A Hybrid Graph Convolutional Networks (GCN)-Collaborative Filtering Recommender System

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***Abstract*—This study proposes a hybrid recommendation system that integrates Graph Convolutional Networks (GCN) and collaborative filtering to improve the accuracy and performance of university library book recommendation systems. The goal is to develop a comprehensive evaluation method for assessing the effectiveness of recommendation algorithms in university libraries. A combination of GCN and collaborative filtering algorithms was employed to enhance recommendation accuracy. GCN was used to capture complex relationships in user data, while collaborative filtering focused on user preferences. Performance evaluation was conducted using a set of functional indicators, and the system was tested using real library data. The evaluation metrics included Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), and evaluation time. The GCN-based evaluation model significantly outperformed traditional methods. It achieved a MAPE of 0.7597 and an RMSE of 0.3775, both superior to BP, CNN, and DBN algorithms. In terms of evaluation time, the GCN algorithm showed moderate performance (0.44s) compared to BP (0.32s), but better than DBN (0.87s) and CNN (0.67s). These results demonstrate the robustness and efficiency of the GCN model in predicting library recommendations. The proposed hybrid system effectively improves the accuracy and evaluation of university library recommendation systems. The GCN-based model outperformed other methods in terms of error rates and evaluation time, making it a valuable tool for enhancing personalized recommendations in library systems. Future research will focus on optimizing the computational efficiency of the GCN model.**

Keywords*—Graph convolutional networks; collaborative filtering; hybrid recommender systems; university library performance evaluation

I. Introduction

The building and development of libraries is very important to colleges and universities because they serve as teaching and research services, academic institutions, and a center for information about school literature. These libraries also play a significant role in scientific research and talent development [1]. The B/S architecture-based library management system is being gradually integrated into the construction of university libraries in response to the increasing popularity of e-books and digital libraries. This system is designed to assist library management personnel in the navigation of effective organization management and the classification of book information, as well as to assist book users in finding the books they need through the use of relevant search engines [2]. The traditional search technology or navigation technology has been unable to meet the increasing demand for personalized literature as the times have evolved [3]. The conventional library management system can no longer fully fulfill its role due to the growing quantity of university library collections and information resources; it is unable to extract unknown and valuable information from massive amounts of data, nor can it make educated guesses about the needs of users or project the future [4]. In recent years, the development of intelligent search technology has enabled college library book recommendation systems to obtain personalized recommendation information. The development and introduction of intelligent library book recommendation system allows users to borrow books, lowers the time users spend searching for books, and enhances the accuracy of recommended books [5]. The design of a college library book recommendation system that is based on a personalized recommendation algorithm must be assessed based on its design method. Consequently, it is of great importance to investigate effective performance evaluation algorithms for this method [2].

The investigation concerning the book recommendation system in college libraries can be broadly classified into three areas: the design of the system, performance evaluation of the system, and customized recommendation algorithms for books in the library [6]. College library book customized recommendation systems are separated into content-based filtering [7-8], collaborative filtering to [9-10] and hybrid recommendation algorithms [11-12]. Recommendation algorithms for content-based filtering are primarily used in the analysis of user data and document content. Noor et al. [7] describes how users and documents are constructed, and how users' feedback is combined with configuration information to modify the subject and feature word vectors. Wang and Gao [8] present clustering algorithms as the foundation of content filtering, where users are categorized into multiple groups and the recommendation of one group of users per category. Collaborative filtering recommendation algorithms, as opposed to content-based filtering algorithms, use the user's expressed preference behavior and the eye-catching content rating to identify users who share similar interests or behaviors and recommend the information the user is interested in to the target user. Yang et al. [9] introduce category similarity and fully incorporates the rating similarity to calculate the similarity of the recommended items of the recommendation algorithm. Berjisian and Bigazzi [11] employ K-mean clustering approach for calculation, comparing the similarity of each target item, based on a certain item space inside the selected search recommendation. While much progress has been made in the study of book recommendation system design in college libraries, there has been little use of personalized recommendation algorithms in these systems, and the evaluation of these systems using personalised recommendation algorithms is not very accurate or sufficiently comprehensive. The assessment intelligence of book recommendation systems is likely to become the future development trend for these systems in college libraries as deep learning algorithms and big data technology advance [12]. The existing deep learning algorithm is easy to fall into the local optimal, feature extraction is not enough, therefore the application of graph deep learning network can increase the level of evaluation intelligence and assessment accuracy of the book recommendation system [13].

In response to the present issues with the imprecise system performance evaluation and the lack of precision in college library book recommendation methods, this research suggests a hybrid library recommendation system built on graph convolutional networks and collaborative filtering [14]. This paper specifically contributes the following three areas: (1) it proposes a collaborative filtering algorithm-based college library recommendation method; (2) it proposes a graph convolutional network-based performance evaluation method for the problem of college library book recommendation system performance evaluation; and (3) it uses the college library book recommendation system's data to validate and analyze the proposed method, showing that it is more accurate and robust than other models.

To address the shortcomings of existing recommendation systems in university libraries, this paper proposes a hybrid model that combines collaborative filtering and Graph Convolutional Networks (GCN). The structure of this study is as follows: Section II presents the overall system design, including user needs and system architecture. It also elaborates on the collaborative filtering algorithm. Section III introduces the GCN-based performance evaluation model. Section IV describes the system implementation and experimental setup. Section V provides a comparative analysis of experimental results. Finally, Section VI concludes the study and suggests directions for future research.

II. Library Recommendation System Design

A. System Analysis

1) Needs analysis: According to the analysis of user requirements for book recommendation system service in university libraries (Fig. 1), the system requirements are divided into functional and non-functional requirements [15] (Fig. 2), as follows:

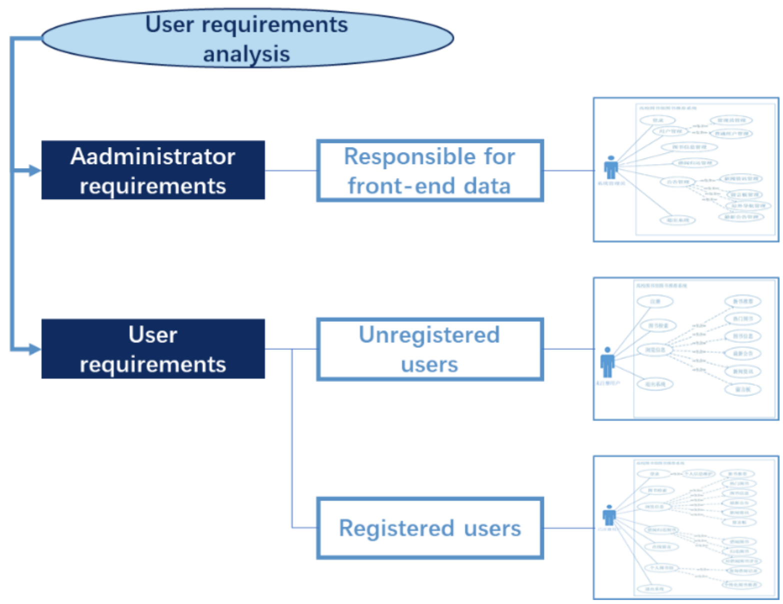


Fig. 1. User requirements analysis.

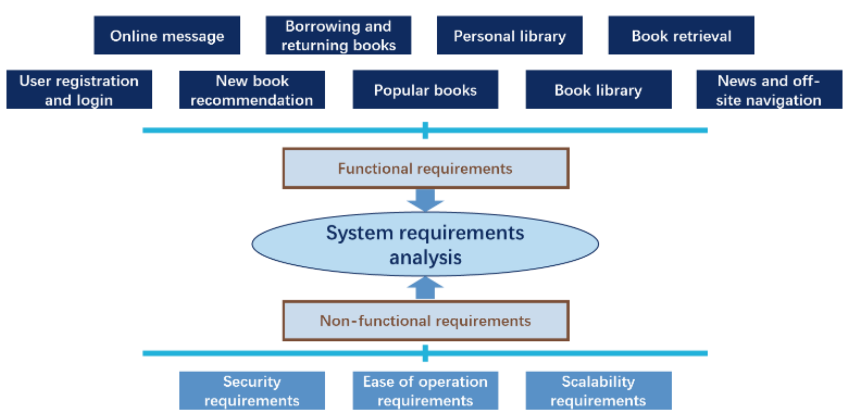


Fig. 2. System requirements analysis.

Functional requirements. Functional requirements mainly include user registration and login, new book recommendations, popular books, book library, news bulletin and off-site navigation, online message, borrowing and returning books, personal library, book search; Non-functional requirements. Non-functional requirements include security requirements, ease of operation requirements, and scalability requirements.

2) System architecture: By assessing the system requirements, the university library book recommendation system incorporates a front-end query system as well as a back-end library management system, and the architecture of the system is specifically represented in Fig. 3.

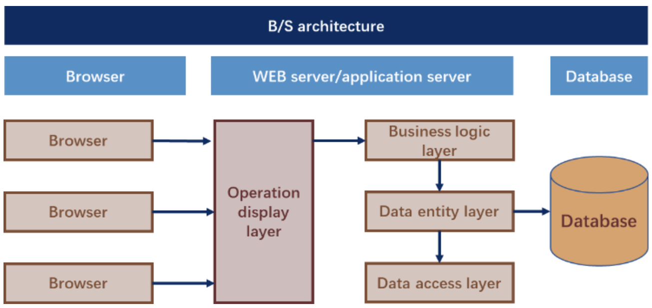


Fig. 3. System architecture.

The operation display layer, data set access layer, data entity layer, and business logic layer make up the majority of the architecture, as shown in Fig. 3. Users can operate through the visual interface, the system through the construction of business logic layer, display layer, business encapsulation operation layer to establish a corresponding process of processing business logic. The data entity layer, which generally has access to the database, i.e., accessing the data in the database and conducting actions such as insertion, etc. [16].

3) System functions: By combining the user requirements and the characteristics of each functional module of the system, the functional structure of the book recommendation system for college libraries is shown in Fig. 4.

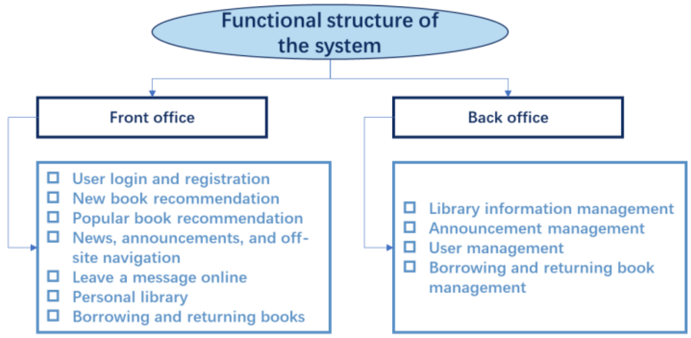


Fig. 4. System functional structure.

The system functions are categorized as foreground and background functions. Foreground functions include the following: 1) user login and registration, new book recommendations, popular book recommendations, book library, and other functional modules. Background functions, such as book information management, bulletin management, user management, borrowing and returning book management, and other functions, are operated by the system administrator by logging in study [17].

4) Overall system process design: When user roles are combined, the system can be separated into two categories of users: 1) system administrators, who have the power to control books, news, and other data in the background; the detailed operation procedure is depicted in Fig. 5; and 6) regular users, whose restricted functions, like examining news updates, recording returned books, and checking out books, are accomplished via the system's front end [18].

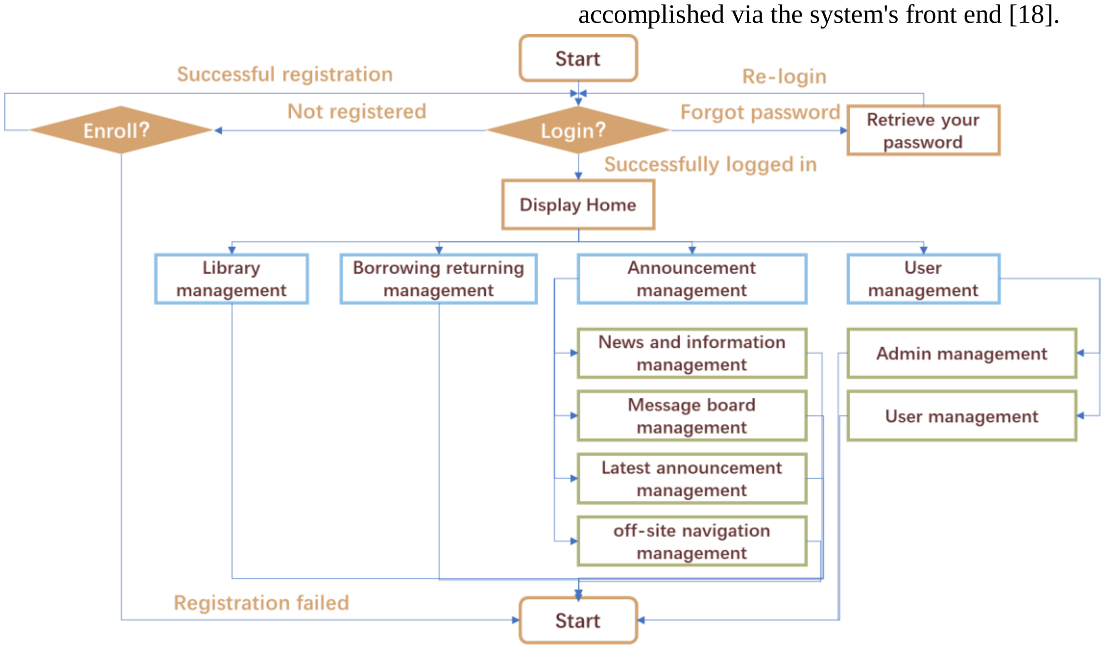


Fig. 5. System administrator flowchart.

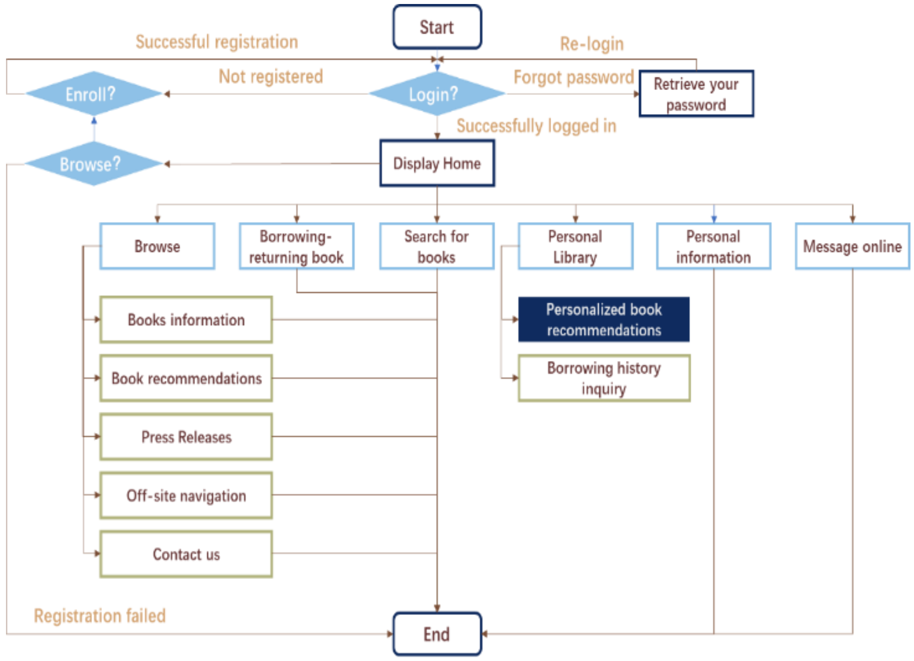


Fig. 6. General user flow chart.

B. *Collaborative Filtering Algorithm*

In the book recommendation system of university libraries, the book recommendation method based on collaborative filtering algorithms, as the core of the recommendation system, is based on the data of the user group's preference for the product, to discover the similarity between users or items, and then provide personalised recommendations. Collaborative filtering is largely separated into two forms (Fig. 7): user-based collaborative filtering [19] and item-based collaborative filtering [20].

1) Introduction to the algorithm: The purpose of User-based Collaborative Filtering (UCF) is to locate comparable groups of users and recommend the goods that these people enjoy to the target audience, as shown in Fig. 8. This methodology works by calculating the similarity between users, which can be calculated by many approaches such as Euclidean distance, cosine similarity or Pearson correlation coefficient.

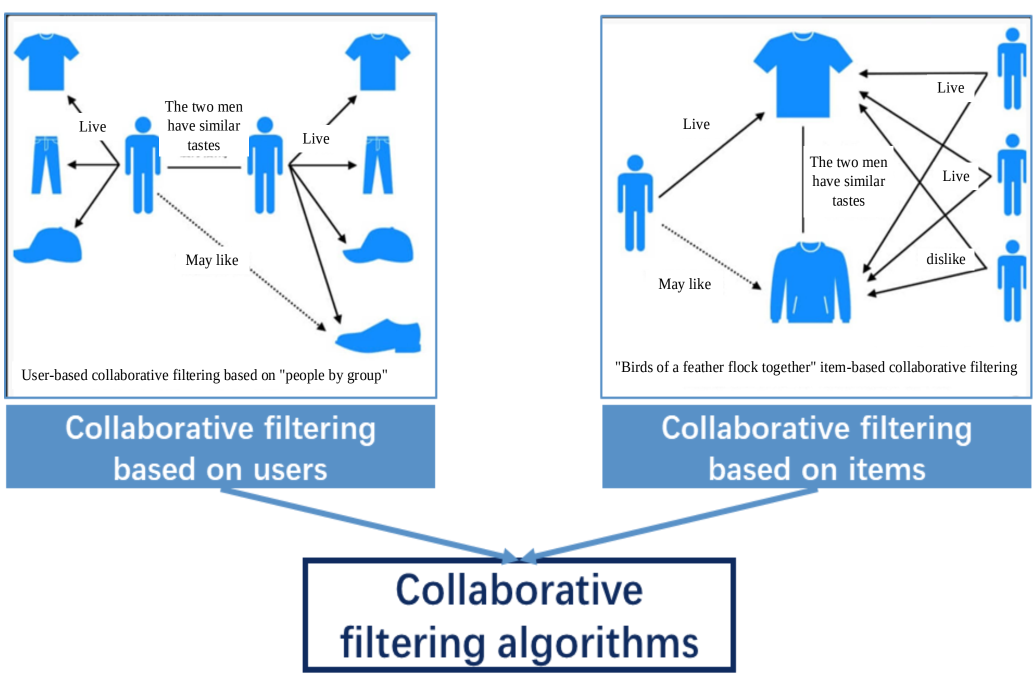


Fig. 7. Classification of collaborative filtering algorithms.

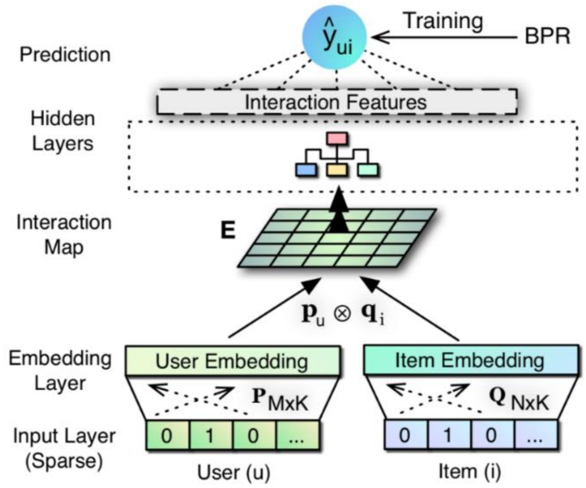


Fig. 8. Principle of user-based collaborative filtering algorithm.

Item-based Collaborative Filtering, on the other hand, recommends related goods to users based on their historical preference information, as seen in Fig. 9. This technique assumes that if people have liked particular goods in the past, they may also like other items that are comparable to those ones. The similarity between objects is also frequently established via a similarity computation method.

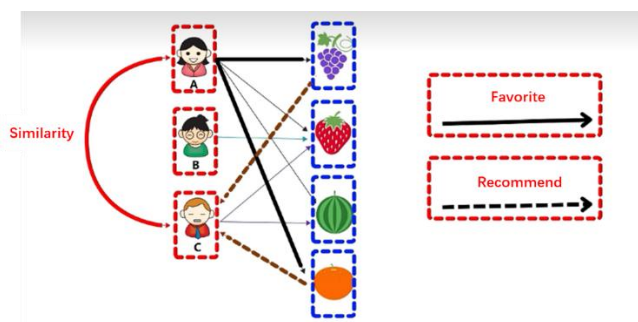


Fig. 9. Principle of item-based collaborative filtering algorithm.

2) Similarity calculation method: Commonly used similarity calculations in collaborative filtering algorithms (e.g., Fig. 10) [21] include:

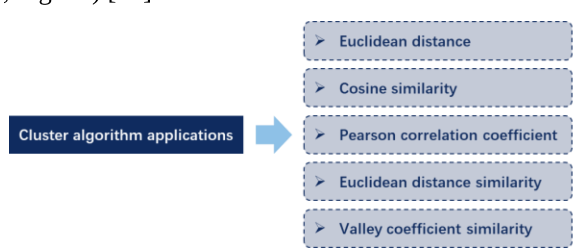


Fig. 10. Similarity calculation method.

Euclidean distance: similarity is measured by calculating the distance between two users or items in a multidimensional space.

Cosine similarity: the similarity is expressed by calculating the cosine of the angle between two vectors, the closer the cosine value is to 1, the more similar the two vectors are.

$$sim(i,j) = \cos(v_i, v_j) = \frac{v_i \cdot v_j}{|v_i| \cdot |v_j|} \tag{1}$$

where i, j is the two variable users; v_i and v_j denote the i- and j-order row vectors of a user's borrowing record, respectively.

Pearson's correlation coefficient: a statistic describing the linear correlation between two numerical variables, with values ranging from [-1, 1], used to measure the linear correlation between users or items.

$$sim(i,j) = \frac{\sum_{c \in I_{ij}} (R_{i,c} - \bar{R}_i)(R_{j,c} - \bar{R}_j)}{\sqrt{\sum_{c \in I_{ij}} (R_{i,c} - \bar{R}_i)^2} \sqrt{\sum_{c \in I_{ij}} (R_{j,c} - \bar{R}_j)^2}} \tag{2}$$

where I represents the entire project/userspace.

Euclidean distance similarity: the coordinates between users/items in this calculation method are row vector/column vector (data scoring matrix), and this is used as a basis for calculating the similarity of users and items.

$$sim(i,j) = \frac{\sum_{c \in I_{ij}} (R_{i,c} - \bar{R}_i)(R_{j,c} - \bar{R}_j)}{1 + \sqrt{\sum_{c \in I_{ij}} (R_{i,c} - R_{j,c})^2}} \tag{3}$$

Gulben coefficient of similarity: the idea is that items that are not similar do not affect the results of calculating similarity, and that only items that are preferred by the user come into play when calculating similarity.

$$sim(i,j) = \frac{N_{ij}}{N_i + N_j - N_{ij}} \tag{4}$$

Among them, N_i indicates the number of user i's favourite items or the number of users choosing category i; N_j indicates the number of user j's favourite items or the number of users choosing category j; N_{ij} indicates the number of users choosing two categories of items at the same time, i.e., the two categories of items are simultaneously recognised and preferred by the users.

3) Collaborative filtering algorithm based on user interest: Based on the diversity in user interests, collaborative filtering recommendations are generated using a strategy and approach to compute the rating matrix [22]. This computation method's results can accurately capture the fluctuations in the relative weights of the item ratings over all time intervals. The key principle of the collaborative filtering algorithm based on user interest is to handle the rating matrix correctly, consequently, frequency weights and time weights are incorporated.

a) Frequency weighting: This indicator is used to indicate the number of times a user has borrowed a book, the more times, the larger its corresponding weight value will be.

$$Wb(u,i)=\frac{b_i}{B_u} \tag{5}$$

Where, b_i and B_u denote the total number of times user u borrowed books of category i, all books respectively.

b) Time weighting: The time weights on the one hand weaken the importance of books borrowed long ago and on the other hand emphasise the importance of books borrowed in the recent past.

$$Wt(u,i)=\begin{cases}\frac{t_2-t_1}{T}\times\frac{t_2}{T} & t_1\neq t_2\\ \frac{t_2}{T}\times\frac{1}{T} & t_1=t_2\end{cases} \tag{6}$$

In summary, the combined weights are calculated as follows:

$$W(u,i)=\begin{cases}\beta\times\frac{b_i}{B_u}+(1-\beta)\times\frac{t_2-t_1}{T}\times\frac{t_2}{T} & t_1\neq t_2\\ \beta\times\frac{b_i}{B_u}+(1-\beta)\times\frac{t_2}{T}\times\frac{1}{T} & t_1=t_2\end{cases} \tag{7}$$

Among them, $\beta\in(0,1)$ represents the proportion of frequency weighting, $(1-\beta)$ represents the proportion of time weighting, and generally β is set to 0.5.

c) Recommendation algorithm steps: The input to the improved recommendation algorithm is the input has been borrowed book set I_u , the output is the Top-N result recommendation set of the user u. The flowchart of the algorithm is shown in Fig. 11.

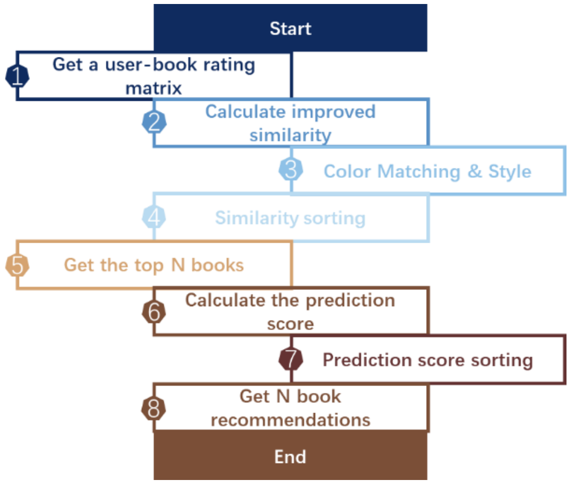


Fig. 11. Flowchart of the improved recommendation algorithm.

III. Performance Testing Methods for Recommender Systems in Higher Education Libraries

A. Graph Convolutional Network Algorithm

Graph Convolutional Networks (GCN) [23] is a neural network model specifically developed to process graph-structured data. It is able to act directly on graph data and leverage the structure information of the graph, and is frequently used for tasks such as node classification, link prediction, community detection, etc. The main idea of GCN is to extend the convolutional operation from standard Euclidean data (e.g., Fig. 12) to graph data, and to learn the representation of a node by aggregating information about the properties of the node and its neighbours.

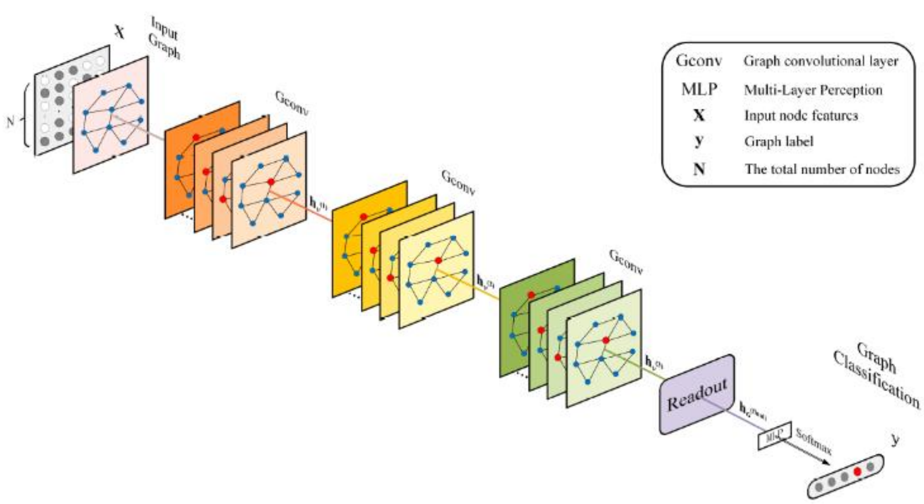


Fig. 12. GCN algorithm structure.

1) Principle of operation: Suppose a graph structure $G=(V,E)$, as an input to the GCN, where V denotes the set of graph nodes and E is the set of edges in the graph; each node $v\in V$ has a feature vector X_v , which represents the feature information of the node; and A denotes the adjacency matrix. The specific model is as follows:

$$H^{l+1}=f\left(H^{(l)},A\right) \tag{8}$$

$$f\left(H^{(l)},A\right)=\sigma\left(AH^{(l)}W^{(l)}\right) \tag{9}$$

Where $H^{(0)} = X$, $H^{L} = Z$, L are the number of layers; $W^{(l)}$ denotes the weight matrix of the l layer, and σ is a nonlinear activation function.

The matrix transformation is:

$$H^{(l+1)} = \sigma\left(D^{-\frac{1}{2}} \cdot A \cdot D^{-\frac{1}{2}} \cdot H^{(l)} \cdot W^{(l)}\right) \tag{10}$$

Where $H^{(l)}$ denotes the feature representation of layer l , A is the adjacency matrix, D is the degree matrix, $W^{(l)}$ is the weight matrix of layer l , and σ is a nonlinear activation function.

2) GCN Applications: Applications for GCN may be found in a number of domains, such as computer vision, recommender systems, social network analysis, chemical molecular structure analysis, traffic prediction, etc. (Fig. 13). It is capable of handling the complexity of graph data and extracting usable features from it for tasks like as classification and prediction [24].

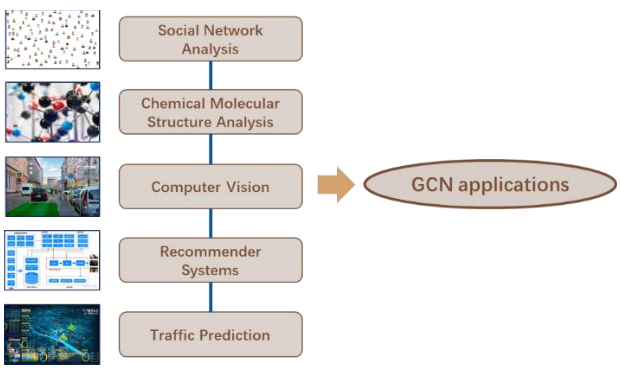


Fig. 13. GCN algorithm application.

B. Application of Algorithms

This study uses GCN to build the college library recommender system performance test and evaluation model in order to address the issue of how to test and evaluate the system's performance. The recommendation system performance evaluation problem is a complex nonlinear evaluation and prediction regression problem, using the college library recommendation system functional indicators as input and the recommendation system performance evaluation score as output. Therefore, this paper adopts GCN to address the college library recommender system performance test evaluation problem, the problem analysis and solution ideas are illustrated in Fig. 14. In order to conduct a performance test and evaluation of the college library book recommendation system, the evaluation problem entails the analysis of the functional indicators of the system, the construction of an indicator system, and the application of the GCN algorithm to establish a mapping relationship between the value of the functional indicators and the evaluation scores.

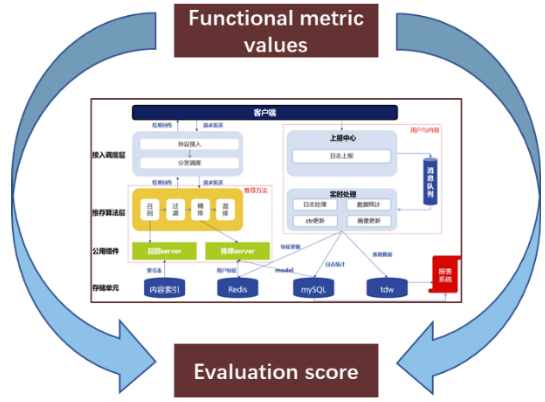


Fig. 14. Ideas for solving the problem of evaluating the book recommendation system in university libraries.

1) Constructing a recommendation system evaluation index system: The evaluation indexes of book recommendation system in college library include the front-end functional indexes and back-end functional indexes [25], and the specific index system is shown in Fig. 15.

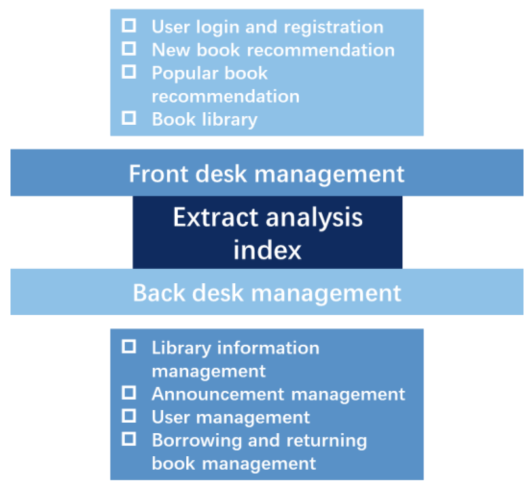


Fig. 15. Construction of the assessment indicator system.

The functions can be categorized as either foreground or background. Foreground management includes the following: 1) user login and registration, new book recommendations, popular book recommendations, library, and other functional modules; 2) system administrator log-in to the system background to manage book information, bulletins, user management, borrowing and returning book management functions, and operations. (2) Constructing a Recommender System Evaluation Model

The development of the book recommendation system evaluation model for the university library is predicated on the GCN algorithm training optimization, the recommendation system performance evaluation score as the output, and the recommendation system function index as the input. The specific flow of the recommendation system assessment model is given in Fig. 16.

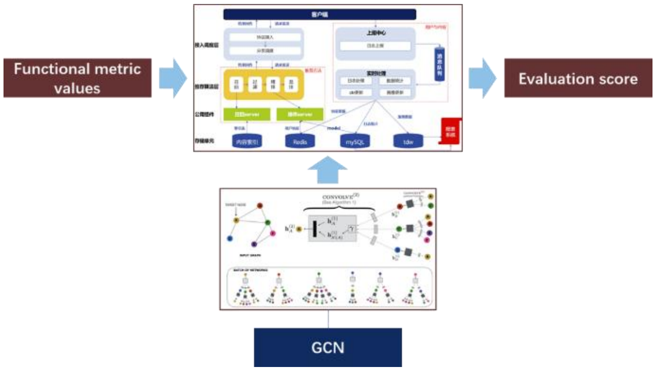


Fig. 16. Construction of the evaluation model of university library recommendation system.

IV. A Method for Designing and Evaluating the Performance of Recommender Systems in University Libraries

The design and assessment process for college library recommender systems is primarily separated into two sections: (1) college library recommender system design. Aiming at the core problem of the recommendation system, the improved collaborative filtering algorithm is used to design the college library book recommendation algorithm, the input is the set of borrowed books, and the output is the user's resultant recommendation set; (2) college library recommendation system evaluation. Using GCN to establish the mapping link between functional index values and assessment values. The college library recommendation system design and evaluation process is specifically shown in Fig. 17.

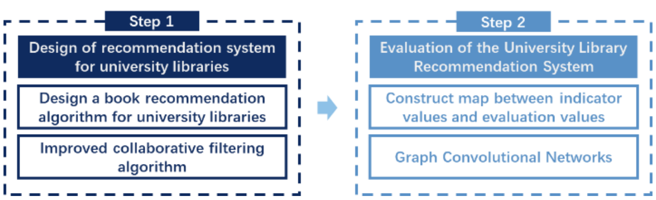


Fig. 17. Schematic of the design and evaluation methodology of the university library recommendation system.

V. Analysis of Results

A. Environmental Settings

The university library recommendation system is developed based on SSH framework using MVC technology. Based on multi-tier architecture, it is developed through B/S access mode and Java language, and the specific environment settings are shown in Table I.

The environment setup for the evaluation algorithm of the recommendation system in the university library is shown in Table II.

TABLE I. Environmental Setup

Environmental projects	Settings
operating system	Windows 10
web server	Apache-tomcat-8.0.36, JDK6.x
programming language	Java
Database management system	MySQL

TABLE II. System Evaluation Environmental Settings

Environmental Projects	Settings
operating system	Windows 10
visualisation software	Matlab2022a
processing unit	AMD Ryzen 9 5900HX with Radeon Graphics 3.30 GHz
programming language	Pycharm

In order to analyse and compare the efficiency of the proposed algorithms in this paper, BP, DBN, CNN and GCN are used for comparative analysis, and the specific algorithm parameters are set as shown in Table III.

TABLE III. System Evaluation Environmental Settings

Arithmetic	Parameterisation
BP	The activation function is tan-sigmoid and the number of hidden layer nodes is 60
DBN	Three hidden layers with 60, 100, 60 nodes in each layer
CNN	The number of hidden layer nodes of the CNN network is 50 and the Adam technique is used to optimise the network training
GCN	The hidden layer node is 100 and the activation function is the Relu function

The dataset used for the evaluation algorithm of the university library recommender system is the data generated by the university library recommender system, in which the data is divided into a training set and a test set with a ratio of 8:2.

B. System Design Implementation

This study builds the university library recommendation system as depicted in Fig. 18, based on user demands. As can be seen from Fig. 18, the home page of the system mainly shows the overall functional structure of the system to the user; the system's book recommendations can be divided into two types: the first is a new book recommendations; the second is a popular book, and are open for users, are personalised book recommendations, including users who have not yet logged on to the system. Users can also access the borrowing record to view their previous personal borrowing of books on the platform, as the personal library module, the primary module of the system, can offer personalized recommendations.

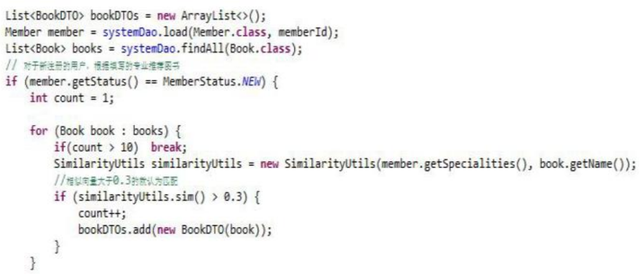
(a) System home page

(b) Book Recommendation Interface

(c) Personalised book recommendation interface for new users

Fig. 18. Design and implementation of recommendation system for university libraries.

The recommendation algorithm code for the university library recommendation system is given in Fig. 19. The system recommends professional literature by calculating the similarity. In this system, if the value of similarity reaches 0.3 or greater, it can recommend 10 books for the user in this or related majors.



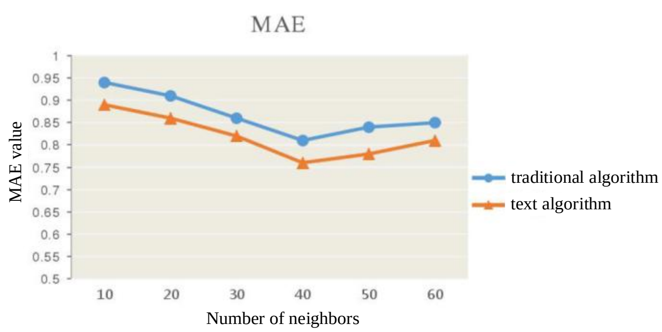
```
List<BookDTO> bookDTOs = new ArrayList<>();
Member member = systemDao.load(Member.class, memberId);
List<Book> books = systemDao.findAll(Book.class);
// 对于新注册的用户，根据填写的专业推荐图书
if (member.getStatus() == MemberStatus.NEW) {
    int count = 1;

    for (Book book : books) {
        if(count > 10)  break;
        SimilarityUtils similarityUtils = new SimilarityUtils(member.getSpecialities(), book.getName());
        //相似向量大于0.3的默认为匹配
        if (similarityUtils.sim() > 0.3) {
            count++;
            bookDTOs.add(new BookDTO(book));
        }
    }
```

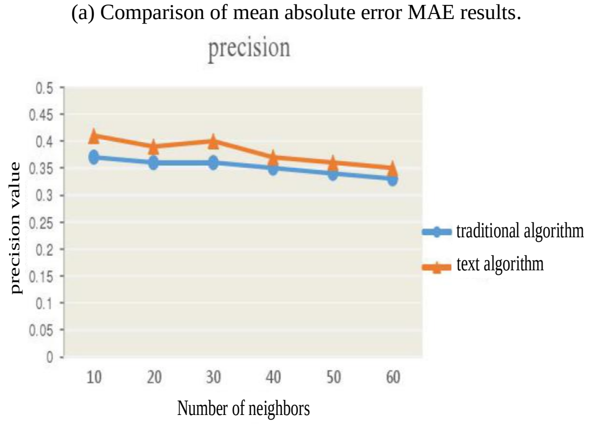
Fig. 19. Recommendation algorithm code for university library recommendation system.

C. Experimental Analysis of System Evaluation Algorithms

In order to validate the performance of the proposed recommender system in this paper, BP, CNN and DBN algorithms are used to compare and analyse with GCN network and specific results are obtained as shown in Fig. 20, Fig. 21 and Table IV.



(a) Comparison of mean absolute error MAE results.

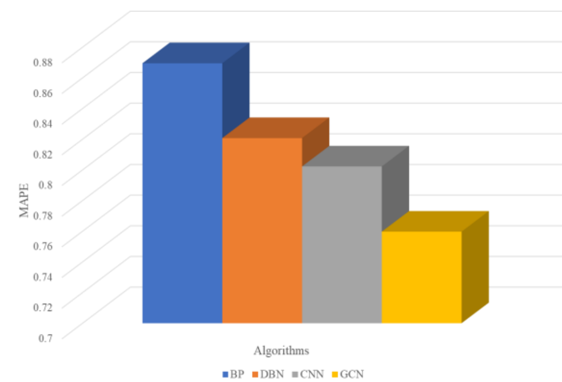


(b) Comparison of test accuracy precision results.

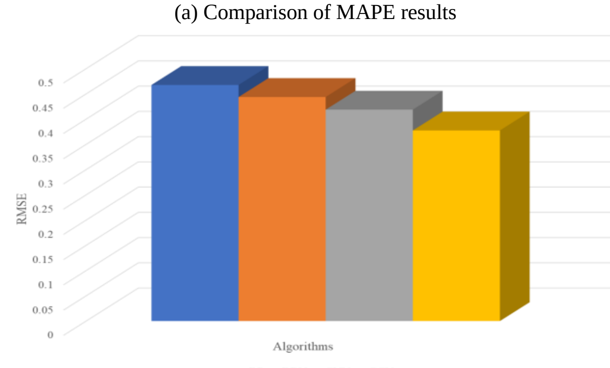
Fig. 20. Performance comparison of recommendation algorithms for recommender systems.

Fig. 20 presents the results of the comparison between the mean absolute error (MAE) and test accuracy precision of the collaborative filtering algorithm and the enhanced collaborative filtering algorithm. As can be seen from Fig. 20, let there are 10 neighbours initially with an interval of 10, and finally the number of nearby users is expanded to 60. Comparing with the previous algorithm, the value of MAE of the new algorithm is less. This clearly shows that after including the adjustment factor, the enhanced algorithm is better able to properly reflect changes in the user's interests, and the recommendation results are better. Compared with the previous approach, the precision value of the enhanced algorithm is bigger. This suggests that the upgraded algorithm is more able to properly reflect the changes in user preferences and generate extremely accurate suggestions by adding adjustment variables.

The performance results of the recommender system evaluation algorithms are compared in Fig. 21, and the specific results of the recommender system evaluation algorithms are presented in Table IV. From Fig. 21 and Table IV demonstrate that the evaluation accuracy of the recommender system evaluation algorithm based on the GCN network is superior to that of BP, CNN, and DBN in terms of MAPE and RMSE, with values of 0.7597 and 0.3775, respectively. On the other hand, the evaluation time of the recommender system evaluation algorithm based on GCN network is greater than that of BP network, with a value of 0.44s, but it is less than that of DBN and CNN.



(a) Comparison of MAPE results



(b) Comparison of RMSE results

Fig. 21. Comparison of the performance of evaluation algorithms for recommender systems.

TABLE IV. EXPERIMENTAL RESULTS OF DIFFERENT ASSESSMENT MODELS

Arithmetic	MAPE	RMSE	Time/s
BP	0.8695	0.4677	0.32
DBN	0.8207	0.4383	0.87
CNN	0.8022	0.4188	0.67
GCN	0.7597	0.3775	0.44

VI. Conclusion

This study proposes a hybrid recommendation system that integrates an enhanced collaborative filtering algorithm with Graph Convolutional Networks (GCN) to improve book recommendation accuracy and performance evaluation in university libraries. The system was designed based on user needs, and its evaluation was conducted using functional indicators mapped through GCN. Comparative experiments show that the proposed model significantly outperforms traditional methods such as BP, DBN, and CNN in terms of Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE), demonstrating both high precision and robustness.

However, this study still has some limitations. Firstly, the current model focuses mainly on offline datasets from university libraries, which may not capture real-time user behavior changes. Secondly, the collaborative filtering component, although improved, still faces cold-start challenges for new users and items. Moreover, the GCN model, while accurate, incurs moderate computational costs, especially as the data scale increases. These factors limit the scalability and real-time applicability of the system in larger, dynamic environments.

Future research will aim to address these limitations by integrating real-time learning mechanisms and adaptive feedback loops into the recommendation system. Additionally, incorporating more diverse data sources, such as user reading habits, textual content analysis, and social interactions, could further enhance the personalization and accuracy of recommendations. Optimizing the GCN structure to reduce computational complexity while maintaining performance is another promising direction to support large-scale, real-time applications in smart library environments.

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