# Progress Seminar

## Blockchain-Enabled Secure and Transparent Lung Disease Classification in Medical Imaging

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# Problem Statement-1- Completed

**Designing a Contrastive Learning Based Robust Multi-label Chest Disease Classification System**

# Problem Statement-2- Implementation Completed

**Blockchain-Secured Federated Learning for Privacy-Preserving Multi-label Chest Disease Classification**

# Problem Statement-3- Yet to Start

**Designing a deep-learning based architecture to optimize features from the input image to enhance the classification**

# Introduction & Background

- The detection and classification of lung diseases from medical images pose significant challenges due to the complexity of pathologies and the need for high diagnosis accuracy.
- However , widespread clinical deployment of AI models is impeded by data sharing barriers arising from **privacy regulations and regulations and institutional silos**, which prevent pooling of diverse, multi-institutional datasets essential for robust model robust model generalization.
- **Model provenance and trust issues**, as centralized repositories lack immutable audit trails to verify that submitted model updates or model updates or weights have not been tampered.
- Block chain  technology addresses these challenges by providing:
    - **Decentralization**: Eliminates single points of failure, enabling hospitals and research institutes to contribute model updates model updates without relinquishing data ownership.
    - **Immutability**: Cryptographic chaining of blocks ensures that once a model hash is recorded, it cannot be altered, enabling altered, enabling verifiable provenance for every model version and audit ready logs of submissions and accesses.
      accesses.
    - **Smart Contracts**: Automate model registration, validation triggers and access control, enforcing predefined rules without rules without interventions.

# Research Motivation and Objectives

## Motivation

- Clinical AI for lung-disease classification demands large, diverse imaging datasets, yet privacy regulations (HIPAA, GDPR) and institutional silos prevent cross-site data sharing.
- Federated learning addresses raw-data privacy but offers no immutable audit trail for model updates, leaving provenance and trust gaps in collaborative AI pipelines.
- Centralized model repositories risk tampering, version drift, and unilateral control—undermining reproducibility and regulatory compliance.
- On-chain storage of full neural networks is infeasible due to block-size limits; off-chain IPFS solutions introduce their own access-control and integrity challenge.

# Research Motivation and Objectives

## Objectives

1. **Design smart contracts that**:
    - Register model submissions on-chain, embedding cryptographic hashes for immutable provenance.
    - Automate performance triggers (e.g., AUC, F1 thresholds) via oracle-fed validation events.
    - Enforce role-based access (contributors, aggregator, end users).
2. **Integrate IPFS for off-chain storage of model weights and explainability artifacts, ensuring:**
    - Deterministic retrieval via content identifiers (CIDs) stored on-chain.
    - Encryption-before-pinning and proxy re-encryption key management for HIPAA-compliant data confidentiality.
3. **Implement multi-layer validation mechanisms encompassing:**
    - Cryptographic integrity checks (SHA-256 hash matching) between on-chain records and IPFS downloads.
    - Performance verification on sealed test sets, recording metrics immutably on blockchain.

# Research Motivation and Objectives

## Objectives

**4. Demonstrate a reference architecture that**:

- Tracks model workflow end-to-end (training → upload → verify → aggregate → deploy).
- Provides audit-ready logs for regulatory and clinical governance.
- Ensures scalability through a hybrid on-chain/off-chain design without sacrificing throughput.

# Covered Objectives

1. **Decentralized Control & Audit of Model Operations**: Design a permissioned blockchain to replace the centralized server, allowing edge nodes to publish encrypted model updates as transactions that are verified and ordered by consensus.

    ✅ Smart Contract Model Registry: *The contract maintains on-chain records for model uploads, including storing the uploader's address, model identifiers, and IPFS hashes. This provides traceability, integrity, and auditability of each model version.*

    ✅ Vendor (Participant) Whitelisting: *Only whitelisted addresses can use certain contract functions, enforcing role-based access and some governance.*

    ✅ No centralized Federated Learning Server: *While not a full decentralized federated learning controller, on-chain storage of model metadata replaces traditional centralized registries in FL.*

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2. **Secure Aggregation and Privacy**:

    ✅ No On-chain Data/Update Aggregation: *The smart contract stores model hashes and metadata, but does not aggregate FL updates on-chain nor enforce secure aggregation protocols (e.g., homomorphic encryption, secure enclaves, or additive masking).*

    ✅ Data Privacy: *No raw data or gradients are ever uploaded; the only reference on-chain is the IPFS hash of trained model binaries or snapshots.*

    ✅ Integrity: *The blockchain ensures that each model upload or update can be immutably traced to the uploader.*

# Covered Objectives Contd..

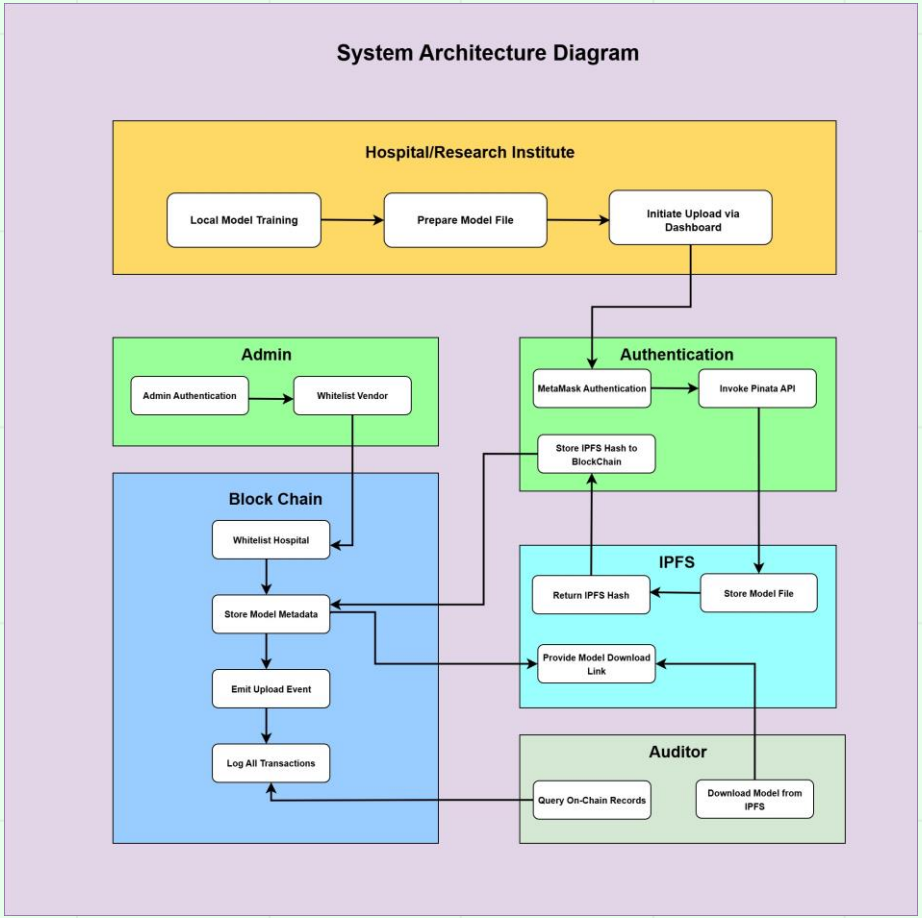
**3. Confidentiality, Integrity, Traceability**:

- ✅ Confidentiality: *Direct model contents are stored on IPFS, not the blockchain itself. Patient data never leaves hospital boundaries, aligning with privacy requirements.*
- ✅ Integrity & Traceability: *Every transaction (upload, whitelist, role assignment) is permanently logged, so model provenance is always auditable to participants.*

**4. Governance Mechanisms**:

- ✅ Whitelisting/Vendor Governance : *Administrators can whitelist or remove vendors on-chain, but there are no tokenomics, rewards, or penalties implemented in the contract*

# System Architecture Overview



# DApps- Decentralized Application

- A **Decentralized Application (DApp)** is an app that interacts with a blockchain through smart contracts, typically offering:
  - A web frontend (often JavaScript frameworks like React)
  - Blockchain-based authentication (wallets such as MetaMask)
  - Direct calls to one or more smart contracts for core functions (no central backend server for main workflows)
  - Use of decentralized storage (e.g., IPFS) for files or metadata

# DApp Components in our work:

| Module | File Name | Reason/Description |
|---|---|---|
| Model Uploader | ModelUploader.js | Uploads ML models to IPFS, interacts with blockchain smart contract, requires MetaMask. |
| Block Chain Connection | BlockchainConnect.js | Handles wallet connections, checks account and network, required for blockchain DApp interactions. |
| Model Registry | AIModelRegistryABI.json | Defines the smart contract interface; the backend logic for decentralized registry and audit. |

# Blockchain Smart Contract

## 1. Whitelist Hospital

- ***Purpose***: Manages approved participant access.
- ***Functionality:***
    - Keeps a mapping (whitelistedVendors[address]) of which hospital/participant addresses are authorized to interact with the contract.
    - Only whitelisted accounts can upload models or perform restricted operations.

## 2. Store Model Metadata

- ***Purpose:*** Registers AI model versions and their storage references.
- ***Functionality:***
    - Accepts a model name and an IPFS hash when a hospital uploads a new model.
    - Records this pairing (storeModel(string modelName, string modelHash)) along with the address of the uploader.
    - Ensures the traceability and transparency of every submitted model.

# Blockchain Smart Contract

### 3. Emit Events

- ***Purpose***: Provides an immutable audit trail and system transparency.
- ***Functionality:***
    - Emits events on critical actions such as:
        - **ModelStored**: Triggered when new model metadata is recorded.
        - **VendorWhitelisted**: Announced whenever a hospital/participant is authorized.
        - **VendorRemoved**: Indicates removal of participant's authorization.

### 4. Log All Transactions

- ***Purpose:*** Ensures transparency, compliance, and accountability..
- ***Functionality:***
    - Every model upload, vendor whitelist/removal, and admin action is written to the blockchain.
    - The log is public and immutable, enabling compliance reviews and dispute resolution.

# How these work together

- **Admin** manages whitelisting and roles.
- **Hospitals (when whitelisted)** can upload models (metadata only), triggering on-chain events.
- **Auditors/External** Users can verify every transaction, download model artifacts by IPFS hash, and confirm participant status—all through the public blockchain.
- These sub-blocks collectively enforce trust, security, and auditability in your decentralized federated learning ecosystem.

| Sub-Block | Blockchain Integration Role |
|---|---|
| Whitelist Hospital | Access control and permission management |
| Store Model Metadata | Decentralized registry of model submissions |
| Emit Events | Transparent audit trail of key actions |
| Role Management | Assignment and enforcement of user/admin vendor rights |
| Log All Transactions | Immutable, public activity and state logging |
| Verification & Querying | Public checks for permissions, models, and role status |

# Auditor

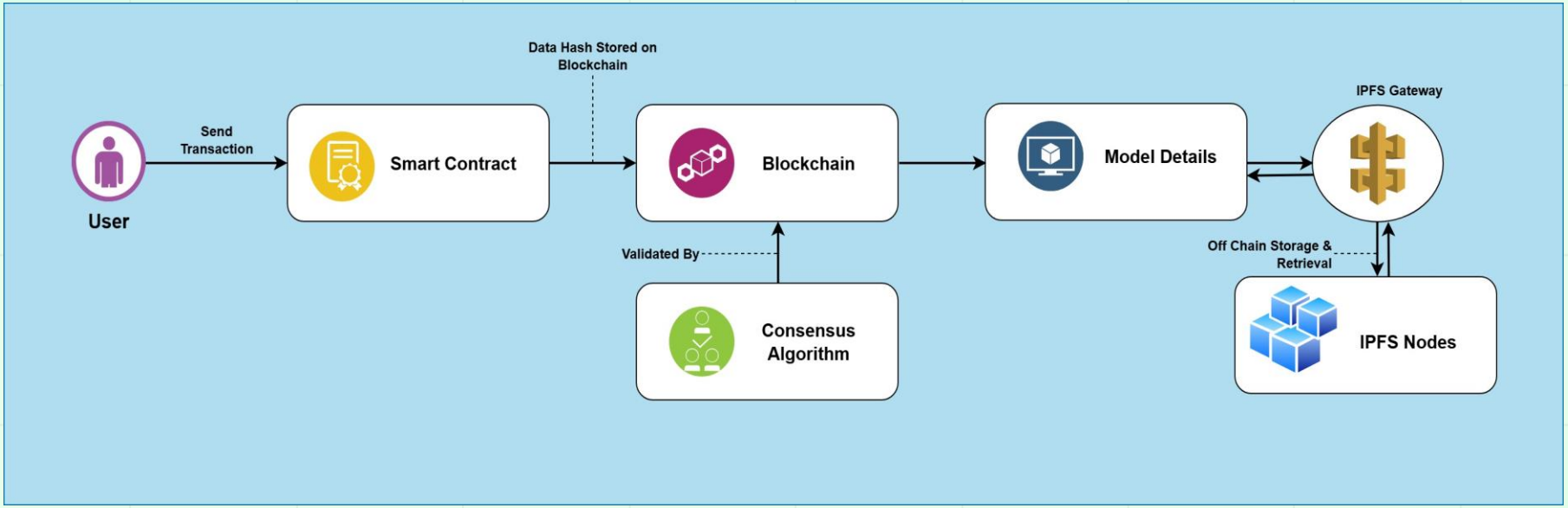
## 1. Query On-Chain Records

- ***Purpose***: Allows auditors and other users to access and review the blockchain ledger to examine every approved action.
- ***Functionality:***
    - Retrieve immutable logs of all model uploads (including model name, IPFS hash, and uploader).
    - Track participant whitelisting, removals, and admin actions through events.
    - Verify timestamps and sequence of transactions for compliance and auditing.

## 2. Download Model from IPFS

- ***Purpose:*** Enables retrieval of the actual machine learning models for evaluation, validation, or research purposes.
- ***Functionality:***
    - Uses publicly stored IPFS hashes (from blockchain registry) to fetch model binaries directly from decentralized storage.
    - Can cross-check that the on-chain hash matches the file content, validating authenticity.

# Blockchain Data Flow



# IPFS – Inter Planetary File System

**It is a peer-to-peer, content-addressed protocol and network designed to create a decentralized, resilient, and verifiable file storage and sharing system.**

**Content Addressing and CIDs**

- Traditional web protocols (HTTP/HTTPS) use location-based addressing, where a URL points to a specific server and path.
- IPFS uses content-based addressing: each file (or data "object") is cryptographically hashed to produce a **Content Identifier (CID).**
- The CID uniquely represents the file's content: any change in the file yields a new CID.
- To retrieve data, peers query the network for the CID instead of a URL.

**Data Chunking and Merkle DAG**

- When a file is added to IPFS:
    - It is split into fixed-size blocks.
    - Each block is hashed, producing its own CID.
    - Blocks are organized into a **Merkle Directed Acyclic Graph (DAG)**, enabling efficient versioning, deduplication, and integrity verification.

# IPFS - InterPlanetary File System

**Distributed Hash Table (DHT)**

- IPFS nodes form a peer-to-peer network. A Distributed Hash Table (DHT) maps CIDs to the addresses of nodes storing the corresponding blocks.
- To fetch a CID, a node locates peers advertising that CID in the DHT, then downloads blocks in parallel from multiple sources.

**Benefits of IPFS**

- *Decentralization & Resilience*: Files are served by any node holding the data; no single point of failure or censorship.
- *Integrity & Immutability*: Content addressing and Merkle DAG ensure tamper resistance—any alteration breaks the CID chain.
- *Versioning*: Merkle DAG inherently tracks historical versions; each update yields a new CID, while preserving links to prior versions.
- *Efficiency*: Parallel block downloads from multiple peers accelerate retrieval, and deduplication conserves bandwidth and storage.

# IPFS in my work

Our work, holds a sophisticated IPFS Integration as follows:

| Step | Process | Technology |
|---|---|---|
| 1. File Upload | User Selects AI Model | React File Input, Form Data |
| 2. IPFS Storage | Upload to Pinata via API | Pinata Cloud API, JWT Authentication |
| 3. Hash Generation | IPFS generates unique CID | Content Addressing (CID) |
| 4. Blockchain Storage | Store model name and IPFS hash | Smart Contract, ether js |
| 5. File Retrieval | Download via IPFS Gateway | Gateway URL with blob handling |

**The IPFS implementation provides:**

- **Decentralized Storage**: Files distributed across IPFS network
- **Content Integrity**: Cryptographic hashing ensures file authenticity
- **Cost Efficiency**: Only hash stored on-chain, reducing blockchain storage costs
- **Availability**: Files accessible as long as pinned on IPFS nodes

# Consensus Algorithm

A consensus algorithm is a protocol used by distributed systems and blockchains to ensure that all network participants (nodes) agree on a single, valid version of the system's data—despite the presence of failures or malicious actors. Its primary function is to maintain integrity, prevent double spending, and enable decentralized trust.

# Why Is Consensus Essential?

- Agreement: Ensures all nodes record the same transactions and data.
- Security: Protects against fraud, conflicting records, and attacks.
- Decentralization: Operates without relying on a central authority.
- Fault Tolerance: Handles failures, network delays, or compromised participants.

# Polygon’s Proof of Stake (PoS)

- Validators lock up (stake) MATIC tokens.
- Selection of validators is proportional to their stake.
- Block Approval: Validators propose and validate new blocks.
- Security: Misbehavior (fraudulent validation) can cause loss of staked funds.
- Efficiency: Lower energy consumption and faster throughput than PoW.

How Consensus Fits in Blockchain Applications

Data Flow Steps:

1. Transaction Submission: A user’s request (e.g., storing AI model data) is broadcast to the network.
2. Validation: Nodes (validators/miners) verify the transaction follows protocol rules.
3. Block Formation: A valid transaction is bundled into a block proposal.
4. Network Agreement: The consensus mechanism determines whether to accept the block.
5. Chain Update: Once agreed, the block becomes part of an immutable chain.
6. Finality: Updates are finalized; the state is updated across all nodes.

# How Consensus Algorithm Fits in Blockchain Application

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**Key Benefits**

- Prevents Double Spending: Ensures each transaction is unique and non-duplicatable.
- Enables Decentralization: Makes it possible for anyone to participate, removing single points of control.
- Scales Trust: Allows global participants to agree on history without prior relationships.

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# Thank You!

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