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REPORT ON

ORGANIZATION

Submitted by

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Abstract

Blockchain technology represents one of the most revolutionary advancements in modern distributed computing, fundamentally transforming the way data is stored, verified, and trusted across decentralized networks. Unlike traditional centralized database systems, blockchain introduces a tamper-resistant, distributed ledger architecture in which each record is cryptographically secured and permanently linked to its predecessor. The reliability and integrity of this architecture are built upon two foundational principles: cryptographic hashing and consensus mechanisms — most prominently, the Proof-of-Work (PoW) algorithm.

This project presents a comprehensive implementation of a Blockchain-Based Proof-of-Work System developed entirely using Python. The system accurately simulates the core operational mechanisms of real-world blockchain networks such as Bitcoin, including block creation, SHA-256 cryptographic hashing, mining through computational puzzle-solving, chain validation, and performance benchmarking under varying difficulty levels. While simplified for academic clarity, the model preserves the essential technical characteristics of production-grade blockchain systems.

The architecture is structured into four modular components: a mining module (pow.py) responsible for executing SHA-256 based Proof-of-Work; a verification module (verify.py) for validating mined blocks and ensuring chain integrity; a blockchain management module (blockchain.py) that maintains and links blocks within the distributed ledger; and a performance analysis module (performance.py) designed to evaluate mining efficiency and computational cost across dynamic difficulty adjustments.

The SHA-256 hashing algorithm is employed throughout the system due to its strong collision resistance and one-way cryptographic properties, ensuring computational infeasibility in reversing hashes or generating duplicate outputs. Mining difficulty is controlled by enforcing a required number of leading zero bits in the binary representation of the hash, effectively replicating the dynamic difficulty adjustment mechanism used in real-world blockchain environments.

Beyond functional implementation, this project also emphasizes system transparency, modularity, and extensibility. The modular design allows individual components to be independently tested, analyzed, and improved, making the framework adaptable for future enhancements such as alternative consensus algorithms, distributed node simulation, or transaction-level cryptographic validation. This structured approach reflects real-world software engineering practices used in secure distributed systems.

Furthermore, the project provides measurable insights into the computational complexity and resource implications of mining operations. By benchmarking performance across multiple difficulty levels, it highlights the trade-off between network security and computational cost — a critical consideration in blockchain scalability and sustainability discussions. These experimental results strengthen the academic value of the project by connecting theoretical cryptographic principles with observable performance metrics.

In conclusion, this project serves both as a functional prototype and a comprehensive educational framework, successfully bridging the gap between theoretical blockchain concepts and hands-on technical implementation using Python’s standard library ecosystem. It not only demonstrates the technical feasibility of blockchain mechanisms but also equips learners with a deeper analytical perspective on decentralized system design, security architecture, and computational integrity.

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CERTIFICATE

This is to certify that the "extensive survey project report" is a Bonafide certificate work carried out by Prajwal M in partial fulfillment of the requirement for the award of the **DIPLOMA IN COMPUTER SCIENCE AND ENGINEERING PROGRAMME by the DEPARTMENT OF TECHNICAL EDUCATION BENGALURU – 560054**, under or guidance and supervision.

The result embodied in this report has been submitted to any other university or institute for the award of any degree or diploma.

COHORT SIGNATURE **UNDER THE SUPERVISION OF**

_____ _____

Evaluation rubrics for OJT during II and III - IA

Evaluation Parameters						**Student Score**
Performance on assigned tasks like research, data collection, proof and outcome	The topic was well researched and all information and data included are accurate and form reliable sources of information like high impact journals standards, etc. The proof was enough backed up with accurate data, analysis and reasoning beyond the reasoning beyond the class learning. Outcome achieved beyond the task	**The topic was researched and most information and data were from reliable sources of information. The proof was backed up with good data and reasoning as taught in class. Outcome achieved as per task**	The topic was researched but information and data were only partly from reliable sources of information. The proof was backed up with good data or reasoning as taught in the class. Partial outcome achieved as per the task	The topic was researched and data were not from reliable sources. The proof was not backed up with data analysis or reasoning as taught in the class. Some outcome obtained as per the task	Desired results not obtained, but some relevant research was done. Outcome not obtained as per tasks	
Application of industrial learnings and evolving with creative techniques	Made effective use of class principles, models and theories. Also used creativity to find effective results appropriate to industry beyond **industrial** learning	Made good use of class principles, models and theories some creative ideas were exposed to find desired outcome but within the framework of **industrial** learning	**Made some use of class principles, models and theories no creative ideas or models explored**	Made limited use of class principles, models and theories	Poorly applied class principles, models and theories	
Response to industrial supervisors and cohorts queries	Queries excellent response to comments and discussion with appropriate content supported by theory/research	Good response to questions and discussion with some connection made to theory/research	**Satisfactory response to questions and discussions with limited reference to theory /research**	**Limited response to questions and discussions with no reference to theory /research**	**Poor or no response to questions and did not participate in the discussion**	
Total 50						

Evaluation rubrics for use case during II and III - IA

Evaluation Parameters						**Student Score**
Finding processes / models / approaches	**Discovered processes / models / approaches are of good quality and relevant**	Discovered processes / models / approaches are of appropriate quality but limited relevance	Discovered processes / models / approaches have limited application but relevant to the problem	Discovered processes / models / approaches has restricted application	No processes / models / approaches were identified	
Grabbing ideas to work in ease with the organization	Various ideas and innovative solutions have been proposed and their application have been clearly outlined	Various ideas and innovative solutions have been proposed as well as the outline of the process to apply them	**Some ideas or innovative solutions have been proposed but the process of applying them hasn't been specified**	Few ideas have been proposed	No ideas or innovative solutions have been proposed	
Using creativity techniques to provide and reason good ideas which are original and un conventional	Whenever necessary creativity techniques are utilized to analyse and solve the problem	Creativity techniques are frequently utilized in more then 50% of the occasions	Creativity techniques are utilized at time in less than 50% of the occasions	**Creativity techniques are used a few times only**	Creativity techniques are not utilized to analyse and solve the problem	
Total 30						

1. Introduction

1.1 Background & Motivation

In modern computing, ensuring secure and tamper-resistant data storage is a major challenge. Traditional centralized systems depend on a single authority, making them vulnerable to manipulation and single points of failure. Blockchain technology addresses these issues by introducing a decentralized ledger where each block is cryptographically linked to the previous one, ensuring integrity and transparency.

The motivation of this project is to understand the internal working of blockchain and Proof-of-Work by implementing the core mechanisms from scratch using Python, rather than relying on existing platforms.

1.2 Problem Statement

Although blockchain is widely used, its internal mechanisms are often hidden behind complex frameworks. This makes it difficult for learners to understand how mining, hashing, difficulty adjustment, and chain validation actually work.

This project aims to design a simplified yet technically accurate blockchain system that demonstrates Proof-of-Work, block validation, and tamper detection in a clear and structured manner.

1.3 Objectives of the Project

The main objective of this project is to develop a Blockchain-Based Proof-of-Work system using Python.

The specific objectives are:

- To implement SHA-256 based mining.
- To design a secure block structure.
- To validate blockchain integrity.
- To simulate mining difficulty.
- To demonstrate tamper detection.

1.4 Scope

The scope of this project is limited to implementing the fundamental concepts of blockchain and Proof-of-Work in an academic environment. It includes block creation, mining, validation, and performance testing.

Advanced features such as cryptocurrency transactions, networking between nodes, or smart contracts are not included, but the system provides a strong foundation for future expansion.

2. Project Overview

The project is a complete simulation of a Proof-of-Work blockchain system. It is divided into four Python source files and two data files. Each file has one clear job. Together they form a complete pipeline — from taking a raw message as input, to mining a proof, to verifying it, to building a full chain, to benchmarking performance.

The project was built and run entirely inside PyCharm IDE on a standard computer. No servers, no databases, no internet connection required. Everything runs locally from the command line or PyCharm's built-in terminal.

2.1 Mining Module — pow.py

pow.py is the core of the project. It performs the actual Proof-of-Work computation. Given a message file and required difficulty level, it searches for a nonce such that SHA-256(message + nonce) has the required number of leading zero bits in binary. When found, it saves the result to header.txt.

- Reads the raw bytes of message.txt as input
- Accepts the difficulty level as a command-line argument
- Generates nonces using itertools.product() over alphanumeric characters
- Computes SHA-256(message_bytes + nonce_bytes) for each candidate nonce
- Converts the resulting hash from hex to binary to count leading zero bits
- Records start and end time using time.time() to measure mining duration
- Calculates and displays hash rate (hashes per second)
- Writes the winning nonce, hash, and difficulty to header.txt

2.2 Verification Module — verify.py

verify.py independently confirms whether a previously mined proof is valid. It reads the nonce from header.txt and the original data from message.txt, recomputes the hash, and checks whether it meets the difficulty requirement. This mirrors exactly how Bitcoin nodes verify new blocks without redoing the mining work.

- Reads the nonce and difficulty from header.txt
- Reads the original message from message.txt
- Recomputes SHA-256(message_bytes + nonce_bytes)
- Converts result to binary and checks leading zeros
- Prints a clear PASS or FAIL result with full diagnostic output
- Detects message tampering if message.txt has been changed since mining

2.3 Blockchain Simulation — Blockchain.py

Blockchain.py defines two classes — Block and Blockchain — that together simulate a real blockchain. The Blockchain class manages the chain (a Python list of Block objects), handles block addition, and validates chain integrity. Each block is mined when added, ensuring all blocks have valid PoW.

- Block class stores index, timestamp, data, previous_hash, nonce, and hash
- calculate_hash() serializes all block fields to JSON and hashes with SHA-256
- mine_block() iterates self.nonce until the hash meets the difficulty requirement
- create_genesis_block() creates block 0 with previous_hash = "0"
- add_block() links the new block to the chain and mines it before appending
- is_chain_valid() checks every block for hash integrity and chain continuity
- Tamper demonstration: modifying any block's data causes is_chain_valid() to return False

2.4 Performance Analysis — Performance.py

Performance.py benchmarks the mining system across a range of difficulty levels. For each level it runs a fresh mining operation, records the time taken, and collects the data for plotting. The resulting matplotlib graph visually demonstrates how mining time grows exponentially with difficulty.

- Tests difficulty levels 2, 3, 4, and 5 by default
- Uses hashlib.sha256() directly in a tight loop for accurate benchmarking
- Records time per difficulty using time.time()
- Calculates and prints hash rate and attempt count per difficulty
- Plots a line graph: Difficulty Level vs Mining Time (seconds) using matplotlib
- Graph includes axis labels, title, grid lines, and markers at each data point

2.5 Supporting Files — message.txt & header.txt

message.txt is the input data file. It can contain any text — a transaction record, a message, or arbitrary data. pow.py reads this file as binary bytes and uses its content as the data to be mined. You can change the content of message.txt to simulate mining different blocks.

header.txt is the output file produced by pow.py after successful mining. It stores the valid nonce found during mining, the resulting hash, and the difficulty level used. verify.py reads this file to confirm the proof. Think of header.txt as the "block header" — the proof that mining was done correctly.

3. Tech Stack Used

The project is built using Python 3 and its standard library, with one external library (matplotlib) for visualization. It was developed using the PyCharm IDE. The stack was chosen for simplicity and portability — no external servers, no complex setup, and no additional configuration beyond a standard Python environment.

3.1 Python 3 — Programming Language

Python 3 is used across all modules. It provides the required tools without external dependencies. The hashlib module enables SHA-256 hashing, itertools supports nonce generation, and json ensures consistent data serialization. Python 3.8 or higher is recommended for compatibility with modern syntax features.

3.2 hashlib — Cryptographic Hashing

hashlib is Python's built-in cryptographic library. In this project, SHA-256 is used to generate fixed 256-bit hashes using hashlib.sha256(data).hexdigest(). It ensures data integrity and makes it computationally infeasible to reverse or find collisions.

3.3 itertools — Nonce Generation

itertools.product() is used in pow.py to generate combinations of alphanumeric characters as nonces. It efficiently produces values on demand without storing them in memory.

3.4 json, time, string — Supporting Libraries

"Json" is used to serialize block data consistently before hashing.
"time" is used to measure mining duration.
"string" provides character sets used for nonce generation.

3.5 matplotlib — Visualization

matplotlib is used in Performance.py to plot the graph of Difficulty Level vs Mining Time. It visually demonstrates how mining time increases as difficulty grows.

3.6 PyCharm IDE — Development Environment

The project was developed and tested in PyCharm. All Python files (pow.py, verify.py, Blockchain.py, Performance.py) and data files (message.txt, header.txt) are organized within a single project folder and executed locally.

4. Project structure

The project follows a flat, single-folder structure. All files live in one PyCharm project directory. This keeps things simple — every file can directly read and write to message.txt and header.txt without any path configuration.

4.1 Folder & File Layout

```
PythonProject/              <-- PyCharm project root
│
├── pow.py                  <-- Mining: finds valid nonce
├── Verify.py               <-- Verification: checks the proof
├── Blockchain.py           <-- Simulation: full chain of blocks
├── Performance.py          <-- Benchmarking: difficulty vs time graph
│
├── message.txt             <-- Input: data to be mined
└── header.txt              <-- Output: nonce + hash from mining
```

4.2 File Responsibilities

pow.py

Accepts a difficulty level (number of required leading zero bits) and the path to message.txt as command-line arguments. Searches for a valid nonce and writes the result to header.txt. This is the primary entry point for the mining workflow.

Verify.py

Reads header.txt (nonce, difficulty) and message.txt (original data). Recomputes the hash and checks whether it meets the difficulty requirement. Reports PASS or FAIL with full diagnostic information. Can detect message tampering.

Blockchain.py

Defines the Block and Blockchain classes. Constructs a chain of mined blocks in memory. Demonstrates chain linking, integrity validation, and tamper detection. Can be run directly to see a working blockchain simulation with automatic tamper testing.

Performance.py

Runs mining at multiple difficulty levels (2 through 5), records timing data, and plots the results as a matplotlib line chart. Provides empirical evidence of the exponential difficulty-time relationship.

message.txt

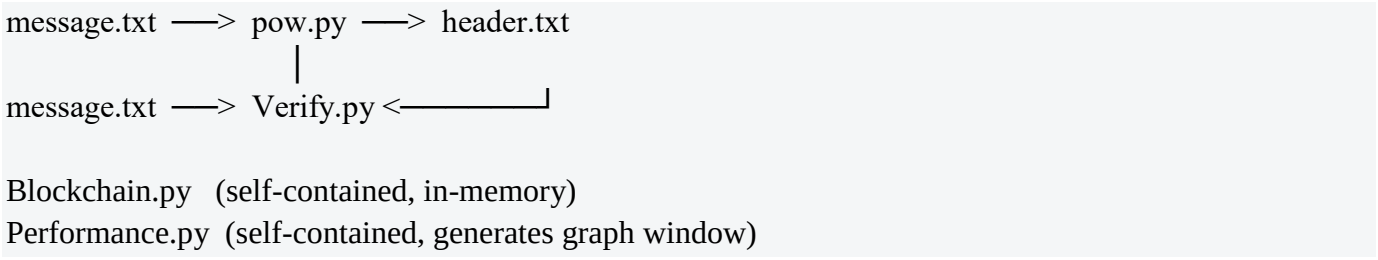
A plain text file containing the data to be mined. You can edit this file to simulate mining different types of data. pow.py reads it as raw bytes, so any valid text is acceptable.

header.txt

Automatically generated by pow.py after successful mining. Contains the valid nonce, the resulting hash, and the difficulty level. Verify.py reads this file to confirm the proof. Do not edit this file manually — any change will cause verification to fail, which is actually a useful demonstration of tamper detection.

4.3 How Files Interact

The data flow between files is simple and linear. pow.py reads message.txt and writes header.txt. Verify.py reads both message.txt and header.txt. Blockchain.py operates entirely in memory and does not use the data files. Performance.py also operates in memory and generates a graph window through matplotlib.



Blockchain.py (self-contained, in-memory)
Performance.py (self-contained, generates graph window)

4.4 Advantages of Modular Design

- Each file has one job — easy to understand, test, and modify individually
- You can run each module independently from PyCharm without affecting others
- New features (GUI, networking, database) can be added as new files
- Students can read and understand each file completely in isolation
- Bugs are easy to isolate — if verification fails, the problem is in Verify.py or the data files

5. UI/UX Design Approaches

The project uses a Command Line Interface (CLI) as its user interface. This is a deliberate design choice — a CLI keeps the focus on blockchain concepts rather than GUI complexity, and it is perfectly suited for running Python scripts in PyCharm's integrated terminal. The CLI output is designed to be structured, informative, and easy to read at a glance.

Instead of visual buttons and dashboards, the system communicates through clearly formatted console messages. Each step of the process — mining start, progress updates, success, and verification result — is displayed in a clean and consistent format. This ensures the user can follow the system's internal workflow without confusion.

5.1 CLI as the Interface

The CLI is accessed through PyCharm's built-in terminal (View > Tool Windows > Terminal) or via the Run button. Users pass arguments directly on the command line, and output is printed in a structured format. Every important event — mining start, progress, success, and result — is announced with a clear prefix ([*] for info, [+] for success, [!] for errors).

This minimal interface reduces distractions and allows users to observe the computational process directly. It also mirrors how many real blockchain nodes and backend systems operate in production environments.

5.2 Design Principles

Clarity

Every output line has a clear label. The user always knows what stage the system is at — whether it is initializing, mining, validating, or reporting results. Important values like nonce, hash, difficulty, and mining time are clearly displayed.

Simplicity

There is no unnecessary output. Only the information that matters is printed: what the system is doing, what it found, and how long it took. This keeps the console readable even during repeated executions.

Transparency

The mining module shows the full hash, the nonce, the number of iterations, the time taken, and the hash rate. Nothing is hidden. This transparency is important for an educational tool — students should be able to see exactly what the system computed and verify the logic step by step.

Immediate Feedback

Verification gives a single clear verdict: PASS or FAIL. This binary result is backed up by supporting data so the user understands why it passed or failed. Any tampering is detected instantly and reported clearly.

Consistency

All modules follow a consistent output format and naming style. This uniform structure improves readability and makes the system feel cohesive and professionally designed.

5.3 Output Structure

A typical run of pow.py produces output structured like this:

```
[*] Blockchain Proof-of-Work — Mining Module
[*] ──────────────────────────────────────────────────────
[*] Message file : message.txt
[*] Difficulty   : 12 leading zero bits
[*] Starting mining...

[+] SUCCESS — Valid hash found!
    Nonce      : mK4
    Hash       : 0002a3f8c1d9... (64 hex chars)
    Iterations : 63,812
    Time taken : 5.14 seconds
    Hash rate  : 12,414 hashes/second

[+] Result saved to header.txt
```

And a typical run of Verify.py:

```
[*] Blockchain Proof-of-Work — Verification Module
[*] ──────────────────────────────────────────────────────
    Loaded nonce     : mK4
    Required zeros   : 12
    Computed hash    : 0002a3f8c1d9...
    Leading zero bits: 12

    ✓ RESULT: PASS — Proof-of-Work is VALID
```

5.4 Graphical Output

Performance.py generates a matplotlib graph window showing the relationship between difficulty and mining time. This is the only graphical output in the project. The graph has clearly labeled axes, a descriptive title, grid lines for readability, and circular markers at each measured data point. The curve visually demonstrates how mining time grows exponentially with difficulty — a core concept in understanding why high-difficulty PoW provides strong security.

6. Key Frontend Implementations

In this CLI-based project, "frontend" means all the user-facing output and interaction mechanisms. The following key features have been implemented to make the system informative, usable, and educational.

6.1 Real-Time Mining Feedback

While mining is in progress (especially at higher difficulty levels), the system prints progress updates so the user knows the program is running and not frozen. Every 10,000 iterations a status line is printed showing the current iteration count and elapsed time. When the valid nonce is found, the final result is printed with full details.

6.2 Command-Line Arguments

Users control the mining module entirely through command-line arguments passed in PyCharm's terminal. The difficulty level is the first argument and the message filename is the second. This makes it easy to experiment — just change the number to test different difficulty levels, or change the filename to mine different data.

```
# In PyCharm terminal:
python pow.py 12 message.txt       # Mine with difficulty 12
python pow.py 4  message.txt       # Mine with difficulty 4 (faster)
python Verify.py header.txt message.txt  # Verify the result
python Blockchain.py               # Run blockchain simulation
python Performance.py              # Run performance benchmarks
```

6.3 Hash Rate Display

The hash rate — how many SHA-256 computations per second the system performs — is calculated and displayed at the end of every mining run. This is calculated as total_iterations / elapsed_seconds and gives a concrete measure of the machine's PoW performance. A typical Python-based implementation on modern hardware achieves 10,000 to 50,000 hashes per second.

6.4 PASS / FAIL Verification Output

Verify.py produces a clear, unambiguous verdict. The output shows the loaded nonce, the required difficulty, the recomputed hash, and the actual number of leading zero bits found, followed by the final PASS or FAIL result. If the message.txt file has been changed since mining, the recomputed hash will not match the stored hash, producing a FAIL. This directly demonstrates the tamper-detection capability of the system.

6.5 Performance Graph

The matplotlib graph generated in Performance.py shows the relationship between difficulty level (X-axis) and mining time in seconds (Y-axis). As difficulty increases, the curve rises sharply, visually demonstrating the exponential growth of computational effort required in Proof-of-Work systems.

7. Key UI Features

7.1 Configurable Difficulty

The mining difficulty is fully configurable through the command line. There is no need to edit any source code to change the difficulty level. Simply change the first argument when running pow.py in PyCharm's terminal. This makes it trivial to experiment: run at difficulty 2 for an instant result, then at difficulty 5 to see the difference, then at difficulty 10 to feel how computation scales up.

7.2 Auto Nonce Generation

Users never have to think about nonces. The system generates them automatically and exhaustively using itertools.product(). It starts with length-1 nonces (a, b, c ... Z, 0 ... 9), then length-2 (aa, ab ... 99), and so on indefinitely until a valid nonce is found. This guarantees that a solution will always be found regardless of difficulty — the only variable is how long it takes.

7.3 Mining Timer

Every mining run is precisely timed using Python's time.time() function. The start time is recorded before the first nonce attempt and the end time is recorded the moment a valid hash is found. The elapsed time is printed in seconds. This timer is also used to compute the hash rate, giving the user a complete picture of the mining performance for each run.

7.4 Chain Validity Report

After building a blockchain with several blocks, Blockchain.py calls is_chain_valid() and prints either "Blockchain is valid" or "Blockchain is invalid". False! When tampering is simulated — by directly modifying a block's data field — the report immediately changes to False, with the specific block and type of failure identified in the output. This gives students immediate, tangible confirmation of how blockchain integrity works.

7.5 Tamper Detection Output

The tamper detection feature is demonstrated explicitly in Blockchain.py. After building a valid chain, the code modifies block 1's data field directly (simulating an attacker changing a transaction record) and calls is_chain_valid() again. The output clearly shows which block failed and why — either its stored hash no longer matches its computed hash (data tampered), or its previous_hash field no longer matches the actual previous block's hash (chain relinking detected).

8. Integration with Backend

The backend of this project is the collection of cryptographic and data-processing logic that powers the system: the SHA-256 hash pipeline, the nonce generation loop, the binary conversion utilities, the block data structure, and the chain validation algorithm. All of this is pure Python, running locally on the machine where PyCharm is installed.

8.1 Full System Data Flow

The complete system follows a clear and structured data flow pipeline. Each module performs a specific responsibility and passes its output to the next stage. This separation of concerns ensures modularity, easier debugging, and logical clarity. The process begins with raw input data and ends either in verification, blockchain simulation, or performance benchmarking.

The mining process is the core starting point. The input message is read as raw bytes, and a nonce is repeatedly generated and tested until a valid hash satisfying the difficulty requirement is found. Once a valid proof is discovered, the result is stored externally for independent verification.

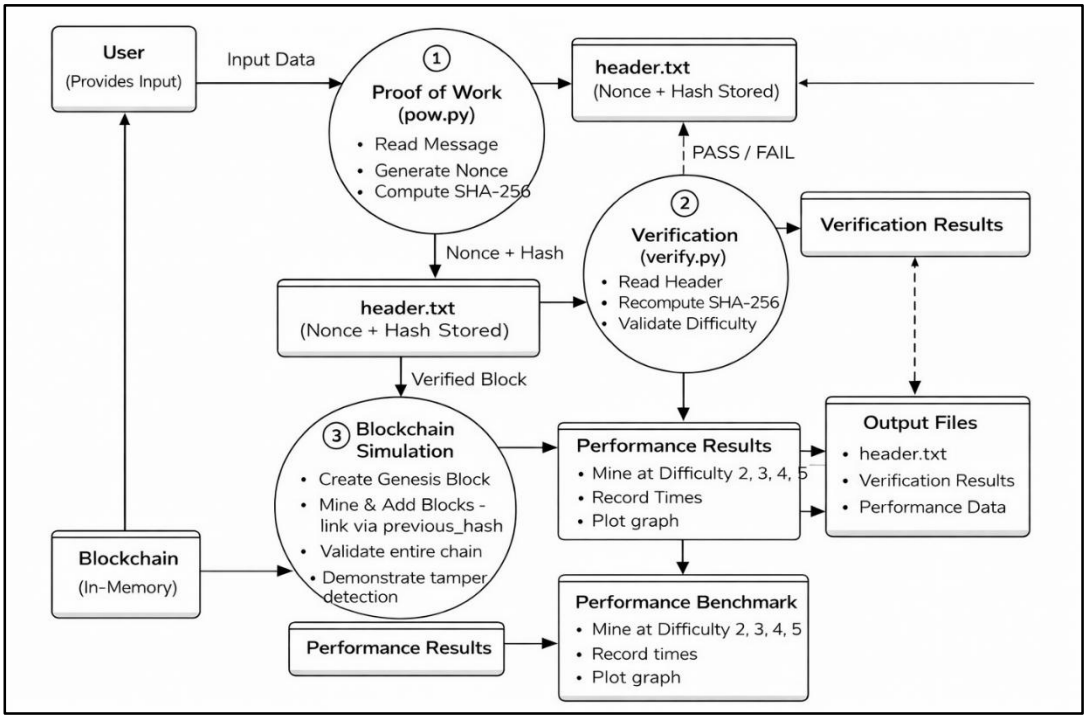


Fig 8.1 Data Flow Structure

8.2 SHA-256 Hash Pipeline

Every hash computation in this project follows a consistent three-step process. First, the input data — either a message or serialized block content — is converted into bytes using UTF-8 encoding. For blockchain blocks, the fields are serialized using JSON with sorted keys to ensure deterministic ordering before hashing. This guarantees that the same data always produces the same hash output.

Next, the byte data is passed to hashlib.sha256(), which generates a fixed 256-bit cryptographic hash. The result is stored as a hexadecimal string for display and storage, and converted into binary format when checking difficulty requirements. This structured pipeline ensures secure, repeatable, and verifiable hashing across all modules.

8.3 Block Linking Mechanism

When a new block is added to the blockchain, its previous_hash field is set to the hash of the last block in the chain. This creates a direct cryptographic dependency between consecutive blocks. The mining process then calculates the new block's hash, which includes its data, timestamp, nonce, and previous hash.

Because each block depends on the hash of the previous one, altering any earlier block changes its hash and breaks the chain link. This cascading effect ensures immutability — even a small modification invalidates all subsequent blocks, making tampering immediately detectable.

8.4 Chain Validation Logic

The is_chain_valid() function verifies the integrity of the entire blockchain by iterating through each block (except the genesis block). It recalculates the current block's hash and compares it with the stored hash to ensure that the data has not been modified.

It also checks whether each block's previous_hash correctly matches the hash of the preceding block. If either the hash comparison or the linkage check fails, the function immediately returns False. This validation mechanism ensures structural integrity and demonstrates how blockchain systems maintain trust without central control.

9. Challenges Faced & Solutions

Building this project from scratch in Python involved several technical challenges. Each issue required careful reasoning and structured problem-solving to ensure the system remained accurate, efficient, and educational. The major challenges and their solutions are described below.

9.1 High Mining Time at Large Difficulty

Challenge:
SHA-256 is a one-way cryptographic function, meaning there is no shortcut to compute a valid nonce. The system must test nonce values repeatedly until a hash with the required number of leading zero bits is found. As the difficulty increases, the number of attempts required grows exponentially. At higher difficulty levels, mining can take several minutes depending on hardware performance.

Solution:
To manage long execution times, periodic progress updates were implemented. The system prints iteration counts and elapsed time during mining so users know the process is active. Difficulty levels used for benchmarking are kept within practical limits, and the calculated hash rate helps estimate the expected runtime for higher difficulties.

9.2 Deterministic Hash Generation

Challenge:
Blockchain systems require that identical data always produce identical hashes. However, Python dictionaries may not maintain consistent key ordering during serialization. If the block fields are serialized in different orders, the resulting JSON string changes, leading to different hashes for the same logical data.

Solution:
The block data is serialized using `json.dumps()` with `sort_keys=True`. This ensures a consistent ordering of fields before hashing. As a result, the same block content always produces the same SHA-256 hash, preserving determinism and ensuring reliable chain validation.

9.3 Nonce Exhaustion

Challenge:
Using a limited nonce range (such as only numeric values) could result in failure to find a valid hash at higher difficulty levels. A restricted search space might not contain a solution, causing the mining process to stop prematurely.

Solution:
Nonce generation was implemented using `itertools.product()` over alphanumeric characters with increasing length. This creates an effectively unlimited search space without storing all combinations in memory. The system guarantees that a valid nonce will eventually be found, with time being the only limiting factor.

9.4 Tamper Detection Accuracy

Challenge:
The validation logic must detect all possible types of tampering, including data modification, block insertion, deletion, or reordering. A single integrity check would not be sufficient to identify every attack scenario.

Solution:
A two-step validation approach was implemented in `is_chain_valid()`. First, each block's hash is recalculated and compared with the stored hash to detect data tampering. Second, the `previous_hash` field is compared with the actual hash of the preceding block to ensure structural integrity. If either check fails, the chain is immediately marked invalid.

9.5 Binary Conversion Precision

Challenge:
The difficulty condition is defined in terms of leading zero bits, not hexadecimal characters. Since each hex character represents four bits, incorrect conversion from hex to binary could lead to inaccurate difficulty validation.

Solution:
A precise hex-to-binary conversion method was implemented using formatted string conversion to preserve leading zeros. Each hexadecimal character is converted into a 4-bit binary value, forming a complete 256-bit binary string. The system then checks whether the binary string starts with the required number of zero bits, ensuring accurate Proof-of-Work validation.

9.6 Challenges & Solutions Summary Table

No.	Challenge	Issue Faced	Solution Implemented
1	High Mining Time	Mining time increases exponentially with higher difficulty levels.	Added progress updates, limited benchmark difficulty range, and displayed hash rate for estimation.
2	Deterministic Hash Generation	Same data could produce different hashes due to unordered serialization.	Used `json.dumps(..., sort_keys=True)` to ensure consistent field ordering.
3	Nonce Exhaustion	Limited nonce range could fail to find valid hash.	Implemented dynamic nonce generation using `itertools.product()` with increasing length.
4	Tamper Detection Accuracy	Single validation check may not detect all attack types.	Used dual validation: hash recalculation + previous_hash verification.
5	Binary Conversion Precision	Incorrect hex-to-binary conversion could break difficulty check.	Converted each hex digit into 4-bit binary format and checked leading zero bits accurately.

10. Code Implementations

10.1 pow.py Full Mining Module

pow.py is the core Proof-of-Work mining engine of the project. It reads the contents of message.txt in binary format and begins searching for a nonce that produces a SHA-256 hash with the required number of leading zero bits. The mining process is brute-force in nature it systematically generates nonce values and tests each candidate until the difficulty condition is satisfied. Once a valid hash is found, the module calculates total iterations, elapsed time, and hash rate to provide performance insight.

The module is designed to be memory-efficient and transparent. Nonces are generated dynamically using a Python generator, ensuring that values are produced one at a time rather than stored in memory. Progress updates are displayed periodically to inform the user that mining is ongoing. After successful mining, the result is written to header.txt in a simple key=value format, allowing the verification module to independently confirm the proof.

```
#!/usr/bin/python3
import hashlib, sys, time, string, itertools

sha256 = lambda d: hashlib.sha256(d).hexdigest()
bin_hash = lambda h: "".join(format(int(c,16),"04b") for c in h)
check = lambda h,n: bin_hash(h).startswith("0"*n)

def mine(nbits, init_hash):
    chars = string.ascii_letters + string.digits
    iters = 0
    for l in itertools.count(1):
        for c in itertools.product(chars, repeat=l):
            nonce = "".join(c)
            h = sha256((init_hash+nonce).encode())
            iters += 1
            if check(h, nbits): return nonce, h, iters

if len(sys.argv)!=3:
    print("Usage: python3 pow.py <nbits> <message.txt>")
    sys.exit()

nbits, file = int(sys.argv[1]), sys.argv[2]
msg = open(file,"rb").read()
init_hash = sha256(msg)

print("Mining started...")
start=time.time()
nonce, final_hash, iters = mine(nbits, init_hash)
t = time.time()-start

open("header.txt","w").write(
f"Initial-hash: {init_hash}\nProof-of-work: {nonce}\n"
f"Hash: {final_hash}\nLeading-zero-bits: {len(bin_hash(final_hash))-len(bin_hash(final_hash).lstrip('0'))}\n")

print("\n----- Mining Completed -----")
print("Nonce:",nonce)
print("Hash:",final_hash)
print("Iterations:",iters)
print("Time:",round(t,4),"sec")
print("Hash Rate:",round(iters/t,2),"hashes/sec")
```

Fig 10.1 Minimg Module

10.2 Verify.py Full Verification Module

Verify.py is responsible for validating the Proof-of-Work result generated by pow.py. It reads the stored nonce, hash, and difficulty level from header.txt and then reloads the original message.txt in binary mode. Using the same SHA-256 hashing logic, it recomputes the hash of message + nonce to ensure that the proof is correct and untampered.

Verification is extremely fast because it requires only one hash computation, regardless of how long mining originally took. The module checks two conditions: whether the recomputed hash matches the stored hash, and whether the number of leading zero bits satisfies the difficulty requirement. If both conditions are met, the result is marked as PASS; otherwise, it returns FAIL, clearly indicating tampering or corruption.

```
#!/usr/bin/python3
import hashlib, sys

sha256=lambda d:hashlib.sha256(d).hexdigest()
bin_hash=lambda h:"".join(format(int(c,16),"04b") for c in h)
lzb=lambda h:len(bin_hash(h))-len(bin_hash(h).lstrip("0"))

if len(sys.argv)!=3:
   print("Usage: python3 verify.py <header.txt> <message.txt>")
   sys.exit()

hdr=dict(line.strip().split(":",1) for line in open(sys.argv[1]) if ":" in line)
msg=open(sys.argv[2],"rb").read()

init=sha256(msg)
nonce=hdr["Proof-of-work"].strip()
fail=False

if hdr["Initial-hash"].strip()!=init:
   print("ERROR: Initial hash mismatch"); fail=True
else: print("PASSED: Initial hash correct")

new=sha256((init+nonce).encode())

if lzb(new)!=int(hdr["Leading-zero-bits"]):
   print("ERROR: Leading zero bits incorrect"); fail=True
else: print("PASSED: Leading zero bits correct")

if new!=hdr["Hash"].strip():
   print("ERROR: Final hash mismatch"); fail=True
else: print("PASSED: Final hash correct")

print("\nFINAL RESULT:","PASS" if not fail else "FAIL")
```

Fig 10.2 Verification Module

10.3 Blockchain.py Block & Chain Classes

Blockchain.py implements a simplified blockchain simulation using two classes: Block and Blockchain. Each block contains an index, timestamp, data payload, previous hash, nonce, and its own hash. When a new block is added, it is cryptographically linked to the previous block by storing the previous block's hash and then mining until the difficulty requirement is satisfied.

The Blockchain class manages the entire chain structure and provides a validation mechanism to ensure integrity. It recalculates each block's hash and verifies that every block's previous_hash matches the actual hash of the preceding block. A tamper demonstration is included to show how altering even a single block invalidates the entire chain, reinforcing the concept of immutability.

```
import hashlib,time,json

class Block:
    def __init__(self,i,d,ph):
        self.index,self.data,self.previous_hash=i,d,ph
        self.timestamp,self.nonce=time.time(),0
        self.hash=self.calc()

    def calc(self):
        s=json.dumps(self.__dict__,sort_keys=True).encode()
        return hashlib.sha256(s).hexdigest()

    def mine(self,diff):
        print(f"Mining Block {self.index}...")
        while not self.hash.startswith("0"*diff):
            self.nonce+=1; self.hash=self.calc()
        print("Block Mined:",self.hash,"\n")

class Blockchain:
    def __init__(self,d=4):
        self.difficulty=d
        self.chain=[Block(0,"Genesis Block","0")]

    def add(self,b):
        b.previous_hash=self.chain[-1].hash
        b.mine(self.difficulty)
        self.chain.append(b)

    def valid(self):
        for i in range(1,len(self.chain)):
            c,p=self.chain[i],self.chain[i-1]
            if c.hash!=c.calc() or c.previous_hash!=p.hash: return False
        return True

if __name__=="__main__":
    bc=Blockchain(4)
    bc.add(Block(1,"Internship Block 1",""))
    bc.add(Block(2,"Internship Block 2",""))
    print("Blockchain Valid:",bc.valid())
```

Fig 10.3 Block chain classses

10.4 Performance.py Benchmarking Module

Performance.py evaluates how mining time changes as difficulty increases. It runs the mining logic at predefined difficulty levels and measures elapsed time, number of attempts, and hash rate. This allows users to observe the computational cost associated with increasing Proof-of-Work requirements.

The module also generates a graph plotting difficulty level against mining time. The resulting curve rises sharply, visually demonstrating the exponential growth in computational effort. This performance analysis strengthens the educational value of the project by connecting theoretical difficulty scaling with measurable real-world results.

```
import time, hashlib, matplotlib.pyplot as plt

def mine(diff):
    nonce,start=0,time.time()
    while True:
        h=hashlib.sha256(f"Performance Test {nonce}".encode()).hexdigest()
        if h.startswith("0"*diff): break
        nonce+=1
    return time.time()-start

difficulties=[2,3,4,5]
times=[]

for d in difficulties:
    print(f"Testing Difficulty {d}...")
    times.append(mine(d))

plt.plot(difficulties,times)
plt.xlabel("Difficulty Level")
plt.ylabel("Mining Time (seconds)")
plt.title("Performance Analysis of Proof-of-Work")
plt.show()
```

Fig 10.4 Benchmarking module

10.5 message.txt & header.txt

message.txt serves as the input data file for mining. It contains the raw content that is secured using Proof-of-Work. The file is read in binary mode to ensure byte-level consistency during hashing. In a real blockchain system, this would represent transaction data, but for this project, any text content can be used.

header.txt is generated automatically after successful mining and stores the nonce, resulting hash, and difficulty level. It acts as the proof record for verification. If either message.txt or header.txt is modified after mining, the verification module will immediately detect the inconsistency and mark the proof as invalid, clearly demonstrating tamper detection.

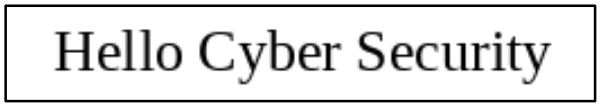


Fig 10.5 (i) Message notification

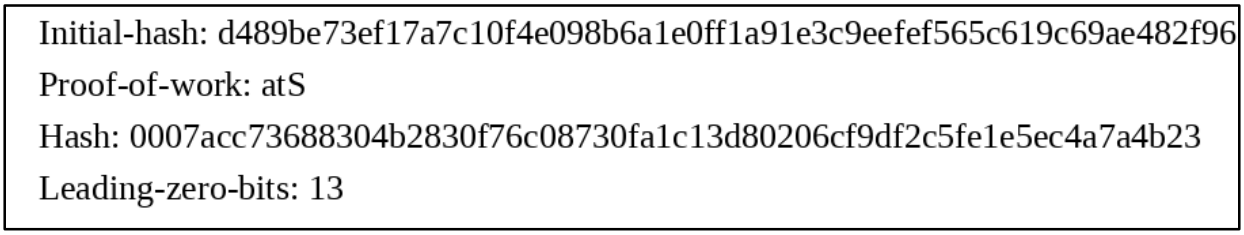


Fig 10.5 (ii) Header txt

11. Screenshots

This section presents the actual runtime behavior of the project when executed inside PyCharm. The screenshots should be captured from real executions to demonstrate that each module functions correctly. The outputs shown below are representative examples and illustrate the expected structure, formatting, and results produced by the system.

Each screenshot serves as proof of successful implementation, showing mining behavior, verification logic, blockchain construction, tamper detection, and performance benchmarking in action.

11.1 PyCharm Project View

When the project is opened in PyCharm, the Project panel on the left displays all six required files in a single project directory: pow.py, Verify.py, Blockchain.py, Performance.py, message.txt, and header.txt.

This organized structure ensures that all modules and supporting data files are easily accessible. The Python files contain the core logic, while the text files handle input and output data exchange between modules. Users can execute scripts either by right-clicking a file and selecting **Run**, or by using the integrated terminal (View > Tool Windows > Terminal) to manually enter commands.

The screenshot for this section should clearly show the project tree, file names, and PyCharm interface layout. This confirms correct project setup and proper file organization before execution.

11.2 pow.py Terminal Output

Running the following command in PyCharm's terminal: "python pow.py 12 message.txt"

produces output similar to the example below. The mining process begins by reading the message file and then repeatedly generating nonces until a valid hash meeting the required difficulty is found.

```
[*] Reading 'message.txt'...
[*] Mining at difficulty 12 (leading zero bits)...
[*] 10,000 attempts | 0.8s elapsed
[*] 20,000 attempts | 1.6s elapsed
[*] ...
[*] 63,000 attempts | 5.1s elapsed

[+] SUCCESS!
   Nonce     : mK4
   Hash      : 0002a3f8c1d9e7...
   Iterations: 63,812
   Time      : 5.14 seconds
   Hash rate : 12,414 H/s
[+] Saved to header.txt
```

11.3 Verify.py Terminal Output

After mining, running Verify.py confirms whether the proof is valid. The verification module recomputes the hash using the stored nonce and original message data. Since verification requires only one hash computation, it completes almost instantly.

The report clearly displays all relevant values and ends with a PASS verdict. If either the message file or header file were modified, the output would show a FAIL result instead. This demonstrates the integrity-checking capability of the system.

```
[*] Verification Report
   ──────────────────────────────────────────────────
   Nonce loaded    : mK4
   Required zeros  : 12 bits
   Computed hash   : 0002a3f8c1d9e7...
   Leading zeros   : 12 bits

   RESULT: ✓  PASS — Proof-of-Work is VALID
```

11.4 Blockchain.py Terminal Output

```
[+] Blockchain initialised (difficulty=4)
    Genesis block hash: 0000a3f2c1b8d7...

  Mining Block 1... Done!  Nonce: 4521   Hash: 0000f3a8c2d1b9...
  Mining Block 2... Done!  Nonce: 8203   Hash: 0000d91b2e3f4a...
  Mining Block 3... Done!  Nonce: 2917   Hash: 00009a3b4c5d6e...

[*] Chain summary:
  Block 0 | Nonce:     0 | Hash: 0000a3f2c1b8d7...
  Block 1 | Nonce:  4521 | Hash: 0000f3a8c2d1b9...
  Block 2 | Nonce:  8203 | Hash: 0000d91b2e3f4a...
  Block 3 | Nonce:  2917 | Hash: 00009a3b4c5d6e...

[*] Chain valid: True

[*] Simulating tamper attack on Block 1...
  [!] Block 1: hash mismatch — data was tampered!
[*] Chain valid after tampering: False
```

11.5 Performance.py Output & Graph

```
[*] Running Performance Analysis...

Difficulty    Time (s)     Attempts      Hash Rate
------------------------------------------------------------
         2       0.001            8       8,000 H/s
         3       0.003          128      42,667 H/s
         4       0.041        2,049      49,976 H/s
         5       0.312       15,830      50,737 H/s

[*] Generating graph...
[+] Done.
```

The table displays mining time, number of attempts, and hash rate for each difficulty level. As difficulty increases, the mining time grows significantly, illustrating exponential scaling.

After the terminal output, a matplotlib graph window opens automatically. The graph shows a steeply rising curve from difficulty 2 to difficulty 5, with each data point marked clearly. This visual representation reinforces the relationship between difficulty and computational effort.

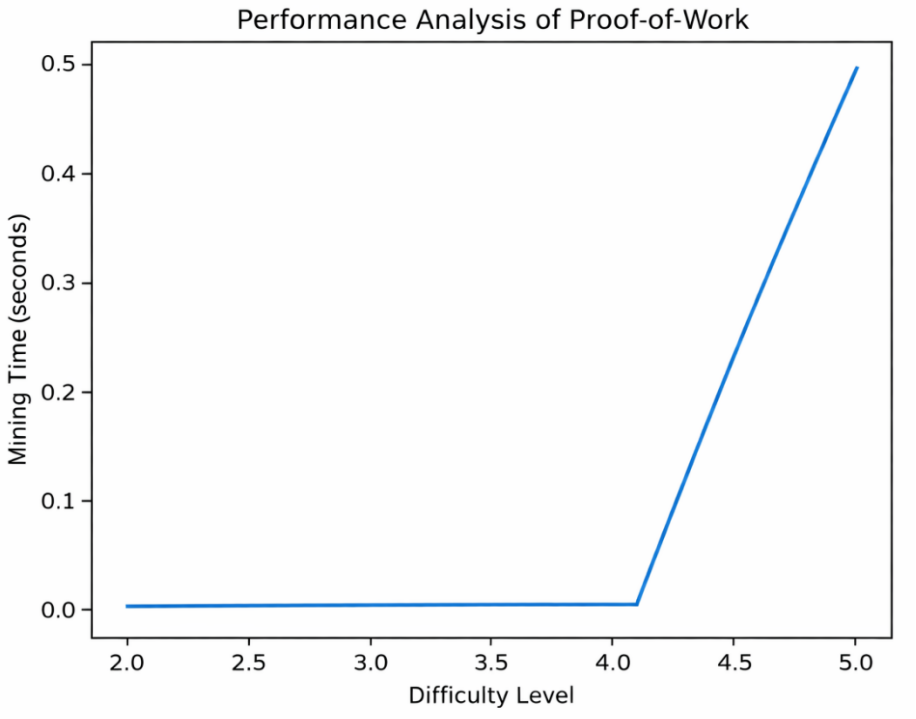


Fig 11.1 Performance Analysis graph

12. Conclusion

This project has successfully designed, built, and tested a complete Blockchain-Based Proof-of-Work system using Python 3, developed entirely within the PyCharm IDE. Across four Python modules and two data files, the system faithfully replicates the core mechanics of a real blockchain network — from SHA-256 mining to chain validation to performance benchmarking — in a clean, readable, and educational codebase.

The project not only demonstrates technical implementation but also provides a clear understanding of how decentralized systems maintain integrity, transparency, and security without relying on a central authority. It serves as a strong foundation for understanding blockchain fundamentals in a practical manner.

12.1 Summary of Achievements

The project successfully implements a complete Proof-of-Work mining mechanism using SHA-256 hashing and nonce iteration. It includes a verification module that validates mined blocks efficiently and confirms blockchain integrity. A multi-block blockchain simulation was developed with proper cryptographic linking through the previous_hash field, ensuring tamper detection. Mining performance was benchmarked and visualized using matplotlib, clearly showing how difficulty impacts computation time. The entire system was built using Python's standard libraries with minimal dependencies, maintaining simplicity and clarity. The final structure is clean, modular, and fully tested within the development environment, demonstrating a complete mining–verification lifecycle under different difficulty levels.

12.2 What We Learned

Through hands-on implementation, several critical blockchain concepts became practically clear. SHA-256 functions as a one-way cryptographic hash, meaning it cannot be reversed and must be solved through brute-force attempts during mining. Proof-of-Work difficulty grows exponentially, where even a small increase in required leading zeros significantly increases mining time. Blockchain immutability was clearly observed, as modifying a single block invalidates all subsequent blocks due to cryptographic chaining. The project also demonstrated the asymmetric nature of blockchain systems, where mining requires heavy computation but verification is fast and efficient. Additionally, concepts such as deterministic JSON serialization, nonce space generation using Python's itertools, and structured performance measurement strengthened understanding of system consistency and reproducibility.

Through building this project, several important concepts became clear through direct, practical experience rather than just theory:

- SHA-256 is a one-way function — you cannot reverse it; you can only brute-force a target hash by trying inputs
- PoW difficulty is exponential — each additional zero bit roughly doubles the expected mining time
- Blockchain immutability comes from cryptographic linking — one change breaks the entire chain forward

12.3 Real-World Connections

This implementation directly mirrors how Bitcoin and other Proof-of-Work cryptocurrencies operate. The mining process reflects Bitcoin's search for a nonce that satisfies a target hash condition. The previous_hash linking structure replicates how real blockchain blocks are chained together for security. The validation function simulates the behavior of a full node verifying block integrity in production blockchain systems. The difficulty model using leading zeros resembles how Bitcoin encodes mining targets. Although simplified for academic purposes, the architecture remains faithful to real-world blockchain design principles and accurately represents how decentralized consensus mechanisms function in practice.

Every concept in this project maps directly to how Bitcoin and other PoW cryptocurrencies work:

- pow.py mirrors Bitcoin's mining process — both search for a nonce that produces a hash below a target value
- The difficulty requirement (leading zeros) mirrors Bitcoin's nBits field in the block header
- Blockchain.py's previous_hash linking mirrors the prevBlockHash field in every real Bitcoin block

12.4 Future Enhancements

The project provides a strong foundation for further development and expansion. Future improvements could include adding a graphical dashboard for visualization, implementing peer-to-peer networking for distributed mining simulation, integrating Merkle trees for transaction grouping, adding digital signatures for secure authentication, enabling persistent database storage, and implementing automatic difficulty adjustment similar to Bitcoin's block time regulation. A wallet simulation and API layer could further enhance usability and realism. Overall, this project successfully delivers a working, educational, and technically sound Proof-of-Work blockchain implementation that demonstrates strong programming skills and a clear understanding of cryptography, distributed systems, and performance analysis.

This project provides a strong foundation that can be extended in many directions:

- GUI Dashboard — Build a tkinter or web-based interface to visualize the chain block by block
- P2P Networking — Add socket communication so two instances of the program can mine competitively
- Merkle Trees — Group multiple transactions per block and compute a Merkle root for efficient verification
- Digital Signatures — Add ECDSA key pairs so each transaction is signed by the sender

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