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Design of Smart City Government Integrated Service System Based on Hybrid Cloud Computing

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ABSTRACT

Information and communication technology (ICT) makes cities "smart," enabling more efficient and advanced municipal services for citizens. However, more research must be done on reference models and application examples specifically for municipal service platforms based on cloud-edge collaboration. Therefore, this paper first develops a reference model (e-government self-service system) that includes resource collaboration, application collaboration, service collaboration, and security collaboration and discusses the main content and challenges of each part. Then, a dynamic resource allocation model based on game theory is introduced to address the issue of resource allocation in cloud-edge collaboration. Finally, a cloud-edge collaborative e-government self-service system is designed and implemented.

Keywords: Cloud Computing, Edge Computing, Smart City, Integrated Service System, Cloud-Edge Collaboration

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1. Introduction

Rapid urban growth provides important opportunities for enjoying a demographic dividend but also brings many challenges to urban development, such as security, sustainability, and resilience [1]. One research work points out that "smart cities" are a globally adopted solution to address urbanization challenges. It is undeniable that smart cities create a safer, more sustainable, prosperous, and resilient future for citizens through advanced

ICT infrastructure [2]. With the acceleration of urbanization, cities face more and more challenges, such as resource constraints, environmental pollution, and traffic congestion. To address these issues, smart cities have become an important direction for urban development. The emergence of cloud computing technology provides strong support for developing smart cities.

Hybrid cloud computing is an important mode of cloud computing, which combines the advantages of public cloud and private cloud, providing more efficient, secure, and flexible services for the smart city government integrated service system. Hybrid cloud computing refers to the combination of private cloud computing and public cloud computing to achieve complementary advantages of cloud computing services [3]. In hybrid cloud computing, enterprises can deploy some sensitive data and applications in the private cloud to ensure data security and control. At the same time, they can also deploy some non-sensitive data and applications in the public cloud to achieve more efficient resource utilization and cost-effectiveness. Hybrid cloud computing allows flexible allocation of computing resources anytime and anywhere, according to business needs. It can use both private and public clouds to achieve optimal resource allocation. It can also ensure data security and privacy by deploying sensitive data in the private cloud to avoid access by other users in the public cloud. In addition, it can flexibly expand according to business needs, and it is very convenient to increase or decrease resources. It can also achieve the best combination of cost-effectiveness by choosing between private and public clouds based on actual needs to avoid resource waste. Hybrid cloud computing has wide application value in the smart city government integrated service system and can provide more efficient, secure, and flexible services for urban management

[4]. By adopting advanced hybrid cloud technology, we are building a smart city government Int Serv system to meet the ever-changing needs of cities and achieve long-term prosperity and stable growth. First, we will introduce the concept and characteristics of hybrid cloud computing and its application value in smart cities. Then, we will analyze the design ideas and specific implementation methods of the smart city government integrated service system based on hybrid cloud computing, including cloud platform construction, city management center establishment, personalized service provision, and information security protection. Through the discussion in this paper, we hope to provide some valuable references and inspiration for the development of smart cities and promote the process of urban digitization and intelligence.

2. Related Work

Smart city governance is a highly complex and dynamic urban social-technical system, and intelligent governance with cloud computing and edge computing are key elements of smart cities. Many applications of municipal service platforms based on cloud computing and edge computing have been proposed in the literature [4]. At the same time, scholars have begun to explore the application of cloud-edge collaboration in areas such as smart manufacturing, intelligent transportation, smart healthcare, and content delivery. However, there is limited research on reference models and application examples specifically for urban integrated service platforms based on cloud-edge collaboration. Nevertheless, previous research has been done on cloud computing. Sekaran et al. introduced the concept, architecture, application scenarios, and future development trends of cloud computing, as well as discussed the challenges and opportunities faced by cloud computing. They believe that cloud computing will become the mainstream mode of future computing, but it needs to address security, performance, scalability, etc. [5]. Kumar et al. further explored the system architecture, performance evaluation, and programming model and introduced several practical cloud computing systems and application cases [6]. They pointed out that cloud computing needs to provide efficient resource management, fault tolerance, privacy protection, and support for various services and applications. Faye et al. discussed cloud databases' development trends and challenges and introduced key technologies and methods for database archiving [7].Conde et al. discussed issues such as the architecture, service model, and deployment patterns of cloud computing. They explored the business models, application scenarios, and future development trends of cloud computing [8]. They pointed out that cloud computing needs to provide scalability, reliability, and security and support various application and data storage requirements. Uma et al. discussed security and privacy issues faced in cloud computing environments and introduced related solutions and technologies [9]. They believe that cloud computing needs to provide comprehensive security measures, including access control, data encryption, security audit, etc., to ensure the security and privacy of user data. Tang et al. discussed research issues and challenges in cloud security and privacy and introduced related solutions and technologies. They believe cloud security must enhance user data management and control capabilities [10]. Based on the above theories, this paper develops explicitly a reference model based on cloud-edge collaboration for municipal service platforms. It identifies the main content and challenges of cloud-edge collaboration, including resource collaboration, application collaboration, service collaboration, and security collaboration. At the same time, based on this reference model, an intelligent e-government self-service system is designed and implemented. Experimental results show that the cloud-edge collaboration mode can provide a better user experience. Furthermore, a transaction model is proposed to study the optimal allocation strategy of computing and communication resources in cloud-edge collaboration. The results show that evolutionary and Nash equilibrium are the optimal solutions.

3. Building a Hybrid Cloud Computing Model

3.1 Top-level Design of Government Cloud Platform Construction

To better promote the application of cloud computing technology in smart cities and propose measures to encourage the development of cloud computing in the field of e-government, a series of measures have been taken, including strengthening research on cloud computing technology, enhancing its application capabilities, and promoting its application in smart city construction. The development of cloud computing technology has permeated various industries and become increasingly prevalent. Cloud computing products have also diversified, such as transforming internet data centers into cloud computing products and developing server clusters as cloud computing solutions. Due to the lack of sufficient awareness of cloud computing technology in some local governments, there is an apparent blindness in the construction of cloud computing centers, and even the investment in public clouds is contrary to market laws. Therefore, the construction of government clouds should take systematic measures to ensure sustainable development and improve and optimize their organizational structure and management system. To ensure cloud computing security, a top-level design needs to be formulated. This design should comply with policies and regulations and establish a management system that includes cloud security, networking, storage, and monitoring. Figure 1 shows this top-level design. Compared to traditional computing environments, cloud computing environments have higher security requirements.

3.2 Dynamic Resource Allocation Model

In the cloud-edge collaborative scenario, cloud servers' computing and communication resources are limited. How to allocate resources optimally is challenging, especially when considering the competition among edge devices. Previous research proposed a transaction model to study the optimization of computing and communication resource allocation in the MSP (Mobile Service Provider) and MSD (Mobile Service Demander) systems. The MSP and MSD models are the most generic. The satisfaction of MSPs is related to the amount of resources they have and can be quantified as the following logarithmic function, as shown in Formula 1. Here, C

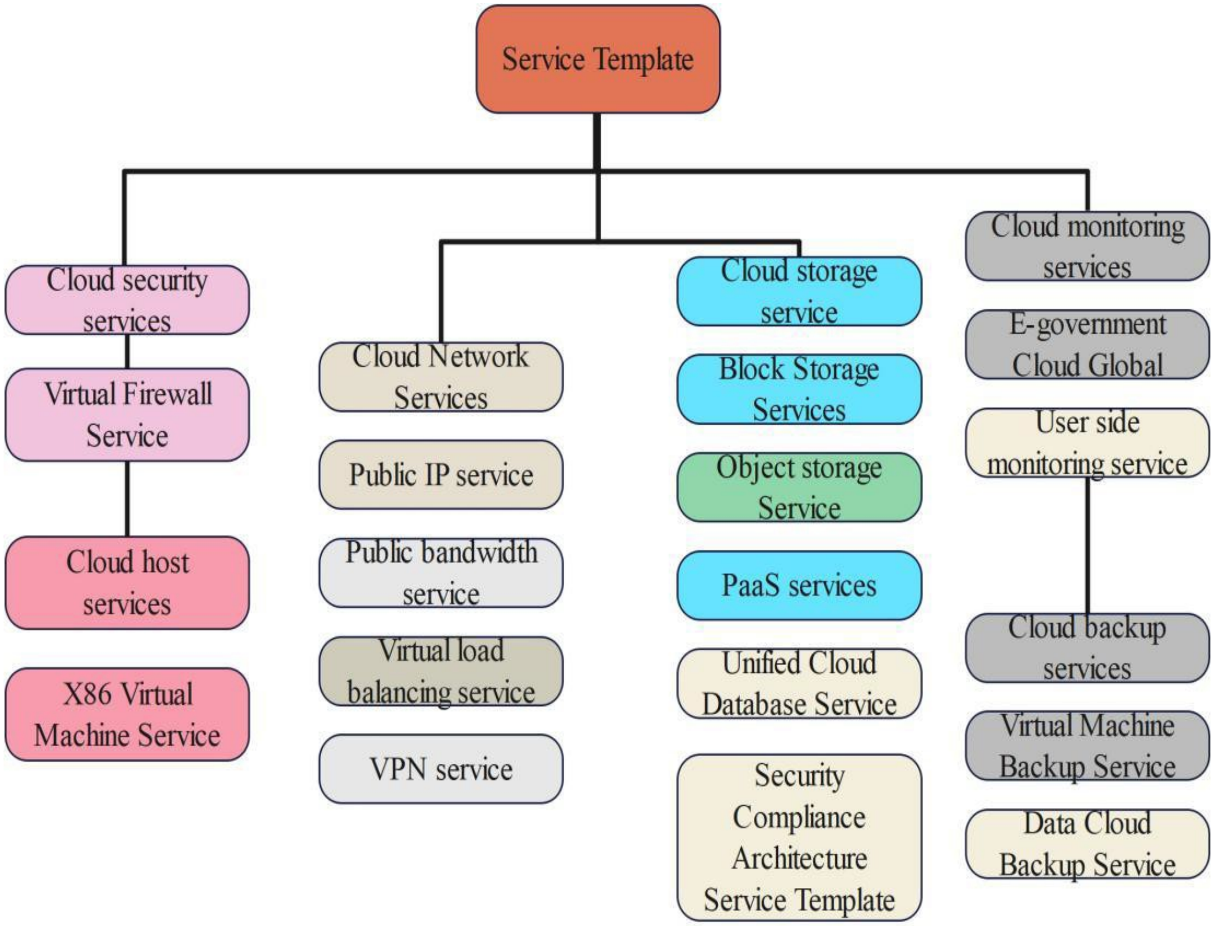

Figure 1. Top-level Design of Government Cloud Plat form

represents CPU cycle count, and K1 is the computational efficiency per symbol. k2B represents the band width, where B is the size of the spectrum, and k2 is the spectral efficiency caused by adaptive modulation (in symbols per bit).

In practical scenarios, MSP can adaptively adjust the quantity of resources sold to SD (Service Demander) based on the competition with other MSPs and the demand of SDs. The selection behavior of SDs is modeled using multi-population dynamic evolutionary game theory. The optimal solution of an evolutionary game is called evolutionary equilibrium, where SDs stop making changes. The profit function of SD in purchasing resources from *SPj* in group l can be defined as Formula 2. By applying the evolutionary game model, we can better understand the dynamic behavior of MSD and explore its evolutionary patterns using stochastic and deterministic iterative algorithms. Research has found that evolutionary equilibrium is the best solution.

Furthermore, to better evaluate the competition among MSPs, we also propose a new iterative algorithm called Nash equilibrium to achieve better results.

$$O(C, B) = u_2 \log\left(k_1 C + k_2 B\right) \qquad (1)$$

$$V_{l,\,j} = u_1 \log\left(\frac{c_j}{f_j \ \Sigma l \in \Lambda g_{l,\,j}} - \frac{(1+\beta_l)\,\Sigma l \in \Lambda g_{l,\,j}}{b_j \ \log_2\left(1+\frac{p_l h_l}{N_0}\right)}\right) \tag{2}$$

3.3 Cloud-Edge Collaboration

Effective cloud-edge collaboration requires deep integration of different infrastructures and systems, enabling seamless migration and execution of services based on business needs. This is a highly challenging task. Generally, from the collaboration perspective, cloud-edge collaboration can be divided into two categories: Cloud-to-Edge (C2E) collaboration and Edge-to-Edge (E2E) collaboration. In the C2E mode, the cloud is mainly responsible for big data analysis, model training, and policy update distribution, while the edge is responsible for local data collection, transmission, policy implementation, and feedback. In the E2E mode, edge devices located in different locations achieve data sharing and collaborative work by establishing secure communication mechanisms. This collaborative mechanism improves the quality and speed of application services while maintaining data privacy and achieving regional autonomy. Resource collaboration refers to the unified management of software and hardware resources of edge nodes and cloud servers by deploying resource scheduling and management interfaces on them. Resource collaboration schedules cloud computing and edge computing resources from a global perspective, significantly improving resource utilization efficiency and satisfaction. The satisfaction function *SI,J* for *SDi* purchasing resources from *SPj* can be defined as shown in Formula 3.

$$S_{i,\,j} = u_1 \log\left(\frac{c_{i,\,j}}{f_j} - \frac{1+\beta_i}{b_{i,\,j} \ \log_2\left(1+\frac{p_i h_i}{N_0}\right)}\right) \tag{3}$$

4. Experimental Design and Analysis

4.1 Experimental Design

Urban residents often need to handle various municipal services, categorized into identity authentication and recognition, service inquiries, service application, and payment. Specifically, these services include medical insurance reimbursement, housing transactions, traffic fine payments, and residential pension insurance payments. These services are closely related to residents' daily lives but are distributed across different municipal departments. Residents often experience low efficiency as they need to carry paper certificates and business materials between departments. The entire process becomes more cumbersome when dealing with services involving multiple departments. The user needs analysis for urban residents can be summarized as follows: The system should comprehensively handle the municipal services from various departments, breaking the data silos among them. Urban residents should be able to easily access the system and achieve "one-stop" municipal services through self-service. These services should include identity authentication and recognition, service inquiries, applications, and payment. The provided municipal services should be flexible and easy to expand and unload based on business needs while also meeting relevant security requirements. The system is designed using a C2E collaborative architecture. The cloud side comprises servers, while the edge comprises AI-embedded self-service terminals. Through resource, application, and service collaboration, the system achieves one-stop self-service e-government for citizens. Regarding resource collaboration, the self-service terminal provides the required infrastructure resources such as computing, storage, connectivity, networking, and virtualization for user authentication, information reading, and writing. The cloud server manages the self-service terminal devices. Regarding application collaboration, the cloud server centrally processes the business process orchestration logic for municipal services, trains highly accurate AI recognition models, and rapidly updates business and AI models to many self-service terminals through cloud-edge application distribution interfaces. As for service collaboration, the edge device determines whether to process the business locally or upload it to the server based on the collected user information and business processing requirements. The edge device receives the processing results from the server, updates local data, and prints the business processing results. When the edge AI model cannot recognize a target, it collects the image and uploads it to the cloud. The cloud side performs further judgment using the high-precision model and returns the result to the edge device. The edge side regularly uploads collected images, videos, and other feature information to the cloud for model training. The self-service terminal motherboard adopts an industrial computer with a working temperature range from 0°C to 60°C. Its main features include a high-performance 64-bit multi-core Intel i7-10700 processor, Intel H420E chipset, support for dual displays with resolutions up to 4K via a pair of mini HDMI ports, hardware video decoding up to 4Kp60, dual-channel DDR4 RAM up to 32GB, up to 1TB SSD, dual-band 2.4/5.0GHz Wi-Fi, Bluetooth 5.0, Gigabit Ethernet, USB 3.0, PCI-E, RS232, and PoE functions. Through the various interfaces, the motherboard connects to input and output devices such as LED displays, dual-lens cameras, touch screens, contactless integrated circuit (IC) card readers, UnionPay card readers, quick response (QR) code scanners, fingerprint scanners, ID card readers, public transportation card readers, printers, and residence permit card readers.

4.2 Results and Analysis

This study selected three major e-government services, namely, face recognition, video decoding, and business processing, to compare and analyze the differences between edge computing and cloud computing in terms of latency, bandwidth, single-task performance, and multi-task concurrency performance. In the latency and bandwidth comparison tests, each service was tested ten times, and the average values were calculated. The experimental results showed that edge computing had significant advantages, with latency reduced by two-thirds and bandwidth increased twice. In the first test, the business needed to be processed in the cloud, and there was no significant difference in latency between the two computing models. However, in subsequent tests, edge computing cached the above business for local processing, resulting in a noticeable difference in latency. As edge computing centralized the business on the local area network. In contrast, cloud computing requires the internet and e-government external network for communication, and cloud computing bandwidth is significantly limited. In the comparison test of single-task performance, each service was fully executed, and the service completion time was recorded. The test was repeated ten times, and the average service completion time was calculated. The results were normalized and compared based on the task processing time of cloud services.

The experimental results showed that the two computing models exhibited significant differences in various businesses, as shown in Figure 2. Cloud computing had a clear advantage over edge computing for multi-department services and video decoding. The reason was that video decoding required significant computing and storage resources, which cloud computing provided more effectively. As for multi-department services, since all services were deployed on the cloud platform, multiple business interactions could be completed internally at

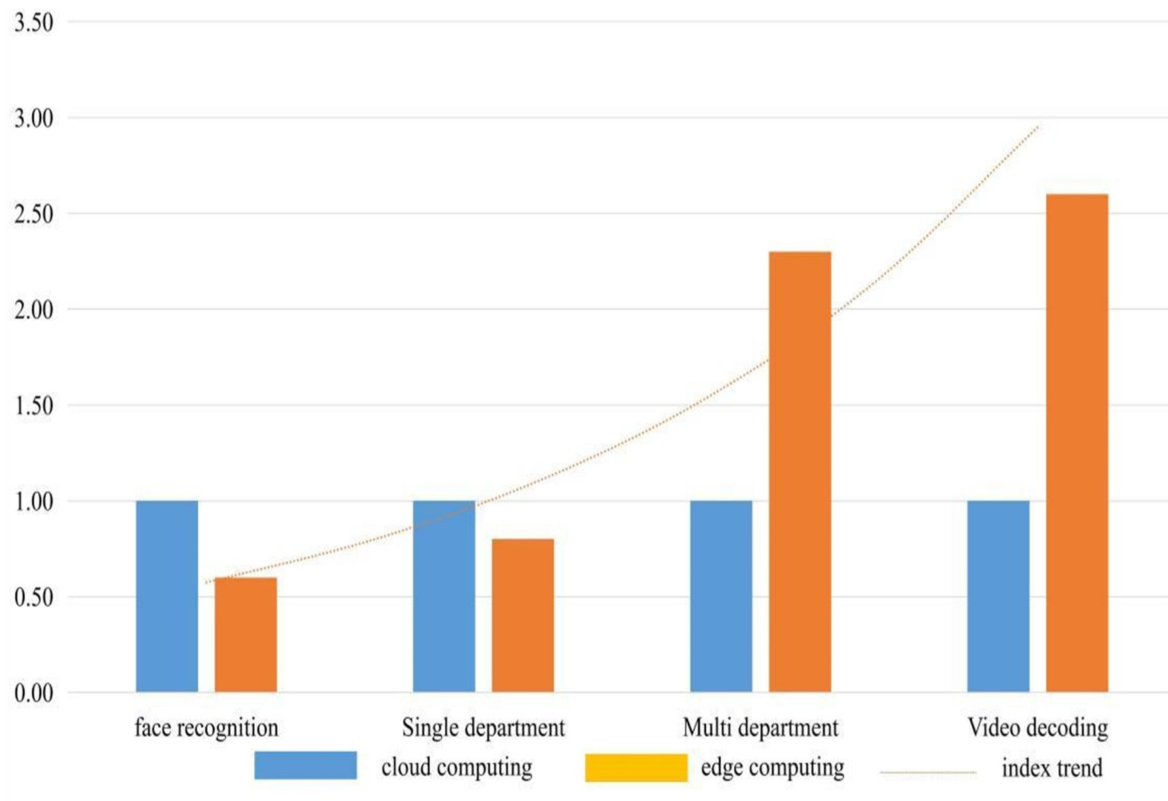

Figure 2. Comparison of task processing efficiency

once, while edge computing required various interactions with the cloud server. For localized businesses such as face recognition and single-department services, edge computing showed higher bandwidth and lower latency. In the system throughput comparison test, each service was run separately, and the number of users was gradually increased to record the maximum number of services completed by the system in one second. In practice, the self-service terminal operated in single-user and multi-task modes. Therefore, the number of terminals and concurrent test users was scaled in a 1:6 ratio. Additionally, a polynomial fitting method was used to distinguish test results better to draw the throughput trend curve for each service.

The experimental results showed that the business throughput trend curve of the edge computing paradigm increased linearly. In contrast, the trend curve of the cloud computing paradigm started with rapid growth in throughput and the increase of concurrent users. It peaked, then decreased, and fluctuated with the rise ofsimultaneous users, as shown in Figure 3. In reality, the self-service terminal is a single-user system. For services processed by the self-service terminal, such as face recognition and single-department services, the throughput increased nearly linearly with the increase of users. However, as the previous theoretical analysis indicated, peaks and fluctuations appeared for businesses involving edge computing and cloud computing collaboration, such as multi-department services. It should be noted that, in practice, the self-service terminal is a single-user system. For services processed by the self-service terminal, such as face recognition and single-department services, the throughput increases roughly linearly with the increase of users. However, as the previous theoretical analysis indicated, peaks and fluctuations will occur for businesses involving edge computing and cloud computing collaboration, such as multi-department services.

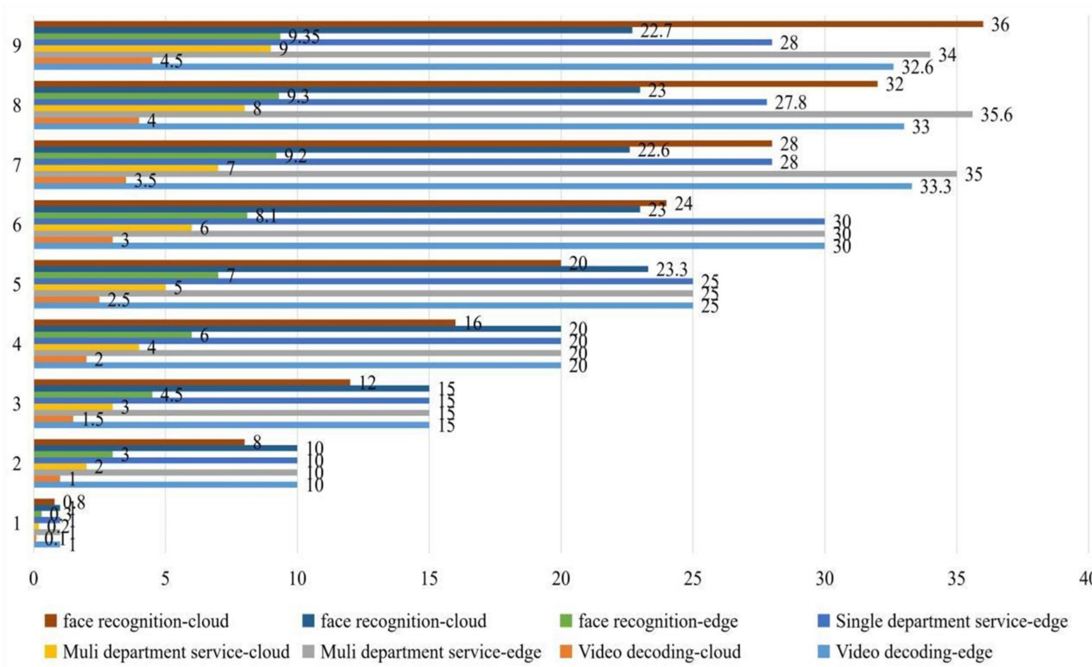

Figure 3. Distribution of Educational Levels Across Different Motivation Groups

5.Conclusions

In this paper, we proposed a hybrid cloud computing-based cloud-edge collaborative reference model and its application instance, the e-government self-service system. The reference model comprehensively explored cloud-edge collaboration's content and challenges from resource, application, service, and security collaboration. The experimental results showed that the designed system provided a better user experience. Furthermore, we proposed a dynamic resource allocation model for cloud-edge collaborative computing and communication resources based on game theory. The research results indicated that the optimal solutions were evolutionary and Nash equilibrium. We hope this research can provide valuable references for decision-makers and builders of smart cities. Future work may further consider the proposed system's real-time performance and computational complexity at the practical level. Additionally, as one of the key issues, the security of cloud-edge collaboration needs further consideration.

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