explanations
Data on the known choice of consumers and the characteristics of selected items	Average data on consumer choice and ratings of recommended items; the selection data for popular products and services only	Impersonal explanations
Information on consumer choice and characteristics of items related to the context of their use	Distribution of ratings and information about the context-oriented benefits of the recommended subject	Partially personalized explanations: the consumer chooses the method of effective use of the subject based on the presented context and the time interval
Knowledge that determines the use of selected items	Subject-oriented knowledge about the characteristics or features of the application of the offered goods and services; temporal rules that specify an increase in ratings or purchases	Personalized explanations, consisting of the recommended method and time of application of the selected subject
Meta-knowledge that sets the conditions and possibilities of using the recommended subjects	Determining the user's preferences from the purchase and use of the recommended item: quantitative benefits for certain qualitative conditions of use; quantitative assessment of the timeliness of the purchase of goods or services	Personalized explanations presented by qualitative, quantitative and temporal characteristics of conditions, restrictions and relevance of use of the selected product or service

To formalize these relationships, it is advisable to perform pre-processing of data. It consists of selecting a subset of data from user behavior records that contain implicit links. To determine static relationships, selection is based on the characteristics and groups of products, or on the similarity of interests of users of the recommendation system. When determining dynamic relationships, the time interval at which these data are

valid is set, as well as the degree of detail of the data over time.

At the current level, the links between the data are hidden and therefore explanations should have been formed on the basis of generalized product data showing the choice of many users or the exceptional characteristics of the items that have been recommended.

For example, information about the popularity of items from the recommended list is used as an explanation based on user preferences. An explanation based on the characteristics of the items may include a description of their unique characteristics (for example, the ability to unlock the device with a fingerprint, high resolution camera), as well as reflect price discounts, promotions, etc.

Thus, the explanation at this level is not yet completely personalized. It motivates the user to buy a recommended item with outstanding characteristics for the subject area. Such characteristics are an advantage for the typical consumer and may not always meet the requirements of the current user of the recommendation system.

The second level contains explicit information about the context of the user's choice, i.e. determines the relationships between the data of the first level. Such a context can be obtained both directly from the input data and presented as additional information about the subject area. For example, information about the cyclical choice of certain goods or services.

At this level, the following information can be used to generate explanations:

- distribution of ratings of the recommended subject which were exposed by users with similar interests;
- information on the context-oriented advantages of the recommended subject, for example: names of outstanding actors or producers for a feature film; description of the used advanced technologies for environmental protection, etc.

Note that in contrast to the characteristics of the subject at the first level of explanation, the information of this level determines the characteristics of the selected subject, taking into account the context of its use. Such information complements the consumer's knowledge and implicitly emphasizes the possible benefits of using the selected item in the way that the applicant chooses. In other words, at the information level, a frame is set for the use of the selected subject. The user fills in this frame according to their preferences.

Therefore, such information plays the role of a partially personalized explanation, which motivates the user to choose and use in a personal way the proposed product, information, service.

The third level contains dependencies that determine consumer choice. The following dependencies can be represented as follows:

- in the form of latent factors that determine the similarity of user preferences when choosing information, goods and services;
- as subject-specific knowledge that determines the similarity of characteristics or features of the proposed recommender system of goods and services;
- as temporal rules that determine the sequence of selection of items for a particular user or for a group of similar consumers.

Latent factors are used in the construction of recommendations through collaborative filtering. These factors are the result of matrix factorization, i.e. the

inverse of the matrix operation. Accordingly, latent factors do not meet the criterion of transparency in explaining the recommendations and therefore cannot be used for interpretation.

Additional knowledge that determines the features of the recommended subject, give the opportunity to form a personal explanation as an approach to obtaining maximum user benefits when choosing the proposed product. It is the "explanatory" method (or methods) of use should motivate the consumer to choose the recommended subject. Such an explanation can usually be presented in the form of a list. Each item in the list contains a description of the possibilities of using the product or service. For example, the explanation may present knowledge about the possibility of attaching the trailer to the car, the professional use of power tools, the method of effective application of herbicides, and so on.

Temporal rules define explanations through the sequence of subject choices. They are a probabilistic representation of the causal relationships that determined the sequence of choice of a user or group of similar consumers. These rules can be used for a qualitative, non-quantitative, explanation of the recommended subject. They can, for example, reflect an increase in positive feedback on the proposed product or service.

At the fourth level of personalization of explanations the conditions and possibilities of application of a subject which are value for the consumer are presented.

The key difference of this level of personalization from the previous ones is that the advantages are given not to the item itself, but to the user's benefit from its acquisition and use.

Terms of use can be reflected in qualitative, quantitative and temporal aspects.

In the first case, set restrictions on the scope of the selected subject. For example, for a CNC machine, woodworking capabilities and metalworking restrictions may be specified.

In the second case, quantitative indicators make it possible to estimate the gain for the presented qualitative conditions of use.

For example, in the personal sale of equipment modules are selected by comparing their capabilities and their cost. If there is no such explanation, i.e. only the cost of additional modules is provided, then the consumer must search and analyze additional information on the Internet. The need for additional time due to lack of explanation may force the consumer to disregard the recommendation and choose the products of competitors.

Temporal characteristics determine the relevance of the purchase of goods or services and can be formed on the basis of generalizations of temporal rules. The moment of choice must meet the urgent needs of the consumer.

Temporal indicators make it possible to determine the selection cycles for groups of regular users and provide an explanation in the form "this product is recommended because over the past month the demand for it from similar consumers is steadily growing by

10% per week." Such an increase in demand may be associated, for example, with the holidays. The user has information about the holidays and therefore the explanation complements his knowledge and confirms the compliance of personalized recommendations to his interests.

The proposed formal presentation of a multilevel personalized explanation includes a description of all four levels.

At the data level, the basic elements of the description D are subsets D_n . Each of subsets contains one data element. The data element consists of three: the name of the variable, its value, as well as the time when this value was obtained:

The representation at the data level has the form:

$$D = \{D_n\}, D_n = \{x_n, v_{n,l}, t_n\}, \quad (1)$$

where x_n – the name of the variable; $v_{n,l} \in V_n$ – value of the variable; t_n – the moment of receiving data.

At the information level, a personalized explanation contains a set of facts and relationships between facts. Each fact $f_{n,l}$ determines the truth of the value $v_{n,l}$ of the variable x_n at the time t_n :

$$f_{n,l} = \begin{cases} \text{true, if } x_n = v_{n,l} | t \geq t_n, \\ \text{false, if } t < t_n \vee x_n \neq v_{n,l}, \end{cases} \quad (2)$$

where t – the moment of time when the truth of the fact $f_{n,l}$ is determined.

Thus, the fact in the proposed representation sets is a logical description of individual data. This approach makes it possible to abstract from the specifics of the subject area at the information level.

Information at this level is defined as a set of relationships Λ that determine the relationships between individual facts:

$$\Lambda = \{\lambda_k\}, \lambda_k = f_{n,l} \rho f_{m,j}, \quad (3)$$

where ρ – the operator that determines the type of causal or temporal relationship between individual facts.

At the knowledge level, relations (3) are integrated into the rules that determine local conditions or restrictions on user choice.

Conditions R^u are based on individual facts that are determined as follows:

$$R^u = \{r_k : \forall k \exists (f_{n,l}, f_{m,j}) : f_{n,l} \rho f_{m,j}\}. \quad (4)$$

That is, the rule - condition is formed at this level only if for at least one pair of facts there is a corresponding relationship λ_k .

The rule - constraint must be true for all possible pairs of facts from the input data set:

$$R^o = \{r_k : \forall k \forall (f_{n,l}, f_{m,j}) \exists \lambda_k\}. \quad (5)$$

Summarizing (4) and (5), we define the conditions and constraints for the conjunction of facts. A

generalized fact F_s is given by a conjunction of facts $f_{n,l}$. It becomes true at the moment of the truth of the last of the facts $f_{n,l}$:

$$F_s = f_{n,l} \wedge \dots \wedge f_{m,j} | t \geq t_n \wedge \dots \wedge t \geq t_m, \quad (6)$$

where t_n, t_m – the moments of time when the facts $f_{n,l}, f_{m,j}$ become true.

Generalized rules-conditions and rules-constraint have the form:

$$R^u = \{R_k^u : \forall k \exists (F_n, F_s) : F_n \rho F_s\}, \quad (7)$$

$$R^o = \{R_k^o : \forall k \exists \rho : \forall (F_n, F_s) \exists F_n \rho F_s\}. \quad (8)$$

The level of knowledge covers sets of rules (7) and (8) under conditions of temporal constraints:

$$R = R^o \bigcup_{R_k^u, R_k^o, t_n \in T} R^u. \quad (9)$$

where T – the time interval at which the input data are taken into account; t_n – the moment of truth of the rule, which corresponds to the moment of truth of the last of the facts of this rule.

The time constraint (9) at this level is significant, because when constructing explanations, it is advisable to take into account the changing context of consumer choice over time. That is, purchases of many goods and services are relevant only at certain times (weekends, holidays, etc.).

The level of meta-knowledge integrates the rules R , forming simple explanations of the conditions and possibilities of using the obtained product.

The algorithm for forming explanations at this level depends on the subject area. In general, the meta-rules P_g of this level determine the result, which in a condensed form specifies the dependence that motivates the user:

$$P = \{P_g : P_g = A(R^*)\}, R^* \subseteq R, \quad (10)$$

where A – analytically or algorithmically implemented function for determining meta-patterns based on a subset of rules R^* .

The formal presentation of the explanation generally combines all four levels and has the form:

$$\Pi = \{D, \Lambda, R, P\}. \quad (11)$$

Thus, the proposed multilevel description provides the possibility of evolutionary construction of explanations with the possibility of more accurate personalization at each subsequent level of the hierarchy.

Conclusions

A formal description of the multilevel presentation of explanations in recommendation systems is proposed. The description is based on the structured levels of explanation presentation taking into account static and

dynamic dependencies that describe the context of consumer choice.

According to the proposed structuring, the explanation can be presented at the levels of data, information, knowledge and meta-knowledge. At the data level, impersonal explanations are formed, in particular regarding the popularity of goods and services. At the level of information, partially personalized explanations can be formed, which determine a group of possible and attractive to the consumer properties and ways of using the recommended subject. At the level of knowledge, personalized explanations determine the recommended way to use the selected subject, which should correspond to the preferences of the consumer. At the level of meta-knowledge, the explanation should determine the benefits of purchasing the item by the user.

Formal presentation of explanations at the data level specifies the description of variables and their values, taking into account the time of acquisition of these values. The time parameter makes it possible to

present knowledge about the temporal dynamics of the user at the following levels.

At the information level, explanations are presented in the form of relationships between facts.

At the level of knowledge, these relations are generalized in the form of rules. Such rules make it possible to present explanations in the form of causal or temporal dependencies that motivate the user to choose the recommended subject.

At the level of meta-knowledge, the rules are analytically or algorithmically transformed into generalized patterns that emphasize the benefits and timeliness of the choice of the recommendation system for the user.

The developed formalization of explanations provides a framework for building and quickly adapting a set of models of multilevel explanations that provide step-by-step detailing of interpretations of recommendations, taking into account both the requirements of the recommendation system and available information and knowledge about the characteristics of selected subjects and user behavior.

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Received (Надійшла) 10.04.2020

Accepted for publication (Прийнята до друку) 20.05.2020

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Багаторівнева персоналізація пояснень в рекомендаційних системах

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Анотація. Предметом вивчення в статті є процеси побудови персоналізованого переліку предметів в рекомендаційних системах. **Метою** є розробка узагальненого формального опису багаторівневого представлення пояснень в рекомендаційних системах для персоналізації таких пояснень з урахуванням особливостей використання рекомендованих предметів. Даний опис задає формальні рамки для побудови багаторівневої моделі пояснення з урахуванням статичних та динамічних характеристик предметної області. **Завдання:** структуризація багаторівневого представлення пояснень у рекомендаційних системах з урахуванням відмінностей у можливостях персоналізації витлумачень за допомогою даних та знань; розробка формального представлення пояснень на рівнях даних, інформації, знань та мета-знань з урахуванням зв'язків між цими рівнями. Використовуваними **підходами** є: підходи до побудови пояснень на основі схожості інтересів користувачів та властивостей предметів користувацького попиту. Отримані наступні **результати**. Виконано структуризацію рівнів опису пояснення з урахуванням знань щодо контексту вибору споживача. Запропоновано формальний опис багаторівневого представлення пояснень у рекомендаційних системах. **Висновки.** Наукова новизна отриманих результатів полягає в наступному. Запропоновано формальний опис пояснень рекомендованого персонального переліку предметів у вигляді ієрархії рівнів даних, інформації, знань і мета-знань про поведінку користувача і характеристики предметів. На рівні даних міститься опис змінних і їх значень з урахуванням моменту часу появи цих значень. Інформація на наступному рівні представлена відносинами між окремими фактами. Знання представлені причинно-наслідковими або темпоральними пояснюючими правилами, які узагальнюють відношення інформаційного рівня для підмножин фактів. Мета-знання задають ключові закономірності, що обумовлюють переваги і актуальність пропонованого вибору для користувача рекомендаційної системи. У практичному аспекті запропонована формалізація визначає типове послідовність побудови і персоналізації багаторівневих пояснень щодо рекомендацій з урахуванням особливостей предметної області.

Ключові слова: рекомендаційні системи; представлення знань; рекомендації; формування пояснень; знання; мета знання; темпоральні правила.

Многоуровневая персонализация объяснений в рекомендательных системах

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Аннотация. Предметом изучения в статье являются процессы построения персонализированного перечня предметов в рекомендательных системах. **Целью** является разработка обобщенного формального описания многоуровневого представления объяснений в рекомендательных системах для персонализации этих пояснений с учетом особенностей использования рекомендованных предметов. Такое описание задает формальные рамки для построения многоуровневой модели объяснения с учетом статических и динамических характеристик предметной области. **Задачи:** структуризация многоуровневого представления объяснений в рекомендательных системах с учетом различий в возможностях персонализации пояснений с помощью данных и знаний; разработка формального представления объяснений на уровнях данных, информации, знаний и метазнаний с учетом связей между этими уровнями. Используемыми **подходами** являются: подходы к построению объяснений на основе сходства интересов пользователей и свойств предметов пользовательского спроса. Получены следующие **результаты**. Выполнено структурирование уровней описания объяснения с учетом знаний о контексте выбора потребителя. Предложено формальное описание многоуровневого представления объяснений в рекомендательных системах. **Выводы.** Научная новизна полученных результатов заключается в следующем. Предложено формальное описание объяснений рекомендованного персонального перечня предметов в виде иерархии уровней данных, информации, знаний и метазнаний о поведении пользователя и характеристик предметов. На уровне данных содержится описание переменных и их значений с учетом момента времени появления этих значений. Информация на следующем уровне представлена отношениями между отдельными фактами. Знания представлены причинно-следственными или темпоральными поясняющими правилами, которые обобщают отношение информационного уровня для подмножеств фактов. Мета-знания задают ключевые закономерности, обуславливающие преимущества и актуальность предлагаемого выбора для пользователя рекомендательной системы. В практическом аспекте предложенная формализация объяснений определяет типовую последовательность построения и персонализации многоуровневых объяснений относительно рекомендаций с учетом особенностей предметной области.

Ключевые слова: рекомендательные системы; представление знаний; рекомендации; формирование объяснений; знания; метазнания; темпоральные правила.