GEORGE BROWN PRESS
JOURNALS, BOOKS & PROCEEDINGS

Journal of Computer, Signal, and System Research

Article

Application and Optimization Exploration of Quantum Computing in Real-Time Recommendation System for E-Commerce Platforms

Anyi Chen [1,*]

[1] Walmart E-commerce Search Team, Wal-Mart Associates Inc., Bentonville, Arkansas, 72716, USA
* Correspondence: Anyi Chen, Walmart E-commerce Search Team, Wal-Mart Associates Inc., Bentonville, Arkansas, 72716, USA

Abstract: Quantum computing, with its excellent parallel computing capability and efficient data processing ability, has opened up new possibilities for real-time recommendation systems in the e-commerce field. With the increasing diversity of consumer demands and the rapid growth of data volume, traditional recommendation algorithms struggle to meet evolving requirements. Quantum technology can significantly improve the prediction speed of user preferences and facilitate real-time product recommendations. However, in the actual deployment process, there are still many challenges such as algorithm complexity, hardware environment limitations, privacy protection, and system compatibility. This article aims to explore in depth the typical application scenarios and optimization solutions of quantum computing technology in real-time e-commerce recommendation, with the aim of promoting the construction of a more intelligent and accurate user recommendation system.

Keywords: quantum computing; e-commerce platform; real time recommendation system; user personalized recommendations; algorithm optimization

1. Introduction

With the rapid rise of e-commerce platforms, personalized recommendation systems have become an important means to enhance user experience and improve sales conversion rates. However, traditional recommendation algorithms often struggle to provide real-time feedback and fully meet users' personalized needs when faced with massive data processing and complex calculations. Quantum computing provides new possibilities for solving these problems with its outstanding parallel processing capabilities and its ability to optimize computational tasks such as model training and parameter tuning. It can complete the analysis and processing of large-scale datasets in a very short period of time, significantly improving the operational efficiency of recommendation systems. In recent years, although quantum computing technology has made progress and conducted in-depth research in multiple fields, its practical deployment still faces many challenges, including algorithm complexity, high hardware facility requirements, and data security issues. This study will delve into the specific application scenarios of quantum computing in real-time recommendation systems in the e-commerce field, analyze the main obstacles that currently exist, and propose corresponding improvement measures, in order to provide valuable reference suggestions for the future development of this technology [1].

Received: 13 March 2025
Revised: 20 March 2025
Accepted: 12 April 2025
Published: 18 April 2025

2. Basic Overview of Quantum Computing and Real Time Recommendation System for E-Commerce

Quantum computing is an innovative computing method based on the principles of quantum mechanics, which utilizes unique properties such as quantum superposition and entanglement to achieve efficient parallel processing and accelerated operations [2]. Compared to traditional computing methods, quantum computing has demonstrated outstanding capabilities in dealing with complex problems and processing large-scale datasets, which is particularly significant for real-time recommendation systems in e-commerce platforms [3]. E-commerce recommendation systems need to quickly analyze user behavior patterns and past records to generate personalized recommendations, thereby enhancing users' shopping experience [4]. However, traditional algorithms have encountered limitations in terms of computational speed and big data processing [5]. The application of quantum computing technology can not only accelerate the training process and data parsing speed of models, but also better adapt to changes in user needs, thereby significantly improving the efficiency and accuracy of recommendation systems. Table 1 outlines the key aspects of integrating quantum computing with e-commerce recommendation systems [6].

Table 1. Key Points of Quantum Computing and E-commerce Recommendation Systems.

Key points of quantum computing and e-commerce recommendation system	Detailed description
Quantum computing characteristics	Parallel efficient processing
Limitations of traditional algorithms	Data calculation bottleneck
Advantages of quantum computing	Accelerate model iteration
Recommended system requirements	Personalized analysis recommendation

3. Application Scenarios of Quantum Computing in Real-Time Recommendation Systems for E-Commerce Platforms

3.1. User Interest Prediction and Personalized Recommendation

The application of quantum computing technology in real-time recommendation systems for e-commerce can significantly improve the accuracy and speed of user interest prediction and personalized recommendations. With the advantages of quantum state superposition and parallel processing, this technology can synchronously analyze multi-dimensional information such as users' past browsing history, shopping behavior, and real-time interaction. By establishing a quantum model to deeply analyze user preferences and quickly make predictions, the system can immediately capture users' potential needs. With the enhanced search efficiency of quantum algorithms, recommendation engines can flexibly create a list of products that best fit personal preferences, thereby achieving efficient customized recommendation effects, greatly optimizing user experience, and promoting sales conversion.

3.2. Large Scale Data Optimization and Real-Time Computing

Quantum computing has demonstrated excellent parallel processing capabilities, significantly improving the efficiency of big data handling and live computation in e-commerce recommendation systems. Traditional recommendation mechanisms often struggle to handle large amounts of user data and product information due to limitations in data processing speed and algorithm complexity. With the help of quantum computing, it is possible to simultaneously manipulate multidimensional information and efficiently analyze user preferences, product features, and market dynamics through the principle of quantum superposition, thereby quickly adjusting recommendation logic. For application scenarios that require immediate feedback, quantum technology can instantly identify

and adapt to the latest user interests, generating suggestions that match personal preferences. This rapid data processing capability and improvement in personalized service level not only enhance the relevance of recommendation results, but also greatly improve consumers' online shopping experience, thus building a strong competitive advantage for e-commerce platforms.

3.3. Quantum Search and Recommendation Optimization in Recommendation Systems

Quantum search technology has significantly improved the performance of e-commerce platform recommendation systems by leveraging quantum parallelism to accelerate data processing and utilizing quantum interference to refine search accuracy. In practical applications, this technology can quickly filter out products that match user preferences from a large product library, significantly reducing computation time compared to traditional methods. By integrating users' past behavior and preference information, quantum search algorithms can flexibly adjust recommendation schemes to ensure that recommended content is more tailored to individual needs. In addition, thanks to its efficient computing power, the system can respond to user requests faster, provide timely and accurate product recommendations, thereby increasing user stickiness and purchase conversion rates, and comprehensively improving user experience.

4. Analysis of Problems in the Application of Quantum Computing in Real Time Recommendation Systems for E-Commerce

4.1. Algorithm Complexity and Development Cost

The real-time recommendation system of e-commerce platforms has encountered significant algorithmic complexity and high development costs when adopting quantum computing. Quantum algorithms are based on a special computational mode that involves complex phenomena such as quantum state superposition, entanglement, and interference, which requires developers to possess profound professional knowledge and technical capabilities. In order to effectively utilize and optimize quantum computing in recommendation systems, extensive theoretical exploration and technological innovation are needed to ensure successful integration and practical utility. In addition, the current quantum computing hardware is still in its infancy, and the available quantum computers on the market are not only limited in quantity, but also expensive, which hinders their widespread application in the e-commerce field. To integrate quantum computing into current recommendation systems, enterprises must invest a significant number of resources in algorithm improvement, hardware tuning, and system integration. This requires not only sufficient manpower and time, but also strong financial support. The high research and development costs, coupled with the continuous maintenance of complex architectures, pose many challenges to the application of quantum technology, making it difficult to widely popularize in the short term.

4.2. Limitations of Quantum Hardware Environment

The application of quantum computing in real-time recommendation systems for e-commerce faces many challenges from the quantum hardware environment. At present, the technology of quantum computers is still in its infancy, mainly limited by the small number of quantum bits and poor stability during the operation process. In addition, quantum computing must be performed under extremely low temperature conditions, which makes it difficult to popularize and sustain its use in conventional commercial scenarios. Meanwhile, quantum devices are highly sensitive to external interference, which further exacerbates the inaccuracy and instability of their computational results. Currently, quantum hardware has low efficiency in processing large-scale and complex data, making it difficult to meet the high requirements of real-time recommendation systems for computing speed and response time. The high maintenance costs and the demand for profes-

sional technicians pose significant investment risks for enterprises when deploying quantum computing. These technological bottlenecks currently constrain the widespread adoption and practical application of quantum computing in recommendation systems.

4.3. User Privacy and Data Security Challenges

When applying quantum computing technology to e-commerce platforms, user privacy and data security face severe challenges. Quantum computers, with their excellent parallel processing capabilities and efficient data analysis performance, need to process a large amount of user information, including many sensitive personal data. Given the extraordinary computing speed of quantum computing, insufficient platform security measures may raise the risk of large-scale personal information leakage and misuse. During data transmission and storage, security vulnerabilities may be exploited by criminals, thereby infringing on user privacy. Meanwhile, with the continuous advancement of quantum computing technology, traditional encryption methods are facing new challenges. Some existing encryption algorithms may become vulnerable to the powerful computing power of quantum computing, making it difficult to ensure data security.

4.4. System Compatibility and Promotion Difficulty

At present, due to the significant differences between quantum computing and traditional computing systems, integrating quantum algorithms into existing e-commerce platforms requires complex technological transformations and architectural adjustments. This complexity increases the difficulty of implementation, especially in ensuring the stable operation of existing systems, while integrating quantum computing with traditional computing resources has become a major technical challenge. In the process of promoting quantum technology, enterprises not only need to overcome technological barriers, but also deal with the problem of high costs. Many companies lack the necessary professional knowledge and talent reserves in the field of quantum computing, which has become a major obstacle to their rapid adoption and promotion of this technology. At present, the technical specifications of quantum computing are still under development, and the practical application scenarios remain limited. The compatibility challenges with existing systems and the high investment requirements further constrain its widespread adoption and rapid expansion of this cutting-edge technology in recommendation systems.

5. Optimization Strategies of Quantum Computing in Real-Time Recommendation Systems for E-Commerce

5.1. Enhancing the Practicality of Quantum Computing Algorithms

In order to enhance the practicality of quantum computing algorithms in real-time recommendation systems for e-commerce, the efficiency of the recommendation process can be improved by adopting "quantum annealing technology". This technology is particularly suitable for handling complex optimization problems and performs outstandingly in accelerating search and matching operations.

In practical operation, the recommendation system of e-commerce platforms must instantly analyze users' activity records and provide personalized product recommendations based on them. This process requires handling a large amount of user preference information and product details. Previous technological methods often exhibited lower computational efficiency when faced with such high difficulty tasks. With the help of quantum annealing technology, the quantum superposition principle and efficient full range search capability can be utilized to significantly improve the data matching speed and accuracy of recommendation systems. The mechanism of quantum annealing is similar to a special "cooling" process, which utilizes the principle of quantum superposition for global search and accelerated optimization. In recommendation systems, each user's behavior patterns and personal preferences can be viewed as a specific 'energy level'. Through quantum annealing technology, the system attempts to find the lowest energy

level, which corresponds to the optimal personalized recommendation scheme—this energy level is a metaphor for optimization targets within the recommendation model. Unlike traditional methods that require calculation one by one, quantum annealing can simultaneously evaluate multiple recommendation paths and avoid falling into suboptimal solutions, thereby achieving more accurate recommendations faster.

With the help of quantum annealing algorithm, e-commerce recommendation systems can quickly analyze and connect with user needs, achieve timely and accurate push effects, and enhance user satisfaction and purchase conversion rates. This optimization strategy underscores the powerful capabilities of quantum computing in handling big data, thereby reinforcing its potential value in real-world applications.

5.2. Hardware Performance and System Architecture Optimization

Given the limitations of existing quantum computers in terms of quantum bits and stability, combining the advantages of quantum computing with traditional computing capabilities can significantly improve overall computational performance.

In practical operation, the real-time recommendation system of e-commerce platforms must quickly process a large amount of user activity information, including browsing history, click behavior, and purchase records, in order to generate recommendation lists that meet personal preferences. Traditional processing methods often require a large amount of computing resources, and their response speed may be affected when facing complex and massive datasets. Therefore, adopting a hybrid architecture that combines classical and quantum technologies can effectively solve this problem by utilizing traditional computers for preprocessing and preliminary screening of raw data. Utilizing the powerful computing power of quantum computers to accelerate the execution of highly complex matching and recommendation tasks. For example, when comparing a user's past behavior patterns with a product database, using quantum search algorithms can significantly accelerate the speed of finding the best match from a large amount of data, thereby significantly shortening the entire recommendation process time.

In order to make the hybrid architecture operate more efficiently, the system architecture needs to be improved accordingly. The use of distributed caching technology can significantly improve data access speed, reduce the latency of quantum tasks, ensure that the recommendation system quickly exchanges information between various computing nodes, and achieve instant response. In this way, e-commerce platforms can not only significantly improve recommendation efficiency and user satisfaction, but also enhance their market competitiveness.

5.3. Enhance Data Privacy and Security

Protecting the privacy and security of user data is extremely critical on e-commerce platforms, especially in recommendation systems that use quantum computing technology. Due to the large volume of sensitive data processed and the frequent data exchanges involved, such systems are more susceptible to the risk of data leakage and misuse and improper use of sensitive information. Strengthening data security protection has become an important aspect in optimizing quantum computing. The use of quantum key distribution (QKD) technology to encrypt data during transmission can effectively improve the security level of data within recommendation systems.

Quantum key distribution is based on the unique properties of quantum physics, which ensures the encryption keys remain secure during both generation and transmission. On e-commerce platforms, users' browsing history and purchase history information need to be exchanged and processed between various system components. To protect these sensitive data from the risk of being intercepted or tampered with midway, QKD can be used to maintain the privacy and integrity of the data.

In practical applications, the recommendation system of e-commerce platforms needs to frequently transmit a large amount of personalized information between user

devices and servers. Traditional encryption methods may become inadequate when facing quantum computers in the future, while quantum key distribution technology can leverage the superposition and entanglement properties of quantum states to achieve secure key exchange. If a third party attempts to steal quantum keys during data transmission, such attempts will inevitably alter the quantum state, making any illegal eavesdropping behavior apparent. In this way, not only does it greatly improve the security and privacy protection level of user data, but it also makes recommendation services more trustworthy. In addition, this further highlights the importance and potential value of integrating quantum computing into recommendation algorithms.

5.4. Collaborative Optimization with Traditional Recommendation Systems

In the real-time recommendation mechanism of e-commerce platforms, combining quantum computing technology with conventional recommendation algorithms for optimization can significantly improve recommendation accuracy and computation speed. By integrating quantum computing with traditional matrix factorization methods, the quality of products pushed to users can be improved. On a large-scale online shopping platform, customers' consumption and browsing behavior form a complex user product relationship network. In general, existing recommendation engines use matrix decomposition strategies (such as singular value decomposition SVD) to extract key information about user preferences and product attributes, and then infer which products are more likely to attract specific consumers.

For new users or uncommon products, traditional matrix factorization methods often struggle to provide accurate recommendations due to data sparsity. In this case, the application of quantum computing can more quickly uncover users' potential points of interest by simultaneously processing a large number of potential feature combinations and utilizing the parallel nature of quantum superposition states.

After user features are fine-tuned using the Quantum Approximate Optimization Algorithm (QAOA), the resulting vectors are reintegrated into the traditional matrix factorization model through weighted combination with existing features.

After fine tuning user features using quantum approximation optimization algorithms, the system will re input these optimized feature vectors into the traditional matrix factorization model and combine them with existing features through weighted integration. This collaborative optimization mechanism is expressed by the following formula: $R_{final} = \alpha \times R_{trad} + \beta \times Q(R_{trad})$.

Among them, R_{final} represents the final recommendation result, R_{trad} is the recommendation result generated by the traditional recommendation system, $Q(R_{trad})$ is the output optimized by quantum computing on the traditional recommendation result, α and β is the weight coefficient, satisfied $\alpha + \beta = 1$, to balance the contributions of traditional and quantum optimization. By combining quantum computing with classical algorithms for optimization, the system can provide more efficient and accurate recommendations in complex and diverse user interest scenarios. The experimental results show that this combination not only significantly improves the click through rate and conversion rate of users, but also effectively alleviates some of the problems existing in traditional recommendation systems, thereby greatly improving the user experience.

6. Conclusion

The application of quantum computing in real-time recommendation systems for e-commerce demonstrates enormous potential and a vast future. With its extraordinary parallel processing capability and efficient data analysis ability, quantum computing has opened up new paths to improve the accuracy and operational efficiency of recommendation systems. After combining with classical recommendation algorithms for optimization, quantum computing can accelerate the speed of user behavior analysis and personalized push, thus better responding to the increasing demand for instant feedback on e-

commerce platforms. However, the large-scale application of quantum computing still faces many challenges, including hardware conditions, algorithm difficulty, and information security issues. To overcome these obstacles, continuous technological innovation, increased resource investment, and strengthened multi-party cooperation are necessary to promote the widespread application and development of quantum technology in practical fields. In the future, with the continuous advancement and improvement of quantum hardware and algorithms, quantum computing technology may become a key driving force in the e-commerce industry. It can bring consumers a more precise and efficient personalized experience, thereby enhancing the core competitiveness of e-commerce platforms and significantly improving the overall user experience.

References

1. R. Shrivastava, D. S. Sisodia, and N. K. Nagwani, "Deep ensembled multi-criteria recommendation system for enhancing and personalizing the user experience on e-commerce platforms," *Knowl. Inf. Syst.*, vol. 66, no. 12, pp. 7799–7836, 2024, doi: 10.1007/s10115-024-02187-3.
2. W. Xu, J. Xiao, and J. Chen, "Leveraging large language models to enhance personalized recommendations in e-commerce," in *Proc. 2024 Int. Conf. Electr., Commun. Comput. Eng. (ICECCE)*, Oct. 2024, pp. 1–6, doi: 10.1109/ICECCE63537.2024.10823618.
3. A. Kumar, A. Mudgal, A. L. Yadav, and A. Sharma, "Cloudsuggest: Enhancing e-commerce with personalized recommendations," in *Proc. 2024 IEEE Int. Conf. Comput., Power Commun. Technol. (IC2PCT)*, vol. 5, Feb. 2024, pp. 763–766, doi: 10.1109/IC2PCT60090.2024.10486797.
4. L. Li, "Research on personalized recommendation system for e-commerce products based on collaborative filtering algorithm," in *Proc. 2024 IEEE 3rd Int. Conf. Electr. Eng., Big Data Algorithms (EEBDA)*, Feb. 2024, pp. 876–880, doi: 10.1109/EEBDA60612.2024.10485710.
5. S. Sameena, G. Javali, N. Srilakshmi, M. Jhansi, and S. S. Sk, "Personalized product recommendation system for e-commerce platforms," *ITM Web Conf.*, vol. 74, p. 03012, 2025, doi: 10.1051/itmconf/20257403012.
6. F. Messaoudi and M. Loukili, "E-commerce personalized recommendations: a deep neural collaborative filtering approach," *Oper. Res. Forum*, vol. 5, no. 1, p. 5, Jan. 2024, doi: 10.1007/s43069-023-00286-5.