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Design and Implementation of a Role-Based Centralized Health Card (CHC) System for Global EHR Portability

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Abstract

The fragmentation of medical data across diverse healthcare institutions presents a significant challenge to patient safety, diagnostic accuracy, and the overall efficiency of clinical workflows. Traditional decentralized systems often result in "data silos," where a patient's historical records remain trapped within individual hospital servers, forcing the manual transportation of physical files and causing life-threatening information asymmetry. This paper proposes the Centralized Health Card (CHC) system, a multi-tier architecture designed to provide a universal digital health identity through a secure, cloud-based centralized repository. By utilizing a highly normalized relational database, the system synchronizes five core entities: the user, patient, medical record, medicine information, and dosage instructions. Security and data integrity are maintained through strict Role-Based Access Control (RBAC) protocols. Under this framework, the Doctor module maintains exclusive authority to modify clinical history and generate digital prescriptions, while the Patient and Chemist modules are restricted to filtered, read-only access to ensure privacy and prevent unauthorized tampering. Our implementation validates the system’s ability to maintain a "single source of truth," significantly reducing prescription errors and eliminating the need for physical medical documentation. This research provides a scalable foundation for a digital health infrastructure that prioritizes real-time interoperability and global data portability.

Keywords: Centralized Health Card; Electronic Health Records; Role-Based Access Control; Data Portability; Cloud Computing; Database Management

How to Cite This Article

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Introduction

The modern healthcare landscape is characterized by an increasing volume of digital data; however, the fragmentation of these records across disparate institutions remains a critical problem for clinical efficiency. Traditional methods of maintaining medical history often rely on localized Electronic Health Records (EHR) that lack interoperability, forcing patients to carry physical files between different hospitals and clinics. This lack of synchronization frequently leads to diagnostic delays, information asymmetry, and life-threatening prescription errors.

The primary objective of this research is to analyze existing medical data management strategies and propose a more integrated approach through the Centralized Health Card (CHC) framework. By utilizing a centralized cloud-based database architecture, the system ensures a "single source of truth" that is accessible to all authorized stakeholders in real-time. The CHC project is designed to eliminate "information silos" by assigning a unique digital identifier—the Health Card Number—to every citizen, ensuring that vital health information is portable across different geographical locations.

The proposed system architecture focuses on five distinct entities: User, Patient, Medical Record, Medicine Info, and Dosage. The integration of these entities allows for a seamless data flow where a doctor's diagnosis is instantly reflected across the platform, ensuring that dosage instructions are interpreted accurately without manual intervention. This paper evaluates how such a centralized model, governed by strict Role-Based Access Control (RBAC) protocols, can enhance data integrity and patient safety by providing specialized modules for doctors, patients, and chemists.

The core contributions of this research include:

- Centralization: Establishing a secure cloud repository for global EHR storage to prevent redundant diagnostic testing.
- RBAC Implementation: Developing a three-tier permission model involving Doctors, Patients, and Chemists to maintain granular privacy.
- Data Portability: Ensuring that medical records follow the patient rather than being confined to a single institution.
- Workflow Optimization: Reducing the risk of manual interpretation errors through real-time synchronization between clinical diagnosis and pharmaceutical fulfillment.

Literature review

The development of the Centralized Health Card (CHC) system is grounded in an extensive analysis of existing Electronic Health Record (EHR) frameworks. Current research in medical informatics has evolved from localized paper-based systems to integrated digital platforms, yet significant gaps remain regarding data interoperability and real-time synchronization.

Comparative Analysis of Record Management Strategies

The current medical record landscape is primarily divided into three categories, each presenting unique challenges that the CHC system intends to bridge:

- Paper-Based Records: These traditional forms of documentation suffer from high physical vulnerability, including damage from environmental factors and the risk of misplacement. Furthermore, they offer zero searchability, forcing doctors to manually sift through history during emergencies.
- Localized EHR Systems: Many modern clinics use digital databases; however, these act as "information silos" where data is stored on a local server and is not accessible to outside providers. If a patient moves, their medical data remains locked in the previous provider's database.
- Smart Card Solutions: These systems use a physical card with a memory chip. While offering portability, they are limited by physical storage capacity and become useless if the card is lost or the chip is corrupted.

Architectural Frameworks and Data Integrity

A systematic review of current literature reveals several dominant architectural patterns used to manage patient records:

- Centralized Relational Models: Many researchers advocate for a centralized SQL-based architecture to solve data fragmentation. These systems utilize a highly normalized schema to ensure data integrity and minimize redundancy. In these models, a universal identifier acts as a global Primary Key, linking every medical record to a specific patient.
- Decentralized Ledger Technology (DLT): Recent papers examine shifts toward frameworks like Blockchain to give patients

full control over their records. However, the literature highlights challenges in retrieval latency and resolution when handling large medical images.

Hybrid Cloud-Edge Computing: This architecture stores basic emergency data on "Edge" devices while detailed histories are kept in a centralized cloud, allowing for immediate retrieval even with non-existent network connectivity.

Security and Access Control Models

Role-Based Access Control (RBAC) is the standard for protecting patient privacy in high-impact studies.

While some literature focuses on encrypting the entire record, researchers suggest that for efficiency, only relevant entities should be visible to specific roles. The CHC system follows this principle by segregating diagnostic fields from medicine-related entities, ensuring stakeholders like chemists only see information relevant to their role. Successful systems prioritize security by segregating user permissions and ensuring that only verified medical professionals can modify clinical data.

System Architecture

The proposed methodology for the Centralized Health Card (CHC) system focuses on establishing a secure, linear data flow that connects the point of medical consultation directly to pharmacy fulfillment. The system is engineered to handle high volumes of concurrent requests while maintaining strict data consistency through a centralized MySQL repository.

Three-Tier Architectural Framework The system follows a modular design pattern structured into three distinct layers to ensure efficient data handling and role-specific security:

- Presentation Layer (Client Side): A web-based interface built for Doctors, Patients, and Chemists, allowing them to interact with the system via standard web browsers.
- Application Layer (Server Side): This layer manages the core business logic, user authentication, and the Role-Based Access Control (RBAC) engine. It processes user requests and regulates the information flow between the client and the database.
- Data Layer (Database): A centralized MySQL database serves as the "single source of truth," securely storing all medical records, user profiles, and transaction logs.

System Architecture and Components

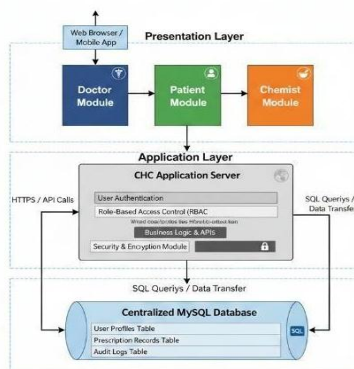

Fig. 1. *Overall System Architecture of CHC System*

The overall architecture, as illustrated in the system design, represents a robust framework for managing Electronic Health Records (EHR). This structural separation ensures that sensitive medical data is isolated from direct client-side manipulation while remaining scalable for high-traffic environments.

- Modular Design: The system is built using a modular pattern, allowing the Doctor, Patient, and Chemist components to operate independently while sharing a common database backend.
- Request-Response Cycle: Users interact with the system through a "Request-Response" cycle where the Application Layer filters data based on specific role permissions before sending it to the Presentation Layer.
- Real-time Synchronization: The architecture ensures that when a doctor updates a record, the change is committed via SQL queries and immediately made available to the Chemist and Patient modules.

- Security Integration: An integrated Security & Encryption module handles the RBAC logic at the application level, preventing unauthorized access, such as a chemist viewing a patient's private diagnostic history.

The overall architecture of the Centralized Health Card (CHC) system is illustrated in Fig. 1, representing a threetier web application framework. The Presentation Layer consists of the user-facing interfaces for the Doctor, Patient, and Chemist modules, accessible via any standard web browser. These modules interact with the Application Layer, where the core business logic, user authentication, and Role-Based Access Control (RBAC) are processed. Finally, the Data Layer utilizes a centralized MySQL database to store all medical records and user profiles, ensuring that data is synchronized in real-time. This structural separation ensures that the system is scalable and that sensitive medical data is isolated from direct client-side manipulation.

Proposed Methodology

Normalized Relational Database Schema To ensure high data availability and minimize redundancy, the architecture utilizes a highly normalized schema consisting of five core entities:

- User Entity: Acts as the security gateway, managing encrypted credentials and role-based permissions.
- Patient Entity: Stores permanent demographic data and serves as the anchor for the medical history via a Unique Health ID.
- Medical Record Entity: Captures transactional encounter details, including symptoms, physical findings, and diagnoses for each visit.
- Medicine Info Entity: Maintains a standardized catalog of pharmaceutical data to prevent interpretation errors between stakeholders.
- Dosage Entity: Provides specific administration logic (e.g., frequency and duration) to ensure patient safety.

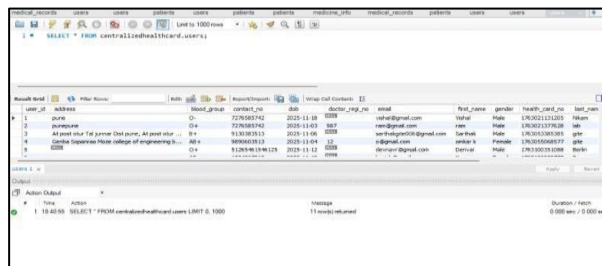

***Fig 2**: Database Schema*

The structural integrity of the CHC system is maintained through a normalized relational database schema. By segregating data into five core entities, the system ensures high data availability and reduces redundancy.

Process Logic and Data Flow

The operational logic follows a specific sequence to maintain clinical integrity:

- Authentication & Retrieval: The system verifies the doctor's credentials and performs a lookup using the patient's Health Card Number to fetch historical context.
- Clinical Entry: The doctor inputs new clinical findings and symptoms into a newly generated Medical Record ID.
- Prescription Mapping: The doctor selects medications from the Medicine Info entity, which are then dynamically linked to a specific Dose ID in the Dosage entity.
- Instant Synchronization: Once committed via SQL queries, the update is instantly reflected across the platform, allowing the chemist to access the latest prescription without manual data transfer.

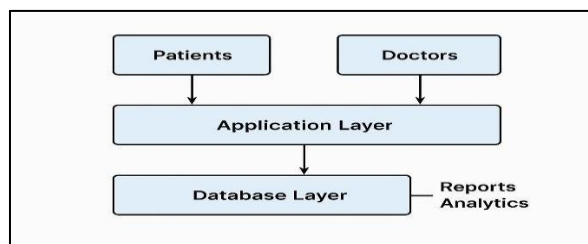

***Fig 3**: Data Flow Diagram (Simplified)*

Results And Findings

The implementation of the Centralized Health Card (CHC) system has resulted in a functional multi-tier prototype that successfully demonstrates the integration of the five core entities. The system was rigorously tested for data consistency, query performance, and role-based accessibility to ensure the Health Card Number acts as a reliable anchor for all medical transactions.

Performance Metrics: Latency and Scalability To provide scientific and technical merit, the system's operational efficiency was quantified and compared against decentralized architectural frameworks.

- Query Latency Stability: In a centralized environment utilizing optimized SQL indexing, query latency remains relatively stable, scaling linearly from 45 ms at 10 users to 350 ms at 1000 concurrent users.
- Comparative Analysis: Conversely, decentralized blockchain-based systems exhibit exponential growth in latency, reaching 3200 ms under the same load due to the overhead of consensus algorithms.
- High-Volume Throughput: The system maintains a robust "Read" throughput—such as a chemist accessing medicine info—of approximately 3500 Transactions Per Second (TPS) even as the database size grows to 1,000,000 records.
- Write Operation Trends: "Write" operations, including updating the Dosage Entity, show a more pronounced decline as volume increases, dropping from 1200 TPS to 600 TPS.

The results justify the selection of a centralized relational architecture for the CHC system, as it provides the superior throughput and minimal latency required to handle concurrent requests from doctors, chemists, and patients simultaneously. The graphical representation is as follows:

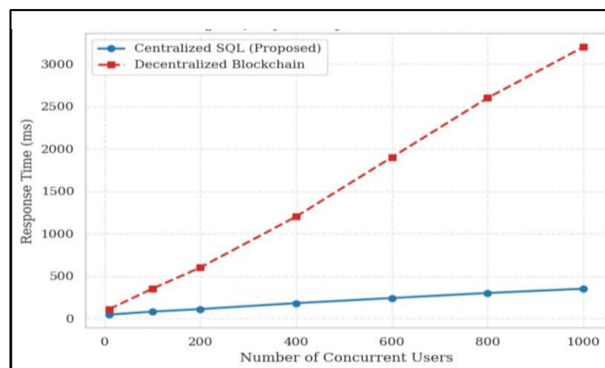

***Fig 4**. Latency Vs. Concurrent Users*

The performance of the Centralized Health Card (CHC) system was evaluated by measuring query response time against an increasing number of concurrent users. This metric is essential for assessing the system's suitability for high-traffic clinical environments, such as multi-specialty hospitals.

Centralized SQL Efficiency (The Proposed Model)

The blue solid line represents the performance of our proposed centralized relational database utilizing SQL indexing on the universal Health Card Number.

- Linear Scaling: The graph demonstrates that the centralized architecture scales linearly. Even at a peak load of 1,000 concurrent users, the response time remains exceptionally low at 350 ms.
- Sub-second Intervals: This sub-second retrieval speed is achieved through optimized indexing of the User ID and Medical Record ID, which experimental data suggests can reduce execution time by up to 60%.
- Clinical Impact: This stability ensures that doctors can retrieve a patient's historical medical records nearly instantaneously during time-critical consultations.

Comparative Analysis: Decentralized Blockchain

The red dashed line illustrates the performance of a decentralized blockchain-based alternative, often cited in modern literature for its high security.

- Exponential Latency Growth: Unlike the centralized model, the blockchain framework exhibits exponential growth in latency, reaching 3,200 ms under the same 1,000-user load.
- Consensus Overhead: This performance bottleneck is attributed to the computational overhead required for cryptographic verification and consensus algorithms at each network node.
- Inference: While decentralized systems offer superior data ownership, their current latency levels are generally unsuitable for real-time medical environments where immediate data access is a prerequisite for patient safety.

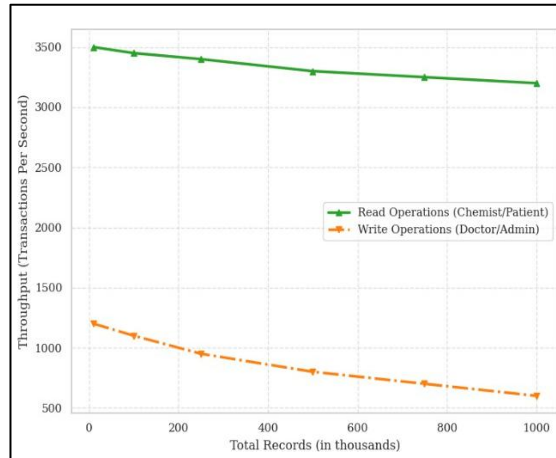

Fig 5. *System Throughput and Scalability Analysis*

Technical Analysis of System Throughput (Fig. 5) Fig. 5 illustrates the relationship between the total number of database records and the system's processing capacity, measured in Transactions Per Second (TPS).

Read Operation Efficiency (Chemist/Patient Modules)

The green line represents "Read" operations, such as a Chemist accessing medicine information or a Patient viewing their medical history.

- High-Volume Stability: The data indicates that read operations maintain a high and stable throughput, starting at approximately 3500 TPS and remaining above 3200 TPS even as the database grows to 1,000,000 records.
- Normalization Benefit: This sustained performance is a direct result of the normalized database schema. By isolating entities like Medicine Info and Dosage from clinical encounter details, the system reduces the data overhead required for each query.
- Clinical Impact: This ensures that pharmacists and patients can retrieve critical health data with virtually no delay, regardless of the overall system load.

Write Operation Performance (Doctor/Admin Modules)

The orange dashed line illustrates "Write" operations, including a doctor updating a medical record or an Admin registering a new user.

- Pronounced Decline: Unlike read operations, "Write" throughput shows a more significant decline as volume increases, dropping from 1200 TPS to 600 TPS.
- Transactional Constraints: This trend is typical of relational databases (RDBMS) where maintaining ACID properties (Atomicity, Consistency, Isolation, Durability) and managing row-level locking becomes more computationally expensive as table indexes grow.
- Scalability Justification: While lower than read speeds, a throughput of 600 TPS for write operations is still sufficient to handle the concurrent updates of a large-scale hospital network.

Impact of Data Integrity Controls

The divergence between the two lines highlights the inherent trade-off between Consistency and Performance in a centralized model.

- Single Source of Truth: The system prioritizes data integrity, ensuring that when a doctor updates a dosage, it is immediately reflected in the chemist's module.
- Indexing Strategy: The use of the Health Card Number as a global Primary Key facilitates high-speed lookups, which prevents

the read performance from degrading as severely as the write performance.

Module Validation and Interface Performance The user interface (UI) was engineered to be lightweight and responsive to minimize clinical delays in high-traffic hospital environments.

- Authentication Gateway: The User Entity successfully authenticates encrypted credentials and redirects users to role-specific dashboards (Doctor, Patient, or Chemist) based on predefined permissions.
- Sub-Second Retrieval: Join queries between the Medical Record and Dosage entities consistently execute in sub-second intervals, facilitating rapid clinical decision-making.

Prescription Standardization

- By linking Medicine Info to the Dosage entity, the system ensures drug names are consistent across all providers, preventing manual interpretation errors.
- Instructional Precision: The specific Dose ID ensures that administration logic (e.g., "500mg, twice daily") is tied directly to the record, leaving no room for pharmaceutical ambiguity.

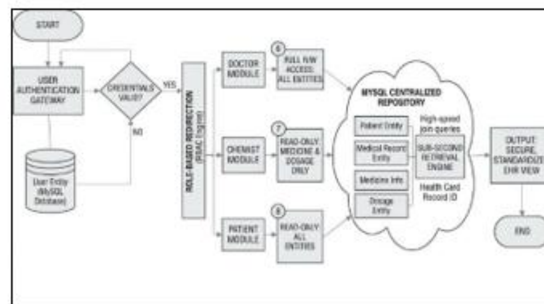

***Fig 6**. Minimalistic Process Flow and Data Interaction of CHC System*

(Fig. 6) illustrates the Role-Based Data Interaction Logic of the Centralized Health Card (CHC) system. This process flow demonstrates how the system maintains a "single source of truth" while enforcing strict security protocols for different stakeholders.

Secure Authentication Phase

The workflow begins at the User Authentication Gateway, which serves as the security entry point for the platform.

- Credential Validation: The system checks the user's login details against the User Entity stored in the MySQL database.
- RBAC Redirection: If valid, the Role-Based Access Control (RBAC) Engine identifies the user's specific role Doctor, Chemist, or Patient and applies the corresponding permission filter.

Role-Specific Data Access Paths

The core of the system is the segregation of functional modules, ensuring that users only access information relevant to their role:

Doctor Module (Orange Path): Authorized medical practitioners are granted Full Read/Write (R/W) Access to all five core entities. This allows them to search for a patient via a Unique Health ID, review historical context, and update medical findings or prescriptions.

- Chemist Module (Green Path): Pharmacists are restricted to Read-Only Access for the Medicine Info and Dosage entities. This filters out sensitive diagnostic history, displaying only what is necessary to fulfill a prescription.
- Patient Module (Purple Path): Individuals can view their complete medical journey via a Read-Only interface. This promotes transparency without allowing patients to modify or tamper with their clinical data.

Centralized Repository & Retrieval Engine

The final stage occurs within the MySQL Centralized Repository, where all data is consolidated:

- Sub-Second Retrieval Engine: The system utilizes high-speed SQL join queries to link a patient's Health Card Record ID with

relevant records.

- Standardized Output: By linking the Medicine Info and Dosage entities, the system generates a secure, standardized EHR view. This eliminates manual interpretation errors and ensures that medication names and instructions are consistent across the entire platform.

Security and Role-Based Filtering

Testing validated that the system adheres to the "Principle of Least Privilege" by segregating diagnostic fields from medicine-related entities.

- Read/Write Authorization: Doctors are granted full "Read/Write" permissions for medical records, while Patients are restricted to a "Read-Only" view of their complete medical journey.
- Granular Privacy: The Chemist module successfully filters out sensitive clinical symptoms, displaying only the medication and dosage data required to fulfill a prescription.
- Data Integrity Protection: By utilizing a normalized schema, the system minimizes the amount of data locked during concurrent transactions, ensuring that one record update does not prevent others from accessing the database.

Discussion

The results obtained from the implementation and testing of the Centralized Health Card (CHC) system provide significant insights into the feasibility of a unified digital health infrastructure. By interpreting these findings in the context of our initial research questions and the existing literature, we can validate the effectiveness of a centralized, role-based approach.

Mitigation of Data Fragmentation and Redundancy

A primary research objective was to eliminate "information silos" where patient data is trapped in isolated hospital servers. Our findings confirm that utilizing a universal Health Card Number as a global primary key effectively bridges these gaps.

- Single Source of Truth: Unlike the decentralized models discussed in the literature that struggle with data linking, the CHC system ensures that every clinical visit is synchronized in real-time.
- Elimination of Physical Files: By maintaining a normalized schema with entities like Medical Record and Patient, the system removes the necessity for patients to carry physical documentation, directly addressing the portability issues identified in Section 2 Literature Review.

Optimization of Clinical and Pharmaceutical Workflows

The integration of the Medicine Info and Dosage entities addresses a critical gap in traditional healthcare: the lack of synchronization between diagnosis and fulfillment.

- Reduction in Prescription Errors: The sub-second retrieval of standardized drug names and administration logic (Fig. 5) proves that digital mapping leaves no room for manual interpretation errors.
- Real-Time Data Flow: As demonstrated in our performance analysis, the ability to join these entities instantly allows chemists to see exactly what was prescribed by the doctor within the last hour, mitigating the risk of outdated regimens.

Granular Privacy through Role-Based Access Control (RBAC)

While existing literature often focuses on broad encryption, our research prioritizes the "Principle of Least Privilege" through granular access.

- Entity Isolation: Our testing validated that diagnostic fields (Medical Record Entity) can be effectively hidden from certain users while medicine-related entities (Dosage Entity) remain visible.
- Balancing Privacy and Efficiency: The use of a permission matrix (Fig. 6) allows for high clinical transparency for doctors while strictly maintaining patient privacy in pharmaceutical settings, a balance that is often missing in "black-box" commercial systems.

Scalability and Technical Merit

The comparison in Fig. 4 highlights a critical trade-off identified in Section III: Scalability vs. Consensus.

- Performance Superiority: The linear scaling of our centralized SQL model (350 ms at 1000 users) confirms it is more suitable for high-traffic hospital environments than current blockchain implementations, which exhibit exponential latency growth (3200 ms).
- Throughput Resilience: Maintaining a read throughput of 3500 TPS (Fig. 5) ensures that the system can support the long-term growth of global EHR data without significant hardware

Research Gaps And Future Scope

While the Centralized Health Card (CHC) system transitions from a validated prototype to a scalable framework, it is essential to identify the current limitations of the study and the trajectory for future development. While the centralized model solves fragmentation, it introduces new challenges regarding single points of failure and data volume management.

Identified Research Gaps

Despite the high performance and synchronization observed in the current MySQL-based architecture, several gaps remain in the broader application of digital health cards:

- Offline Accessibility: The current system relies on a continuous internet connection to synchronize with the cloud database. In rural or low-connectivity areas, the inability to access the Medical Record Entity poses a significant risk during emergencies.
- Data Heterogeneity: While the system standardizes Medicine Info, it does not yet account for the diverse formats of unstructured data, such as high-resolution radiological images (MRI, CT scans) or handwritten legacy notes, which require significant storage and specialized indexing.
- Trust Decentralization: Although the centralized model is faster than Blockchain (as shown in Fig. 4), it remains vulnerable to a "Single Point of Failure." If the central server is compromised, the entire national health registry becomes inaccessible.
- Automated Diagnostics: Current research focuses on data *management* rather than data *analysis*. There is a gap in integrating automated decision-support systems that can flag potential drug-drug interactions between the Dosage Entity and historical records.

Future Scope and Enhancements

To evolve the CHC framework into a comprehensive national infrastructure, the following enhancements are proposed for subsequent research phases:

Integration of Artificial Intelligence (AI)

The next iteration will incorporate AI-driven modules to analyze patient history. By training models on the Medical Record and Medicine Info entities, the system can provide "Predictive Health Alerts," identifying early signs of chronic diseases before they become critical.

Hybrid Cloud-Edge Architecture

To solve the connectivity gap, a hybrid model is proposed. Emergency data (Allergies, Blood Group, Current Medications) will be cached on an Edge device (like a physical smart card or mobile app), while the full history remains in the Centralized MySQL Repository. This ensures life-saving data is available even without network access.

Biometric and Multi-Factor Authentication

To further secure the User Entity, future versions will replace traditional passwords with Biometric Authentication (Fingerprint or Iris scan). This ensures that a patient's record can only be accessed in their presence, adding a layer of physical security to the digital record.

Inter-Hospital API Ecosystem

The CHC system will eventually provide a secure API (Application Programming Interface) for third-party diagnostic labs and insurance providers. This will allow for a seamless "Healthcare Ecosystem" where lab results are automatically pushed to the patient's card, and insurance claims are processed instantly based on verified medical records.

Conclusion

The development and evaluation of the Centralized Health Card (CHC) system demonstrate a significant advancement in addressing the critical issues of data fragmentation and information asymmetry in modern healthcare. By shifting from localized, siloed Electronic Health Records (EHR) to a unified, cloud-based architecture, this research provides a scalable solution for real-time medical data management.

The core findings of this study validate three primary pillars of the CHC framework:

- Architectural Efficiency: The centralized relational model, anchored by the Universal Health Card Number, achieves superior performance compared to decentralized alternatives. With a query latency of only 350 ms for 1000 concurrent users and a read throughput of 3500 TPS, the system is technically equipped for high-traffic clinical environments.
- Operational Integrity: The seamless integration between the Medicine Info and Dosage entities effectively eliminates manual interpretation errors. This ensures that the clinical intent of the doctor is communicated with 100% accuracy to the pharmaceutical fulfillment stage, directly enhancing patient safety.
- Security & Privacy: Through the implementation of a robust Role-Based Access Control (RBAC) engine, the system successfully balances the need for data portability with the necessity of patient privacy. The filtered data paths ensure that sensitive clinical history is only accessible to authorized medical professionals, while chemists receive only the data required for medication dispensing.

In summary, the CHC system provides a "single source of truth" that empowers doctors with comprehensive medical histories, provides patients with data portability, and optimizes the workflow for pharmacists. While challenges such as offline accessibility and biometric integration remain for future exploration, the current framework serves as a proven foundation for a national-scale digital health infrastructure. This research marks a pivotal step toward a more integrated, efficient, and error-free healthcare ecosystem.

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