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KNOWLEDGE REPRESENTATION IN THE RECOMMENDATION SYSTEM BASED ON THE WHITE BOX PRINCIPLE

Abstract. The **subject matter** of the article is the construction of a rating list of goods and services in recommendation systems. The **goal** is to develop a knowledge representation model in recommendation systems using the white box principle. Such a model contains knowledge about the possible sequences of choosing restrictions on the properties of goods and services according to user preferences. The recommender system should provide a reasonable choice of the object according to the requirements of the user, subject to restrictions on the key properties of this object. **Tasks:** to structure the process of applying the principles of black and white boxes when building recommendations based on the use of a knowledge base; develop knowledge representations according to the principle of the white box in order to combine a static description of the properties of objects and a description of possible sequences for clarifying the requirements for the properties of these objects. The principles **used** are: the principle of the white box, which provides an account of requirements that take into account the properties of the constituent elements of the object selected by the consumer. The following **results** are obtained. The key features of the processes of forming recommendations on the principles of black and white boxes based on the use of the knowledge base are highlighted. The knowledge representation is developed according to the principle of the white box, which allows taking into account both the properties of objects and the process of their selection by the consumer. **Conclusions.** The scientific novelty of the results is as follows. A model for representing knowledge in a recommendation system according to the principle of a white box is proposed. The declarative aspect of this representation of knowledge is implemented in the form of predicates that define restrictions on the values of the properties of objects offered to the consumer. The procedural aspect is implemented in the form of adapted temporal dependencies that specify the sequence of refinement of time limits. This model combines the advantages of approaches based on the similarity of customer requirements and the similarity of product characteristics, which makes it possible to adjust recommendations online for a cold start situation. With this adjustment, it is advisable to use the similarity of the user selection processes for given requirements for goods.

Keywords: recommender systems; e-commerce systems; presentation of knowledge; formation of recommendations; principles of black and white boxes.

Introduction

Recommendation systems provide support for consumer decision-making of goods and services and are commonly used in e-commerce systems. They enable the consumer to make an informed choice in the context of a wide range of properties with similar characteristics. For example, choose one of the same smartphones or computers from different manufacturers.

Recommendation systems form recommendations in the form of a rating list of goods and services, taking into account known consumer choices and (or) known features of the objects. The purpose of making recommendations is to formulate a list of goods and services that is relevant to the interests of the consumer and motivates him to purchase the relevant objects [1].

Current approaches to building recommendations are based on the use of consumer choice data or the characteristics of objects (goods and services) that meet the requirements of that consumer [2].

The first group of approaches uses information about your purchase history, as well as product or service ratings from similar users.

The second group of approaches uses information about the properties of goods and services to make recommendations. That is, consumer requirements are predicted on the basis of similarity of properties already as the goods already selected by him, so new, offered by the recommendation system.

These approaches allow you to effectively build a list of assets for regular users of recommendation systems, based on an array of inputs of their choice in the past. However, in situations of cold start [3] and cyclic cold start, these approaches do not ensure that recommendations are made according to the needs of the consumer.

The first situation is typical for new users who have not yet chosen products and services. Therefore, there is no data set that allows us to formulate recommendations based on the above approaches.

The second situation usually arises when choosing complex goods and services. Such objects are usually of high cost or have specific characteristics and are therefore rarely selected by the consumer at large intervals. This category of property includes, for example, cars, sophisticated vehicles, books, hiking tours, and more.

Knowledge-based approaches are used to build recommendations in these situations [1, 2]. Such approaches involve step-by-step (interactive) personalization of proposals based on refinement of user requirements. These requirements are set in the form of a combination of properties of goods and services.

The process of refining the recommendation is performed on the basis of a knowledge base containing information about the properties of the goods and services, their possible combinations, as well as a formal description of the situations in which these goods are used.

Knowledge-based recommendation systems use two approaches to build a list of objects according to user requirements:

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– interactive refinement of restrictions on the properties of a group of goods or services [4];

– selection of goods on the basis of precedents (cases).

In the first case, all known characteristics of the goods are used to build recommendations, and in the second case, only the target properties characterizing not only the goods but also the situation of their use [5, 6].

Summarizing, both approaches use different forms of constraints in order to find an implicit link between product properties and user requirements. This makes it possible to formulate recommendations in a cold start situation. A key drawback of these approaches is the need to build and continually expand the knowledge base. This task requires a considerable amount of time, because the specifications of the goods are usually different and in most cases the automated replenishment of the knowledge base is fraught with considerable difficulties.

To overcome these difficulties, given the irregular choice of goods and services, it is advisable to use the methods of automated construction of knowledge bases [7, 8]. Such methods make it possible to account for changes in the washed consumer over time based on weighted temporal rules [9, 10]. This makes it possible to take into account the peculiarities of cyclic cold start [11], which indicates the relevance of the problem presented in the paper.

The purpose of the article is to develop a model of knowledge representation in the white box recommendation systems.

This model contains knowledge about the possible sequences of selecting restrictions on the properties of goods and services according to user requirements. To achieve this goal, you need to solve the following problems:

– to structure the processes of applying the principles of black and white boxes when building recommendations based on the use of knowledge base;

– develop a white box representation of knowledge to combine a static description of the properties of the objects and a description of the possible sequences of refining the requirements for the properties of those objects.

Apply black and white box principles when building recommendations based on the use of a knowledge base

Restrictions used to build knowledge-oriented recommendations may take into account the context of the use of the product or service by the user, or may meet the specific characteristics of the product. In the first case, the constraints are constructed according to the principle of the black box, and in the second - the white box [12, 13]. These principles are widely used in solving the problem of software testing.

A comparative description of the principles of using black and white in relation to the interactive construction of recommendations based on the knowledge base is given in Table. 1.

The principle of the black box allows you to check the capabilities of the system without taking into account its internal structure. This principle is to review and test the functionality of a particular system at the level of its inputs and outputs.

Table 1 – **Comparison of black and white box principles when building recommendations based on the use of a knowledge base**

Features	The principle of the black box	The principle of the white box
Goal	Make recommendations based on the context of use of the product or service.	To formulate recommendations taking into account both the values of the set of properties of a product (service) and the acceptable combinations of these properties.
Input information	A subset of the target properties of a product (service), which is key in the context of their use from a user perspective.	The set of valid values, as well as combinations of values of the properties of the goods (services).
The process of getting recommendations	Selection of the use case of an object that corresponds to many of its target properties. Based on the received case, a selection of goods with the specified properties is performed.	Forming a list of objects that satisfy the constraint. In the case of an empty set of recommendations, the restrictions are relaxed.
Representation of the process of obtaining recommendations	A set of situations, each characterizing a unique context for the use of a product or service. Each situation is represented by a hierarchy of temporal dependencies. Hierarchy elements can be sequences of temporal dependencies	The set of linear sequences of dependencies between combinations of values of the properties of the product, reflecting the refinement of requirements.
Approach	Case-based	Constraint-based

The implementation of this principle in the formulation of recommendations based on the knowledge base is as follows. The input specifies the context for the application of the product or service being offered, and the output specifies the properties of that object in the given context. Making recommendations is to determine the case from known inputs and then select the properties of the object according to the selected case.

Thus, this principle determines the precedent approach to building recommendations.

According to the principle of the white box, when analyzing or describing an object, it is necessary to consider not only the relationship between inputs and

outputs, but also its internal structure. That is, the implementation of the principle of the white box requires consideration of the chain: input information - the interaction of internal elements - the output recommendation.

The knowledge base of the recommendation system in this case should characterize the possible values of the properties of the recommended object, as well as the acceptable combinations of these values. That is, the principle of the white box makes it possible to clarify the restrictions in the process of making recommendations online.

Development of generalized representation of knowledge in the recommendation system according to the principle of white box

These differences in the use of the principles of black and white box make it possible to draw the following conclusions about the representation of knowledge in the recommendation system.

First, restrictions on the properties of goods and services according to the white box principle may be represented by temporal dependencies. The antecedents and implications of these dependencies determine the possible combinations of user-selected object property values.

The type of temporal dependency determines the sequence of refinement of these properties by the user.

The sequence of recommendations is determined by the linear sequence of temporal dependencies. Interactive choice of a product or service is realized by changing the restrictions on the important properties of the objects for the user.

This choice is set by moving to the second linear selection sequence.

Schematic representation for the selection process are presented in Fig. 1.

The representation of constraints C on the knowledge base of the recommendation system is consisting of a set of predicates C_j on the properties $x_{j,k}$ of the objects that the consumer chooses:

$$C = \left\{ C_j \left(x_{j,1}, x_{j,2}, ..., x_{j,k}, ..., x_{j,K} \right) : \forall j,k \left(x_{j,k} = v_{j,k} \vee x_{j,k} \in V_{j,k} \right) \right\}, \quad (1)$$

where $v_{j,k}$ – value k – properties in j – restriction;

$V_{j,k}$ – set or range of valid values k – properties in j – constraint.

An example of a screen fragment is shown in Fig. 2.

Temporal dependencies [9] make it possible to formalize the process of refining recommendations over time.

The dependencies R_n that are adapted to this task determine the sequence of constraints selected for one or more users:

$$R_n \left(C_{n,j}, T, K, C_{n,m} \right) : C_{n,j} \wedge T \Rightarrow C_{n,m} : K, \quad (2)$$

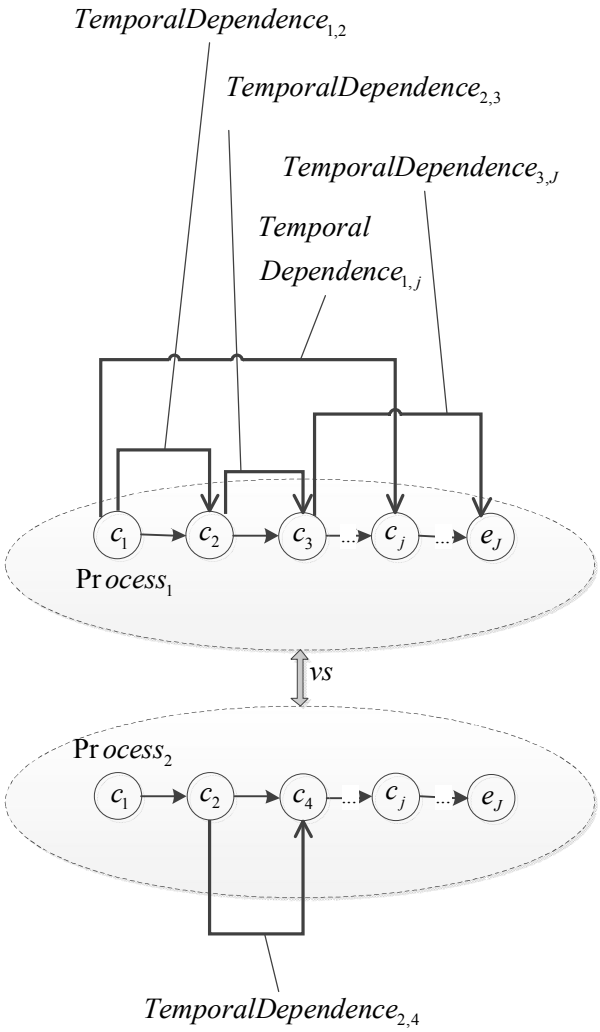

Fig. 1. An example of a sequence of recommendations based on refinement of constraints according to the white box principle

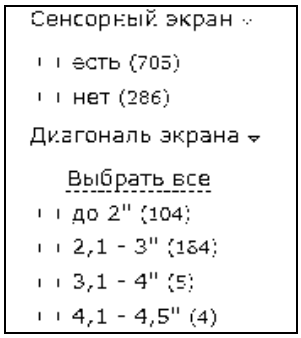

Fig. 2. Fragment screen constraints on the example of "Electronic World" store

where T – temporal operator, which determines the sequence of constraints;

$C_{n,j}$ and $C_{n,m}$ – restrictions included n – rules;

K – is a quantifier that determines the sequence of conditions on which rule (2) will be true.

Depending on the particular quantizer, rule (2) will look like (3) or (4):

$$\forall (C_j, C_m) C_j \wedge T \Rightarrow C_m, \quad (3)$$

$$\exists(C_j, C_m): C_j \wedge T \Rightarrow C_m. \quad (4)$$

Temporal operators T usually determine the sequential choice of constraints, the refinement of constraints after the condition, the associated choice of constraints.

In the first case, a direct sequence of actions to select a product or service by the user is specified.

Refinement of constraints makes it possible to describe the cyclic change of constraints in the case of an empty set of recommendations.

The temporal operator for related choices sets such constraints that determine similar or more detailed product characteristics.

In particular, in the example in Fig. 3 after selecting the range for the diagonal of the screen of the mobile phone, you can further select the exact screen size.

This choice is made both in the next refinement cycle and in one of the next steps to adjust the requirements.

The generalized representation of knowledge according to the principle of the white box contains both limitations and temporal dependencies between these limitations:

$$W = \Big(R\{R_n\}, C: \forall Item_l \in Item\ \exists\langle R_1, ..., R_N\rangle: C_{N,m} = True\Big), \quad (5)$$

where $Item = \{Item_l\}$ – set of products or services offered by the referral system.

According to expression (5), each product or service can be distinguished by following a series of rules $\langle R_1, ..., R_N\rangle$.

Conclusions

A generalized model of knowledge representation in the recommendation system according to the white box principle is proposed.

The resulting presentation combines a declarative and procedural description of the process of making recommendations.

The declarative aspect is represented by restrictions in the form of predicates on the permissible values of the properties of the objects offered to the consumer.

The procedural aspect is given in the form of adapted temporal rules that specify the sequence of refinement of restrictions.

The key advantage of the proposed model is that it combines the benefits of approaches based on the similarity of consumer requirements and the similarity of product characteristics.

This makes it possible to tailor recommendations in real time based on the similarity of user selection processes for similar products.

References

1. Aggarwal, C.C. (2017), *Recommender Systems: The Textbook*, Springer, New York, 498 p.
2. Ricci, F., Rokach, L., Shapira, B. and Kantor, P. (2011), *Recommender systems handbook*, Springer, New York, 842 p.
3. Schein, A.I., Popescul, A., Ungar, L.H. and Pennock, D.M. (2002), "Methods and metrics for cold-start recommendations", *Proceedings of the 25th annual international ACM SIGIR conference on Research and development in information retrieval*, pp. 253–260.
4. Felfernig, A. and Burke, R. (2008), "Constraint-based recommender systems: technologies and research issues", *10th International Conference on Electronic Commerce*, Innsbruck, Austria, pp. 1–10.
5. Bridge, D.M. Goker, L. McGinty, and Smyth B. (2005), "Case-based recommender systems", *The Knowledge Engineering Review*, 20(3), pp. 315–320.
6. Smyth B. (2007), "Case-based recommendation", *The Adaptive Web*, Springer, pp. 342–376.
7. Chala O.V. (2018), "Construction of temporal rules for representing knowledge in information control systems", *Advanced Information Systems*, Vol. 2, No. 3, pp. 54–59, DOI: https://doi.org/10.20998/2522-9052.2018.3.09
8. Levykin, V. and Chala O. (2018), "Method of determining weights of temporal rules in Markov logic network for building knowledge base in information control system", *EUREKA: Physics and Engineering,* 5, pp. 3–10.
9. Chala, O. (2018), "Models of temporal dependencies for a probabilistic knowledge base", *Econtechmod*, Vol. 7(3), pp. 53–58.
10. Levykin, V. and Chala, O. (2018), "Development of a method of probabilistic inference of sequences of business process activities to support business process management", *Eastern-European Journal of Eenterprise Technologies*, Vol. 5/3(95), pp. 16–24, DOI: https://doi.org/10.15587/1729-4061.2018.142664
11. Chalyi, S., Leshchynskyi, V. and Leshchynska I. (2019), "Method of forming recommendations using temporal constraints in a situation of cyclic cold start of the recommender system", *EUREKA: Physics and Engineering*, 4, pp. 34-40.
12. Chalyi, S., Leshchynskyi, V. and Leshchynska I. (2019), "Designing explanations in the recommender systems based on the principle of a black box", *Advanced Information Systems*, Vol. 3, No. 2, pp. 47–51, DOI: https://doi.org/10.20998/2522-9052.2019.2.08
13. Chalyi, S., Leshchynskyi, V. and Leshchynska I. (2019), "The concept of designing explanations in the recommender systems based on the white box", *Control, Navigation and Communication Systems*, No. 3(55), pp. 156–160, DOI: https://doi.org/10.26906/SUNZ.2019.3.156

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Побудова представлення знань в рекомендаційній системі на основі принципу білого ящику

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Анотація. Предметом вивчення в статті є процеси побудови рейтингового переліку товарів та послуг в рекомендаційних системах. **Метою** є розробка моделі представлення знань в рекомендаційній систем за принципом білого ящику. Така модель містить знання про можливі послідовності вибору обмежень на властивості товарів та послуг згідно вимогам користувача. Рекомендаційна система повинна забезпечити обґрунтований вибір об'єкта відповідно до вимог користувача за умови обмежень по ключовими властивостями цього об'єкту. **Завдання**: структурувати процес застосування принципів чорного та білого ящиків при побудові рекомендацій на основі використання бази знань; розробити представлення знань згідно принципу білого ящику з тим, щоб поєднати статичний опис властивостей об’єктів та опис можливих послідовностей уточнення вимог до властивостей цих об’єктів. Використовуваними **принципами** є: принцип білого ящику, що забезпечує врахування вимог, які враховують властивості складових елементів об’єкту вибору споживача. Отримані наступні **результати**. Виділено ключові особливості процесів формування рекомендацій згідно принципів чорного та білого ящиків на основі використання бази знань. Розроблено представлення знань згідно принципу білого ящику, що дає можливість враховувати як властивості об’єктів так і процес їх вибору споживачем. **Висновки**. Наукова новизна отриманих результатів полягає в наступному. Запропоновано модель представлення знань в рекомендаційній системі згідно принципу білого ящику. Декларативний аспект даного представлення знань реалізований у формі предикатів, що визначають обмеження на значення властивостей об’єктів, які пропонуються споживачеві. Процедурний аспект реалізований у вигляді адаптованих темпоральних залежностей, що задають послідовність уточнення обмежень у часі. Дана модель поєднує переваги підходів на основі схожості вимог споживачів та схожості характеристик товарів, що дає можливість коригувати рекомендації в режимі он-лайн для ситуації холодного старту на основі визначення схожості процесів вибору користувача при заданих вимогах до товарів.

Ключові слова: рекомендаційні системи; системи електронної комерції; представлення знань; формування рекомендацій; принципи чорного та білого ящиків.

Построение представления знаний в рекомендательной системе на основе принципа белого ящике

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Аннотация. Предметом изучения в статье являются процессы построения рейтингового перечня товаров и услуг в рекомендательных системах. **Целью** является разработка модели представления знаний в рекомендательной систем с использованием принципа белого ящика. Такая модель содержит знания о возможных последовательностях выбора ограничений на свойства товаров и услуг согласно предпочтениям пользователя. Рекомендательная система должна обеспечить обоснованный выбор объекта согласно требованиям пользователя при условии ограничений по ключевыми свойствами этого объекта. **Задачи**: структурировать процесс применения принципов черного и белого ящиков при построении рекомендаций на основе использования базы знаний; разработать представления знаний согласно принципу белого ящика с тем, чтобы совместить статическое описание свойств объектов и описание возможных последовательностей уточнения требований к свойствам этих объектов. Используемыми **принципами** являются: принцип белого ящика, который обеспечивает учет требований, учитывающих свойства составляющих элементов выбираемого потребителем объекта. Получены следующие **результаты**. Выделены ключевые особенности процессов формирования рекомендаций по принципам черного и белого ящиков на основе использования базы знаний. Разработано представление знаний согласно принципу белого ящика, что позволяет учитывать как свойства объектов, так и процесс их выбора потребителем. **Выводы**. Научная новизна полученных результатов заключается в следующем. Предложена модель представления знаний в рекомендательной системе согласно принципу белого ящика. Декларативный аспект данного представления знаний реализован в форме предикатов, определяющих ограничения на значения свойств объектов, предлагаемых потребителю. Процедурный аспект реализован в виде адаптированных темпоральных зависимостей, задающих последовательность уточнения ограничений во времени. Данная модель сочетает преимущества подходов на основе сходства требований потребителей и сходства характеристик товаров, что дает возможность корректировать рекомендации в режиме он-лайн для ситуации холодного старта. При такой корректировке целесообразно использовать сходство процессов выбора пользователя при заданных требованиях к товарам.

Ключевые слова: рекомендательные системы; системы электронной коммерции; представление знаний; формирование рекомендаций; принципы черного и белого ящиков.