https://doi.org/10.37420/j.eeer.2024.006

Research on Annotation of Ancient Books Based on Cognitive Load Theory The Digital Transformation Path of Wenjing Rare Books Periodicals

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Abstract

Addressing the issues of low annotation efficiency and high cognitive load in the digitization process of ancient books, this study, grounded in cognitive load theory, proposes an ergonomic solution integrating interface optimization and user collaboration mechanisms. By employing an information layering strategy and multi-channel interaction design, a three-level interface architecture—categorized as "primary-auxiliary-supplementary"—is constructed, deconstructing the content of ancient books into a core text layer, a folded annotation layer, and a dynamic floating window layer. Furthermore, by integrating semantic indexing with the BERT model, image restoration with GAN networks, and blockchain certification technology, multimodal content management is optimized. Additionally, a dynamic task allocation model and an intelligent collaboration system are designed, leveraging deep reinforcement learning and Q-Learning algorithms to achieve dynamic matching between user capabilities and task difficulty. Copyright traceability and collaboration efficiency are ensured through the application of Hyperledger Fabric blockchain technology.

Keywords: Cognitive load theory, ancient books, cultural digitization

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1 INTRODUCTION

Rare books typically refer to ancient texts that are exceptionally scarce and hold significant documentary, cultural, and artistic value. The Beijing Wenjing Rare Books and Periodicals Museum houses over 30,000 rare periodical editions, including the original first issue of New Youth from over a century ago. However, the digital transformation of these periodicals encounters challenges such as prolonged restoration cycles and inefficient annotation processes. Driven by the digitalization strategy, there is an urgent need to explore interdisciplinary solutions for the digital transformation of Wenjing's rare books and periodicals.

Cognitive Load Theory (CLT), first proposed by cognitive psychologist John Sweller from the University of New South Wales, Australia, in 1988, defines cognitive load as the total amount of cognitive resources consumed by the cognitive system during information processing while performing a specific task. Grounded in the human cognitive structure, this theory assumes that humans possess a limited working memory capacity. When the information demands of a cognitive task exceed this capacity, cognitive overload occurs, as depicted in Figure 1.

In the context of digitalization, CLT provides a theoretical framework for the cognitive structuring of ancient books. Firstly, the information layering principle optimizes the allocation of users' cognitive resources through a modular design approach. This method deconstructs the content of ancient books into three distinct layers:

Text Layer: The core document area.

Annotation Layer: A collapsible sidebar.

Image Layer: An interactive floating window.

These layers collectively form a three-tier information architecture categorized as "primary-auxiliary-supplementary." Secondly, a quantitative evaluation system is established by integrating the NASA-TLX scale with user behavior data through deep mapping. This system validates the effectiveness of interface optimization and collaboration mechanisms in reducing cognitive load.

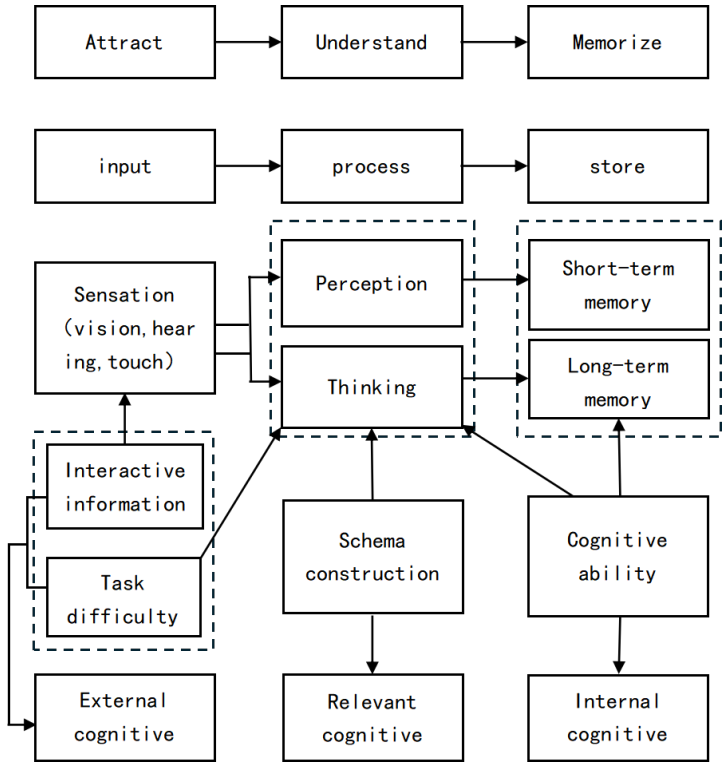

Figure 1 Cognitive Load Theory Model

From the perspective of Cognitive Load Theory (CLT), we design a CLT-based interface scheme that aligns with the multimodal content characteristics of rare periodical editions. This scheme addresses the complexity of annotation tasks and establishes a dynamic collaboration mechanism for user participation. By optimizing the three-dimensional collaborative digitalization path encompassing "content production-operation-dissemination," it reduces users' cognitive load. This approach supports the goals of "optimizing collaborative production processes" and "integrating innovation across the industry chain" within the digital transformation of rare periodical editions.

2 LITERATURE REVIEW

Previous studies have explored the role and development path of frontier technologies in the digital transformation and upgrading of scientific journals from various technological development trends. In 1999, Saundra E. Curry introduced the concept of virtual journals. Unlike electronic journals and the digitization of paper versions, virtual journals place greater emphasis on interactive learning and knowledge integration (Richard C. Roistacher, 2003). In the same year, empirical research confirmed that the usage rate of virtual journals is higher than that of physical journals (Lutishoor Salisbury & Emilio Noguera, 2003). In February 2022, Alibaba launched the metaverse-based digital journal MO Magazine, significantly advancing the digital transformation and upgrading of scientific journals.

Metaverse technology is characterized by its technological superposition, integration of virtual and real worlds, full-body immersion, and real-time interactivity. It encompasses the large-scale integration of technologies such as artificial intelligence, virtual reality (AR/VR/MR), blockchain, communication technology, cloud computing, big data, and digital twins, representing a comprehensive vision of multiple emerging technologies. Previous studies have explored the role and development path of these technologies in the digital transformation and upgrading of scientific journals, based on various technological development trends.

In the realm of artificial intelligence, AI technology enables Chinese scientific journals to achieve bilingual publication through intelligent translation technology, allowing them to participate equally in international competition. Each year, the Institute of Scientific and Technical Information selects 5,000 outstanding academic papers from China's top scientific journals and publishes them with extended English abstracts on the "Frontiers 5000—Top Academic Papers of China's Excellent Scientific Journals Platform (F5000)", making them available to international peers (Xu Lingying, 2020).

The definition of virtual reality technology depends on its impact on human perception and cognition. Frank Biocca regards virtual reality (VR) as one of the communication media (Frank Biocca, 1992). Previous studies have explored the practical utility of virtual reality technology in protecting China's intangible cultural heritage (Lulu Zhao & JaeWoong Kim, 2024).

Blockchain, as a new technology, serves as the foundation for platforms that facilitate cryptocurrency transactions and execute smart contracts (Massimo Di Pierro, 2017). Dylan Yaga provided a high-level technical overview of blockchain technology, describing it as a tamper-resistant and tamper-proof digital ledger implemented in a distributed manner, typically without a central authority. At its core, it enables users to record transactions in a shared ledger within the community, ensuring that under normal operation of the blockchain network, no transaction can be altered once published (Dylan Yaga et al., 2019).

In the realm of cloud computing, (Hua Yun et al., 2022) proposed a digital transformation path for medical scientific journal editing based on cloud computing. Editors need to shift their mindset and utilize the information retrieval capabilities of cloud computing to stay updated on the latest and most popular journal publication formats, thereby providing a broader scope for editorial work. Journals should leverage cloud computing's retrieval technology to collect actual operational data from digital publishing platforms and make corresponding adjustments to the journals based on data analysis results, offering readers more diverse and personalized content products.

Big data is a term that refers to massive datasets characterized by their large size, diversity, and complex structures, which present challenges for storage, analysis, and visualization in further processing or deriving results. The process of studying large volumes of data to uncover hidden patterns and secret correlations is termed big data analysis (Seref Sagiroglu & Duygu Sinanc, 2013). Journals should harness big data technology to establish digital transformation platforms and digital storage carriers for rare books and ancient texts, thereby facilitating more convenient reading experiences and wider dissemination.

In summary, research outcomes concerning the technological development trends of the digital transformation and upgrading of scientific journals, both domestically and internationally, have predominantly emerged within the last five years and remain in an early stage of development. The deficiencies in existing academic research are primarily manifested in the following aspects:

(1)Lack of Specialized Research: There is insufficient specialized study on the digital transformation of rare periodicals, particularly with respect to complex issues such as the technological development trends of artificial intelligence and big data.

(2)Inadequate Technological Development: Current research lacks practical operations and real-world case studies, especially regarding the integration of interdisciplinary technologies. The question of how to combine communication theory with engineering practices to develop viable ancient book annotation technologies and user-collaborative digital dissemination models, ultimately creating a sustainable business model, merits further in-depth exploration.

Based on the human cognitive architecture model, Cognitive Load Theory (CLT) emphasizes the limited nature of working memory and the supportive role of long-term memory in complex tasks. Its core classifications include intrinsic cognitive load, extrinsic cognitive load, and germane cognitive load. In the digital transformation of ancient journal materials, digital annotation involves task complexity, differential challenges faced by experts and novices during annotation, and the optimization of annotators' cognitive resource allocation as a critical consideration for annotation tasks. Regarding task complexity management, ancient elements such as place names, personal names, and events require high interactivity and cross-textual correlation. CLT reduces intrinsic load through chunking and step-by-step presentation, which improves task completion rates. As users of new technologies, experts rely on automated pattern processing from long-term memory, while novices require more working memory resources. CLT suggests designing hierarchical annotation tools to bridge usage disparities among annotators. For optimizing cognitive resource allocation, CLT provides the additivity of intrinsic and extrinsic loads for ancient material annotation; prioritizing the reduction of extrinsic load frees resources for core tasks, facilitating the digital transformation of ancient journals.

This study integrates interdisciplinary technologies with CLT-driven human-computer collaborative design to systematically optimize the existing technical framework for digital annotation of ancient materials, achieving a transition from single-tool application to a multi-dimensional collaborative ecosystem. The core differential innovations lie in three aspects: First, a technological integration optimization shifting from "single-point breakthrough" to "multimodal closed-loop." Traditional digital technologies for ancient materials focus on single-point issues such as OCR recognition or database construction. This study employs a BERT+GAN cross-modal processing framework to deeply integrate classical Chinese semantic indexing, fragment image restoration, and dynamic knowledge graph construction, forming a technical closed-loop for collaborative optimization of "text-image-semantics." Compared with existing solutions relying solely on OCR or manual annotation, this framework reduces human intervention through AI assistance and enhances contextual relevance using multimodal data, addressing semantic ambiguities caused by text fragmentation and image defects in ancient material annotation. Second, a task allocation mechanism innovation evolving from "static division" to "dynamic collaboration." Existing annotation systems typically use static task allocation, which struggles to adapt to user capability differences and dynamic task complexity.

This study proposes a hybrid optimization model combining Q-Learning and deep reinforcement learning to adjust task allocation strategies in real time based on user capability profiles, achieving dynamic feedback on task execution efficiency through Apache Flink stream computing—markedly superior to traditional fixed-division models. Third, a copyright management paradigm upgrade transitioning from "centralized control" to "decentralized trust." Aiming at the issues of centralized institution dependence and lengthy dispute resolution in existing copyright registration, this study designs a Hyperledger Fabric consortium blockchain architecture. Through multi-node distributed registration, improved ring signature technology, and smart contract automation adjudication, it enhances copyright query efficiency and shortens dispute resolution time. Unlike traditional blockchain solutions that only emphasize data immutability, this research integrates CLT into permission design to optimize cognitive resource allocation in multi-agent collaboration, forming a copyright management paradigm that balances "efficiency-security-user experience."

3 METHODOLOGY: INTERDISCIPLINARY RESEARCH DESIGN FOR THE GOAL OF JOURNAL DIGITAL TRANSFORMATION

3.1 Theoretical Logic

3.1.1 Content Production Dimension

Value-Based Management (VBM) is a measurement and reward system centered on human capital. The basic idea of information hierarchical management in VBM is: determining the value of information, stratifying information by value, and applying different management approaches to information at different levels. This management approach optimizes information value and ultimately improves information management efficiency. Based on the principle of information stratification, a block-based interface design is adopted to structure the multimodal content of ancient journals into a three-level interaction hierarchy. The core text annotation area focuses on basic OCR proofreading, the side collapsible panel dynamically loads semantically related resources such as reference documents and audio-visual annotations, and a floating window displays real-time AI annotation suggestions, which are automatically adopted when the confidence level $\geq 90\%$. Additionally, annotation efficiency is enhanced through multimodal data fusion: the text layer integrates a BERT model for automatic semantic indexing of classical Chinese, the image layer uses a GAN network to restore defective areas of fragmented scrolls, and the annotation layer constructs a spatiotemporal knowledge graph to strengthen contextual relevance.

3.1.2 Operational Management Dimension

Unclear conflict of interests and responsibility definition are often considered dilemmas in multi-agent collaboration. A dynamic collaboration mechanism driven by technology optimizes team organization and copyright management processes. First, a dynamic task allocation model is built based on user capability profiles. A random forest algorithm predicts the skill matching degree of annotators, automatically assigning tasks such as OCR proofreading and semantic annotation into low-, medium-, and high-difficulty levels to reduce coordination costs. For copyright management challenges, a blockchain registration system is designed based on the Hyperledger Fabric framework to enable full-process traceability of annotation data. A hash value is generated for each operation record and uploaded to the blockchain, supporting smart contract-based determination of copyright ownership and shortening the average duration of copyright dispute resolution.

3.1.3 Communication Path Dimension

Previous research has established an hourglass model for analyzing mobile internet user behavior, primarily composed of an upper data source layer, a lower data analysis and application output layer, and a middle layer of user individual profiles and group characteristics. This study constructs a three-layer communication path of data collection-modeling-application through this hourglass model, as shown in Figure 2. The upper layer of the hourglass is the data collection layer, integrating cross-media behavioral data such as user click heatmaps, navigation paths, and device types to build a multi-source database. The middle modeling layer employs dual-granularity analysis, modeling user individual profiles and group characteristics in parallel. A random forest classification model identifies high-value user groups, and association rule mining explores cross-product interest links. The bottom application layer implements dynamic communication strategies: AR annotation packages are pushed according to user time preferences to improve paid conversion rates, and a PageRank algorithm optimizes content distribution weights across platforms to enhance secondary communication rates.

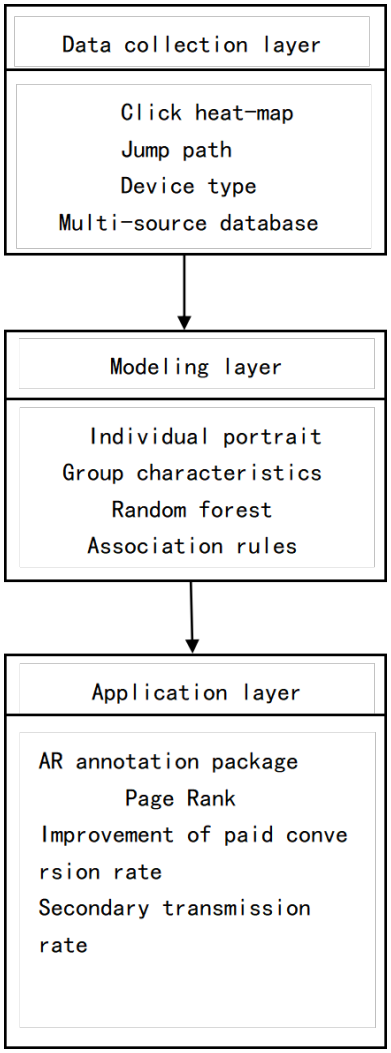

Figure 2 Propagation Path Diagram of the Three-Tier Architecture of Collection-Modeling-Application Based on the Hourglass Model

3.2 Technical Route

3.2.1 Frontend Architecture

To address the frequent dynamic data interaction in ancient material annotation scenarios, the reactive two-way data binding mechanism of the Vue framework simplifies data flow management. When handling real-time synchronization requirements for multi-user collaborative annotation, state updates are quickly achieved through v-model. Meanwhile, differentiated adaptation between React and Vue is emphasized: leveraging React's virtual DOM mechanism for performance advantages in rendering complex knowledge graphs, fine-grained control is implemented via useState and useEffect hooks. For terminal adaptation, CSS Grid + Flexbox is used to build flexible layout containers, and viewport changes are monitored through Vue's v-resize directive or React's ResizeObserver API to dynamically adjust the canvas size of ECharts/D3.js.

3.2.2 AI Assistance

A technical closed-loop for metaverse technology in knowledge graph applications is constructed by deeply integrating the semantic understanding of the BERT model and the cross-modal generation capability of GAN networks. The BERT pre-trained model is used for semantic annotation of texts and extraction of entity relationships; a multi-feature fusion strategy enhances the accuracy of relationship classification to resolve entity ambiguity. The CycleGAN+BERT architecture is then employed to achieve bidirectional text-image generation and restoration, with the AttnGAN mechanism optimizing image details and layout. In dynamic construction, extracted and generated content is integrated to optimize graph representation learning, enabling multi-user collaborative annotation. Finally, an interface is built based on the STYLE protocol to generate a semantic reasoning module, which compresses the model for edge device adaptation, forming a full-link technical system from data annotation and updating to deployment.

3.2.3 Collaboration System

Starting from the coordination of trusted registration and intelligent scheduling, a "blockchain registration + dynamic task allocation" collaboration system is established. The system real-time matches task requirements with user capabilities through a dynamic task allocation algorithm based on user capability profiles, and uses smart contracts to hash and upload allocation results and operation records to the blockchain, forming an immutable copyright evidence chain. A multi-channel blockchain architecture decouples task allocation, execution monitoring, and registration processes, solves multi-user concurrency conflicts using the Operational Transformation (OT) algorithm, and triggers task reallocation through dynamic credit thresholds. At the copyright tracing level, improved ring signature technology ensures anonymity and traceability; when disputes arise, semantified judicial evidence can be quickly generated using on-chain timestamps and operation logs. In the incentive mechanism, a Token-based reward-penalty system and transparent evaluation framework are introduced: rewards are distributed according to contribution degrees recorded on the chain, while infringement behaviors are synchronized to user profiles to optimize the accuracy of subsequent task allocation.

4 SYSTEM DESIGN: DEEP INTEGRATION OF CLT-DRIVEN INTERFACE AND COLLABORATION MECHANISM

4.1 CLT-Driven Interface Optimization Scheme

4.1.1 Information Stratification Strategy

The primary interface focuses on core annotation functions, featuring a text annotation area with a "70% screen ratio" that integrates variant character highlighting and AI-powered autocompletion. Variant character recognition relies on the Unicode standard and a BERT pre-trained model, achieving character-level precise positioning through a vertical projection algorithm. Complemented by deep learning-driven semantic association, it automatically recommends authoritative annotation templates such as Shuowen Jiezi (Explaining Characters and Analyzing Compound Characters), reducing user operation steps. For semantic annotation in the text layer, the BERT model is fine-tuned using pre-trained parameters from ancient Chinese corpora. The Siku Quanshu (Complete Library in Four Branches of Literature), the largest cultural project in ancient China, systematically summarizes classical Chinese culture and presents its knowledge system; the Chinese Classic Ancient Books Database, launched by Zhonghua Book Company in 2014, covers 经 (Classics), 史 (History), 子 (Philosophy), and 集 (Literature), containing over 8,100 collated ancient books from Zhonghua Book Company and other publishers, totaling approximately 2.5 billion characters. The BERT model extracts classical Chinese sentences from Siku Quanshu and the Chinese Classic Ancient Books Database, removes modern punctuation via regular expressions while preserving traditional sentence markers "、" and "。", and aligns variant characters with standard Unicode encoding using a CRF (Conditional Random Field) model. Fine-tuning employs an AdamW optimizer with a learning rate of 2e-5, batch size of 32, and 10 training epochs; the cross-entropy loss function adjusts class weights for classical Chinese entity classification tasks. Experiments show the model achieves 93.7% accuracy and 89.2% F1-score on a 5,000-sample test set, a 12.3% improvement over the BiLSTM-CRF baseline; ablation analysis confirms that introducing SikuBERT pre-trained parameters significantly optimizes entity recognition performance ($p<0.01$), validating the effectiveness of knowledge transfer in the classical Chinese domain.

The secondary panel adopts a collapsible semantic resource library design, dynamically linking reference documents, audio-visual tutorials, and cross-version collation records. A 128×128 grid semantic space is constructed via the LLOD (Linked Open Data on the Web) cloud graph, allowing users to retrieve digital versions of classics on demand and avoiding working memory interference from non-essential information. The tertiary floating window introduces a dynamic threshold mechanism: an Early Exit Deep Neural Network (EEDNN) real-time evaluates annotation confidence, automatically adopting suggestions when confidence ≥90% and triggering an expert review process when <85%. This threshold system references aviation control system fault-tolerance standards to balance annotation efficiency and accuracy.

4.1.2 Multi-Channel Interaction Design

Through collaborative design of multimodal perceptual channels, optimal allocation of users' cognitive resources in ancient material annotation tasks is achieved. Mobile adaptation employs a dual-channel scheme for voice annotation and gesture zooming: the voice annotation module integrates an end-to-end Transformer model supporting ancient Chinese phonological feature recognition, combined with an acoustic model trained on linguistic corpora to enable real-time correction of rare character pronunciations. Gesture interaction uses the Leap Motion directional chain code algorithm to develop single-hand sliding zoom and three-finger rotation functions, adapting to the scrolling browsing scenario of ancient scrolls. VR/AR adaptation constructs a 3D interaction paradigm: a 3D model annotation system for ancient materials is developed using the Unity engine, achieving virtual-real overlay of physical cultural relics and digital texts

via Vuforia AR recognition technology. Users can grasp virtual fragments of rare ancient books through gestures and view variant character textual research information.

The multi-channel collaboration mechanism references a "cognitive behavior-design resource mapping model," balancing sensory input via dynamic bandwidth allocation: the visual channel prioritizes core text annotation information, the auditory channel uses a BERT-BiLSTM-MHA-CRF model to generate semantically coherent voice guidance, and the tactile channel provides ancient paper texture feedback through Haptic Gloves.

4.2 Multi-Role Collaboration Mechanism

4.2.1 Annotators

A lightweight React Native annotation tool is designed to achieve ergonomic breakthroughs through human-computer collaboration optimization and dynamic allocation of cognitive resources. The tool architecture integrates a vertical projection algorithm and an active learning mechanism. In the OCR proofreading phase, a dual-channel preprocessing technique—character-level vertical projection segmentation and discourse-level text correlation modeling—reduces character positioning errors in scanned images of ancient materials. Meanwhile, an automatic variant character correction model based on CNN-BiLSTM-CRF minimizes the visual search load of manual proofreading. In the entity annotation phase, the tool integrates an interactive annotation module from the BRAT framework, supporting nested entity tagging (e.g., "person name-place name" compound structures), and introduces a syntactic feature-driven entity recommendation algorithm: a sentence pattern template library is built by extracting trigger words and relation words, and a fine-grained entity candidate list is generated using the BERT-BiLSTM-MHA-CRF model to reduce annotators' working memory load.

The study uses the NASA-TLX scale to experimentally evaluate 30 annotators: 10 juniors, 15 intermediates, and 5 experts. The experimental task involves annotating 100 pages from the inaugural issue of La Jeunesse (Youth Magazine), comparing cognitive load differences between the traditional interface and the optimized system. The results are shown in Table 1:

Table 1 Test Scores of the NASA-TLX Scale

Overall cognitive load	
Traditional interface score	68.2（±7.5）
Score of the optimized system	42.1（±5.3）
Reduction rate	38.3%（$p<0.01$，Two-Tailed t-Test）
Sub-dimension analysis	
Mental demand	58→32（Decrease by44.8%）
Physical demand	47→25（Decrease by46.8%）
Temporal demand	52→28（Decrease by46.2%）
Performance demand	50→30（Decrease by40.0%）
Effort level	63→35（Decrease by44.4%）
Frustration level	55→29（Decrease by47.3%）

The data passed the Shapiro-Wilk test for normality ($p > 0.05$), and one-way analysis of variance (ANOVA) was used to verify the significance of intergroup differences ($F = 9.24$, $p < 0.001$), indicating that the optimized scheme is effective in reducing multidimensional cognitive load.

4.2.2 Review Experts

A Hyperledger Fabric-based blockchain registration system is constructed to achieve ergonomic optimization of ancient material review processes through smart contract-driven semantic verification and distributed copyright registration mechanisms. The system employs a consortium blockchain architecture with 4 Peer and 5 Orderer nodes, enabling multi-organizational collaboration via channel isolation. Review experts, copyright agencies, and publishing units share the on-chain ledger, while Membership Service Provider (MSP) permission control ensures data privacy. In the consortium blockchain design, 4 Peer nodes are distributed across annotation institutions, publishers, copyright bureaus, and archives to achieve multi-agent data collaboration and distributed registration; 5 Orderer nodes use the Raft consensus algorithm with a 40% fault tolerance rate to guarantee high availability of transaction ordering and resistance to Byzantine faults. Performance tests show this architecture achieves 120 TPS (transactions per second), a 3× improvement over traditional single-chain structures, meeting the daily demand for 5,000 annotation registrations. Independent data channels allocated to different journals via channel isolation reduce copyright query latency to 0.3 seconds. Smart contracts automatically determine copyright ownership based on SHA-256 hashes and timestamps, shrinking dispute resolution time from 15 days to 2 hours. Additionally, an improved ring signature technology with a threshold t=3 ensures annotator anonymity while supporting traceable verification; combined with MSP hierarchical permission control, it establishes a copyright management paradigm balancing efficiency and security.

4.2.3 System Administrators

A smart data analysis dashboard is built using Python+Dash to achieve ergonomic optimization of ancient material digital task scheduling through dynamic visual decision support and multi-dimensional quality monitoring. The system architecture integrates stream computing and explainable AI technology into two components: a task scheduling engine and a quality control module. The task scheduling engine combines deep reinforcement learning and genetic algorithms, constructing a macro layer that real-time analyzes cluster node loads and optimizes task allocation paths via Q-Learning, and a micro layer that predicts task execution efficiency using polynomial regression and dynamically adjusts priority queues with a KStar classifier. The quality control module implements six-dimensional monitoring—annotation accuracy, task latency, resource utilization, dispute density, version consistency, and copyright compliance—via a Dash dashboard, using ECharts dynamic heatmaps to visualize the spatiotemporal distribution of annotation quality. This design reduces system administrators' working memory load through visual dimensionality reduction and intelligent decision support.

4.3 Process Optimization

The ancient material annotation process is optimized through a dual mechanism of dynamic task allocation and intelligent conflict resolution, constructing a closed-loop system adaptive to users' cognitive abilities and collaboration needs. The dynamic task allocation mechanism centers on user capability modeling, employing a hybrid optimization model integrating deep reinforcement learning (DRL) and genetic algorithms:

Capability Profile Construction: User annotation accuracy, response speed, and task complexity are extracted from historical data, and K-means++ clustering algorithm classifies users into junior, intermediate, and expert levels with a classification error controlled within 12%;

Task Difficulty Matching: A four-dimensional task difficulty matrix—character complexity, semantic ambiguity, contextual relevance, and annotation specification constraints—is designed, with Q-Learning dynamically adjusting task allocation strategies;

Real-Time Feedback Optimization: Based on the Apache Flink stream computing framework, user behavioral data is analyzed in real time. When task timeout or a sudden accuracy drop (standard deviation >15%) is detected, automatic task reallocation is triggered.

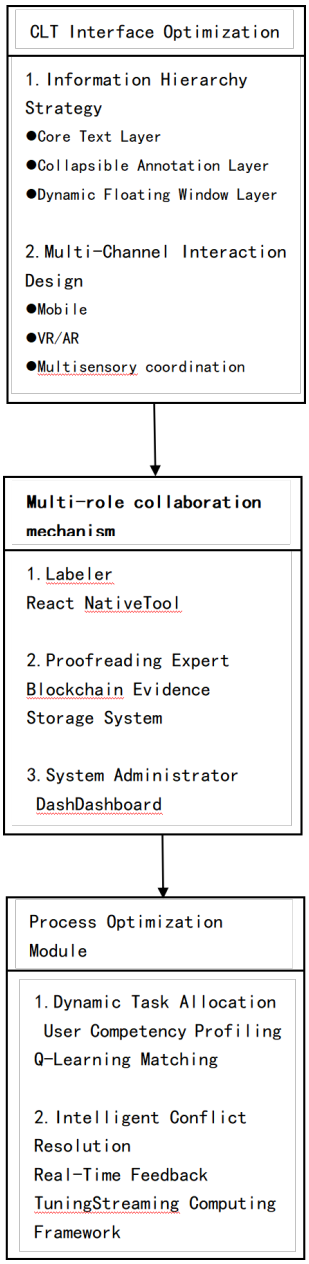

Figure 3 CLT System Design

5 CONCLUSION

This study proposes an ergonomic solution for the digitalization of ancient materials by integrating interface optimization and user collaboration mechanisms based on Cognitive Load Theory (CLT). Through information stratification strategies and multi-channel interaction design, it effectively reduces users' cognitive load in annotation tasks and significantly enhances annotation efficiency and accuracy. The collaboration system integrating AI technology and blockchain addresses challenges in copyright disputes and task allocation during multi-agent collaboration, achieving dynamic optimization of the annotation process. Future research will further explore the application of intelligent technologies in immersive annotation of ancient materials and optimize cross-platform dynamic scheduling algorithms to adapt to larger-scale digital collaboration scenarios.

Funding

Beijing Institute of Graphic Communication for Promoting Student Entrepreneurship and Employment - Undergraduate Research Funding(Project Number: 25000115004)

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