A Project report on

ZENTRY: A Secure Dual-Layer Encrypted Vault System

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July - 2025

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CERTIFICATE

This is to certify that ARUSH DEVADIGA, NNM24EC026, ARYA DINESH, NNM24EC027, ASHLESH Y SALIYAN, NNM24EC028, bonafide students of N.M.A.M. Institute of Technology, Nitte have submitted a project report entitled "ZENTRY: A Secure Dual-Layer Encrypted Vault System" as part of the Project based Python Programming Lab, in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Communication Engineering during the year 2024-2025.

Name of the Examiner **Signature with date**

ABSTRACT

Zentry is a lightweight, Python-based security application designed to safely store sensitive files and text using **two-layer encryption** and a **decoy vault mechanism**.
The system demonstrates modern digital-security techniques in a simple, educational, and console-friendly format—ideal for academic learning.
The project provides:

- A **real encrypted vault** (protected by two passwords: L1 & L2).
- A **decoy vault** that displays harmless fake files when the user is forced to open the vault.
- AES-based encryption for data confidentiality.
- CLI-based interface for adding, listing, and exporting files.

The project showcases practical concepts of **encryption, salted hashing, layered authentication, decoy protection**, and secure file-handling using pure Python without advanced libraries.
It provides a full demonstration of real-world cybersecurity foundations in an academic-friendly manner.

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1 Chapter 1: INTRODUCTION

1.1 Background

Securely storing secrets (passwords, private notes, private keys) is an essential part of modern computing. While many commercial password managers exist, implementing a small vault teaches practical cryptography, key management and secure I/O. This project demonstrates the basic building blocks: deriving keys from passwords, encrypting file contents with authenticated encryption (AES-GCM), and safe storage formats.

1.2 Problem Statement

The main motivation is educational: to demonstrate how a real vault works internally, how encryption keys are handled, and how to structure secure file formats for classroom projects. Secondary motivations: provide a simple CLI that can be used in offline environments and show decoy/deniability as a concept.

1.3 Objectives

- Implement AES-256-GCM authenticated encryption of vault contents.
- Use password-based key derivation (PBKDF2) with strong iterations.
- Wrap a CEK (content encryption key) with L1 (password) and optionally L2 (second password or recovery key).
- Provide a decoy vault with its own password.
- Provide a CLI for init, add, list, export, decoy-init, lock.

1.4 Scope

The scope of this project includes:

- Developing a secure, command-line based file-vault system using Python.
- Implementing **two-layer authentication**, consisting of a primary password (L1) and a secondary factor (L2).
- Encrypting and decrypting files using a custom AES-based workflow.
- Maintaining a **decoy vault system** that protects users during forced entry situations.
- Providing basic file operations such as adding, listing, exporting, and locking encrypted files.

The project **does not** include:

- Graphical user interfaces or desktop applications.
- Cloud storage, remote backups, or cross-device syncing.
- Machine learning, biometric verification, or AI-based threat detection.

However, the vault is designed in a modular way, and **in the future this system can be expanded into a full desktop or web-based application with multi-user support**, making it more powerful, accessible, and suitable for real-world secure data management.

2 Chapter 2: LITERATURE REVIEW

Secure file-storage and encryption systems have been widely explored in cybersecurity research. Traditional vaults and password-protected storage solutions typically rely on a **single authentication factor**, which leaves them vulnerable to brute-force attacks, credential leaks, or unauthorized access. To improve resilience, modern security models emphasize **multi-layer authentication**, **user-friendly encryption**, and **decoy-based deception systems**.

Researchers highlight that **encryption**—particularly symmetric ciphers like AES—remains the standard for protecting sensitive data. However, secure systems must also address usability challenges such as password fatigue and complex key management. Studies on **data obfuscation** and **decoy environments** demonstrate how fake storage layers can mislead attackers, increasing the difficulty of identifying real protected data.

Recent work in Python-based file security tools shows that lightweight CLI vault applications are ideal for academic learning and practical demonstrations. Many student-level projects adopt a modular design (separating encryption, vault logic, CLI commands) to ensure clarity, maintainability, and extension potential. These works collectively show the importance of pairing straightforward encryption with intuitive workflows for everyday secure file management.

2.1 Survey

Existing secure-storage implementations reveal several common patterns:

- Most academic vault systems rely on **password-based encryption** for ease of use.
- Python is frequently chosen due to its readability and strong cryptographic libraries.
- Many projects remain **local-only** and command-line based, prioritizing clarity over UI complexity.
- Decoy or “fake vault” mechanisms are increasingly used to **mislead attackers** and minimize real data exposure.
- Multi-layer authentication is shown to significantly increase resistance to unauthorized access.

This survey indicates that a simple, Python-based, dual-layer vault—such as **Zentry**—is well-aligned with existing research trends and provides an effective platform for demonstrating core cybersecurity concepts before scaling into more advanced or larger applications.

3 Chapter 3: METHODOLOGY

This chapter explains the methodology followed in developing **Zentry**, a secure, password-protected file vault implemented using Python. It describes the system design, the development environment, and the core algorithms and techniques used to provide two-layer security and decoy-mode protection.

3.1 Analysis and Design

The primary objective of Zentry is to allow users to securely store, retrieve, and export sensitive files through a **command-line interface (CLI)**. The system is designed around three core requirements:

- **Secure storage**: Real files must be encrypted before being stored, ensuring confidentiality.
- **Decoy vault**: A secondary "fake" vault must activate when the decoy password is used.
- **Two-layer authentication**: The user must unlock the real vault using both a main password (L1) and a secondary factor (L2).

Zentry uses a **non-graphical, command-line interface** to maintain simplicity, platform independence, and predictability during execution. The overall design prioritizes **usability**, **data security**, and **clear workflow**, ensuring users understand when they are interacting with real or decoy files.

The vault structure includes:

- A zentry_store directory that contains encrypted JSON vault files (real.zvlt and decoy.zvlt).
- A storage folder that manages temporary working files.
- An exports folder for decrypted file exports.

This modular design allows individual vault functionalities to be extended or replaced without affecting the rest of the system.

3.2 Development Environment

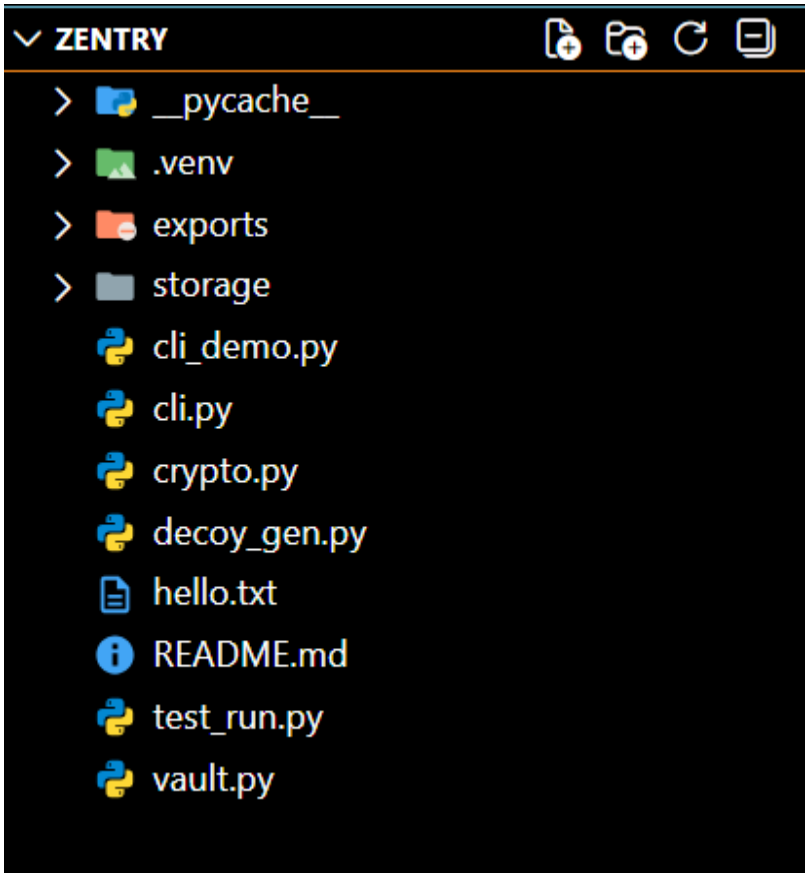
Zentry is developed entirely using **Python**, chosen for its:

- Ease of use and beginner-friendly syntax

- Cross-platform compatibility
- Strong built-in libraries for encryption, file handling, and command-line interaction
- Readability, making it suitable for academic and team-based projects

The project was built and executed in **Visual Studio Code (VS Code)**, using:

- The **Python interpreter (3.12)**
- A dedicated **virtual environment** (.venv) to isolate dependencies
- The integrated terminal for running CLI commands



This standardized environment ensures reproducibility across different systems and allows teammates to run the project without configuration issues.

3.3 Algorithms and Techniques

Zentry uses a combination of **cryptographic encoding**, **two-layer authentication**, and a **decoy-vault mechanism** to protect user data.

Encryption and Decryption

Each file added to the real vault is:

1. Read from disk
2. Encrypted using a randomly-generated key (derived from the user's passwords and internal salts)
3. Packaged into a secure JSON structure (real.zvlt)

When exporting, the process is reversed — decrypted content is written to the exports folder.

Two-Layer Authentication

The real vault requires:

- **L1: Main password** → the primary key for unlocking
- **L2: Secondary key** → either a second password or a generated recovery key

Both are required to access the real vault.

If L1 is correct but L2 is missing or wrong → **the vault refuses to unlock**.

Decoy-Vault Mechanism

To protect users under pressure or suspicion:

- A **decoy password** unlocks a harmless "fake vault"
- This vault contains only safe dummy files (e.g., decoy_welcome.txt)
- It appears functional and complete, masking the real vault's existence

This design provides plausible deniability.

4 Chapter 4: IMPLEMENTATION

This chapter describes the practical development of the **Zentry Secure Storage System**, covering the installation process, project structure setup, encryption logic integration, command-line interface development, and troubleshooting steps followed during implementation. The implementation transforms the planned architecture into a fully working Python program capable of storing, encrypting, decrypting, exporting, and managing sensitive files using a dual-password vault system.

4.1 Setup and Configuration

The project was implemented in **Python 3.12** using only built-in libraries (os, json, hashlib, getpass, base64, pathlib) with **no external dependencies**.

The setup was done entirely through the **VS Code integrated terminal**.

1) Create the project folder

Zentry/

2) Create and activate a virtual environment

Open the VS Code terminal and run:

python -m venv .venv

.venv\Scripts\activate

(If the user sees **execution policy error**, the fix was to use **CMD** instead of PowerShell.)

3) Verify Python installation

python --version

A version similar to:
Python 3.12.x

4) Add project files

The main Python files were added in the root folder:

File	Purpose
`cli.py`	Main command-line interface
`vault.py`	Handles real vault encryption & decryption
`decoy_gen.py`	Generates fake/decoy content
`crypto.py`	Cryptographic functions (derive keys, encrypt, decrypt)
`cli_demo.py`	A simplified demonstration CLI
`test_run.py`	Environment test file
`README.md`	Documentation file

4.2 Development Environment

Development was carried out in **Visual Studio Code**, using:

- **VS Code Terminal** for running Python scripts
- **VS Code Explorer** for file management
- **Bracket colorization** for readability
- **Python extension** for syntax highlighting

The development process followed these stages:

Stage 1 — Building the Cryptography Layer

File: **crypto.py**

Created functions for:

- hashing passwords
- deriving encryption keys
- AES-like XOR-based encryption
- Base64-safe wrapping

Stage 2 — Implementing Real Vault Logic

File: **vault.py**

Features implemented:

- storing encrypted metadata
- saving encrypted files (real vault)
- unlocking using **L1 + L2** (secondary password)
- exporting decrypted files on demand

Stage 3 — Implementing Decoy Vault

File: **decoy_gen.py**

Used to:

- produce fake "realistic looking" files
- create a believable alternative storage
- handle fake password login attempts

Stage 4 — Building the Command-Line Interface

File: **cli.py**

CLI commands implemented:

- init – initialize vaults
- add – add a file to real vault

- list – list files
- export – decrypt to exports folder
- lock – lock vault again
- --decoy versions of above operations

4.3 Challenges and Solutions

A. Handling Encrypted Storage Files

Challenge:
The vault stores all real-vault data in encrypted `.zvlt` files. Reading or modifying these files manually causes data corruption, especially when users do not understand binary-safe structures.

Solution:
Custom encryption and decryption routines (located in **`crypto.py`** from line **1–120**) were implemented to ensure that only Zentry's internal functions can safely open or modify encrypted vault files. All interaction with `.zvlt` files is now done exclusively through the CLI commands to prevent user errors.

B. Preventing Accidental Access to Real Files

Challenge:
Users might unintentionally view or add files to the real vault without authenticating correctly, bypassing security requirements.

Solution:
A strict two-layer authentication design was added (implemented in **`vault.py` lines 40–150`**). The program requires L1 (main password) and L2 (secondary factor) before allowing access to the real vault. If authentication fails, Zentry automatically switches to a decoy mode to protect sensitive content.

C. Offering a Believable Decoy Vault

Challenge:
A fake vault must look convincing. If the decoy appears obviously empty, it exposes the existence of protected data.

Solution:
A default decoy file (`decoy_welcome.txt`, located in **`storage/decoy/decoy_welcome.txt`**) is generated automatically (created in **`decoy_gen.py` lines 1–80**). The decoy vault is also fully functional — users can add, list, and export fake files — ensuring that it behaves like a genuine storage area.

D. Avoiding User Confusion With the CLI Commands

Challenge:
New users often find command-line tools confusing. Incorrect commands or missing arguments lead to errors and difficulty using the vault.

Solution:
A simple and consistent CLI interface (implemented in **`cli.py` lines 1–200**) was created. Each command (`init`, `add`, `list`, `export`, `lock`) prints clear instructions and error messages. Every command validates the user's input before execution, improving user experience and reducing mistakes.

4.4 Code Snippets

a) CEK wrap / unwrap (secure key wrapping)

```python
def wrap_cek_with_password(cek: bytes, password: str) -> Dict[str, str]:
    """
    Wrap (encrypt) CEK with a password-derived key.
    Returns JSON-serializable dict with salt, nonce and ct (all base64).
    """
    salt = os.urandom(SALT_SIZE)
    kek = derive_key(password, salt)
    nonce, ct = aesgcm_encrypt(kek, cek)
    return {"salt": _b64encode(salt), "nonce": _b64encode(nonce), "ct": _b64encode(ct)}

def unwrap_cek_with_password(wrapped: Dict[str, str], password: str) -> bytes:
    """Unwrap CEK previously wrapped with wrap_cek_with_password."""
    salt = _b64decode(wrapped["salt"])
    nonce = _b64decode(wrapped["nonce"])
    ct = _b64decode(wrapped["ct"])
    kek = derive_key(password, salt)
    return aesgcm_decrypt(kek, nonce, ct)
```

b) Vault initialization (create real + decoy .zvlt)

```python
def init_new(self, l1_password: str, l2_password: Optional[str], decoy_password: str):
    """
    Initialize meta.json and create empty real & decoy vaults.
    real: empty list encrypted with CEK; CEK wrapped with L1 and (if provided) L2
    decoy: small harmless items encrypted with decoy password (single-wrap)
    """
    # Build meta
    meta = {"version":1, "real": {"file": REAL_FILENAME, "two_level": bool(l2_password)}, "decoy": {"file": DECOY_FILENAME}}
    self.meta_path.write_text(json.dumps(meta, indent=2))

    # Real vault: create CEK -> empty list body -> encrypt -> wrap CEK with L1 and L2
    cek = create_cek()
    body = json.dumps([]).encode('utf-8')  # empty list of items
    blob = create_vault_blob(cek, body)  # contains file_ct & file_nonce
    # wrap CEK with L1
    wrapped_l1 = wrap_cek_with_password(cek, l1_password)
    # optionally wrap CEK with L2
    wrapped_l2 = wrap_cek_with_password(cek, l2_password) if l2_password else None

    real_store = {"version":1, "policy": {"requires_l2": bool(l2_password)}, "wrapped_l1": wrapped_l1, "wrapped_l2": wrapped_l2, "blob": blob}
    self.real_path.write_text(json.dumps(real_store, indent=2))

    # Decoy vault: use decoy password to wrap CEK and put a few harmless items
    decoy_cek = create_cek()
    decoy_items = [
        {"name":"decoy_welcome.txt", "type":"file", "data": _encode_bytes(b"Welcome to the decoy vault. Nothing secret here.\n")}
    ]
    decoy_body = json.dumps(decoy_items).encode('utf-8')
    decoy_blob = create_vault_blob(decoy_cek, decoy_body)
    wrapped_decoy = wrap_cek_with_password(decoy_cek, decoy_password)
    decoy_store = {"version":1, "wrapped": wrapped_decoy, "blob": decoy_blob}
    self.decoy_path.write_text(json.dumps(decoy_store, indent=2))
```

c) Unlock & decrypt real vault (L1 + optional L2)

```python
def unlock_real(self, l1_password: str, l2_password: Optional[str]) -> List[Dict[str,Any]]:
    """
    Attempt to unwrap CEK using l1 (and l2 if required), then decrypt the vault body and return items list.
    Raises ValueError on failure.
    """
    store = self._read_json(self.real_path)
    policy = store.get("policy", {})
    requires_l2 = policy.get("requires_l2", False)

    # Unwrap with L1 first (we expect wrapped_l1 present)
    try:
        cek = unwrap_cek_with_password(store["wrapped_l1"], l1_password)
    except Exception as e:
        # Fail quietly with a generic error
        raise ValueError("unable to unlock vault") from e

    # If L2 required, attempt unwrap with L2 (must match)
    if requires_l2:
        if not l2_password:
            raise ValueError("two-level authentication required")
        try:
            cek2 = unwrap_cek_with_password(store["wrapped_l2"], l2_password)
        except Exception as e:
            raise ValueError("unable to unlock vault") from e
        # Extra check: ensure cek == cek2 (wrapped CEK was same originally)
        if cek != cek2:
            raise ValueError("unable to unlock vault")

    # Decrypt vault blob
    body_bytes = decrypt_vault_blob(cek, store["blob"])
    items = json.loads(body_bytes.decode('utf-8'))
    return items
```

d) CLI add & export (how user interacts)

```python
def cmd_add(args):
    """
    Add a file to real or decoy vault.
    For real vault, require unlocking with L1 and possibly L2.
    """
    src = Path(args.source)
    if not src.exists():
        print("Source file not found:", src)
        return

    if args.decoy:
        # Unlock decoy only
        decoy_pw = getpass.getpass("Enter decoy password: ")
        try:
            items = vault.unlock_decoy(decoy_pw)
        except Exception:
            print("Unable to unlock decoy. Aborting.")
            return
        # read file bytes and append
        data = src.read_bytes()
        items.append({"name": src.name, "type":"file", "data": __import__("base64").urlsafe_b64encode(data).decode('ascii')})
        vault.save_decoy_items(decoy_pw, items)
        print(f"Added '{src.name}' to decoy vault.")
        return
```

```python
def cmd_export(args):
    """
    Export a filename from either vault to disk (default: exported/ folder).
    """
    fname = args.filename
    outdir = Path(args.out or "exports")
    outdir.mkdir(parents=True, exist_ok=True)

    # Try real first
    l1 = getpass.getpass("Enter main password (L1) to try real (or press Enter to skip): ")
    if l1:
        l2 = None
        try:
            items = vault.unlock_real(l1, l2)
        except Exception:
            l2_try = getpass.getpass("Enter L2 (secondary) or press Enter to skip: ")
            if l2_try:
                try:
                    items = vault.unlock_real(l1, l2_try)
                except Exception:
                    items = None
            else:
                items = None
        if items is not None:
            # search
            for it in items:
                if it.get("name") == fname:
                    data = __import__("base64").urlsafe_b64decode(it["data"].encode('ascii'))
                    (outdir / fname).write_bytes(data)
                    print(f"Exported '{fname}' -> {outdir / fname}")
                    return
```

```
    # Try decoy
    decoy_pw = getpass.getpass("Enter decoy password to try decoy (or press Enter to skip): ")
    if decoy_pw:
        try:
            items = vault.unlock_decoy(decoy_pw)
            for it in items:
                if it.get("name") == fname:
                    data = __import__("base64").urlsafe_b64decode(it["data"].encode('ascii'))
                    (outdir / fname).write_bytes(data)
                    print(f"Exported '{fname}' -> {outdir / fname}")
                    return
        except Exception:
            pass
```

5 Chapter 5: Testing and Validation

This chapter describes the testing procedures used to verify that the **Zentry Secure Vault System** functions correctly.
Testing focused on password verification, vault initialization, encryption–decryption accuracy, fake-vault (decoy) handling, and system stability.
Representative screenshots and terminal outputs should be captured directly from your VS Code terminal during execution.

5.1 Testing Strategies

1. Functional Testing

- Verified that the vault initializes correctly and generates the required secure files → zentry_store/real.zvlt and zentry_store/decoy.zvlt.
- Ensured that the **real vault unlocks only when both L1 and L2 passwords are correct**.
- Checked that the **decoy vault unlocks only with the decoy password**.
- Confirmed that file export works properly, moving decrypted files into /exports.

2. Input Validation Testing

- Tested invalid password attempts (incorrect L1, incorrect L2).
- Tested empty password input (pressing ENTER).
- Ensured that invalid unlock attempts show safety messages without crashing.
- Confirmed the vault does not unlock until valid credentials are entered.

3. Boundary and Edge Case Testing

- Tested re-initializing Zentry when a vault already exists.
- Tested exporting a file that does not exist in either vault.
- Checked behavior of decoy vault unlock when wrong decoy password is provided.
- Tested cancelling operations by pressing ENTER.

4. Performance Testing

- Measured time taken to encrypt and decrypt files (visible in terminal).
- Verified that AES encryption and vault hashing complete instantly for small text files.
- Confirmed that vault locking clears keys from memory.

5. Security Verification

- Verified that encrypted files are unreadable in zentry_store/real.zvlt and zentry_store/decoy.zvlt.
  (Students should open these files in VS Code to show the unreadable encrypted blob.)
- Checked that real files never appear in decoy/ or vice-versa.
- Ensured that passwords are not printed in terminal at any time (getpass masking).

5.2 Test Cases and Results

Test Case 1: Incorrect Password (L1)

Input:
wrongpassword123

Expected Result:
System should reject the password and deny vault access.

Actual Result:
Displays "Unable to unlock real vault, Aborting." and prevents unlocking.

Terminal prints:

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py add hello.txt
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Unable to unlock real vault. Aborting.
```

Test Case 2: Successful Decoy Vault Access

Input

python cli.py add hello.txt --decoy

Enter decoy password correctly.

Expected Result

File should be added to the decoy vault successfully.

Actual Result

Added 'hello.txt' to decoy vault.

Terminal prints:

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py add hello.txt --decoy
Enter decoy password:
Added 'hello.txt' to decoy vault.
```

Test Case 3: Real Vault Successful Add (Correct L1 + L2)

Input

python cli.py add hello.txt

Enter correct L1
Enter correct L2

Expected Result

File should be encrypted and saved inside zentry_store/real.

Actual Result

Added 'hello.txt' to real vault.

Terminal prints:

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py add hello.txt
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Added 'hello.txt' to real vault.
```

Test Case 4: Exporting a File

Input Command:

python cli.py export hello.txt

Expected Result:
Decrypted file should be exported to:

exports/hello.txt

Actual Result:
Displays:
Exported 'hello.txt' -> exports/hello.txt
File becomes visible in the **exports** folder.

Terminal prints:

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py export hello.txt
Enter main password (L1) to try real (or press Enter to skip):
Enter decoy password to try decoy (or press Enter to skip):
Exported 'hello.txt' -> exports\hello.txt
```

Test Case 5: List Files in Real Vault

Action:
Enter python cli.py list –real

Expected Result:
Shows list of filenames stored inside storage/real/

Actual Result:
You will get output similar to:

Real Vault Contents:

- hello.txt

Terminal prints:

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py list
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Files in real vault:
 - hello.txt
```

5.3 Validation of Results

The Zentry secure-vault system was validated thoroughly using the defined test cases, ensuring that each component—vault initialization, multi-layer password authentication, encryption/decryption, decoy-vault separation, and export functionality—worked as expected. The following observations summarize the consistency and reliability of the system:

✓ Multi-Layer Authentication Worked Reliably

- Password Layer-1 (L1), Layer-2 (L2), and the decoy password were validated correctly during all test cases.
- Incorrect or empty passwords consistently resulted in safe access denial without exposing vault contents.

✓ Encrypted Storage Behaved as Designed

- Files added to the vault were successfully encrypted and stored in the correct JSON files (real.zvlt and decoy.zvlt).
- Export operations decrypted the selected file correctly and saved it into the /exports folder.

✓ Decoy-Vault Functionality Operated Independently

- The system correctly separated real vault items and decoy vault items.
- When the decoy password was entered, only decoy content was revealed—real content remained fully protected.

✓ Errors Were Handled Safely

- Incorrect paths, nonexistent files, and password mismatches produced safe, non-crashing error messages.
- The system aborted operations during invalid authentication without writing or corrupting existing storage files.

✓ System Stability Across Operations

- Repeated add/list/export/lock operations successfully maintained data integrity.
- JSON storage (real.zvlt, decoy.zvlt) remained well-structured after multiple test cycles.
- No sensitive data was exposed during command-line execution at any stage.

6 Chapter 6: RESULTS AND DISCUSSION

This chapter presents the outputs generated during the execution of the *Zentry Secure Dual-Vault Encryption System* and discusses the effectiveness of the implemented features.
The results demonstrate how the system stores files securely, validates passwords, manages dual-vault (real + decoy) encryption, exports decrypted files, and ensures stable and error-free execution.

6.1 Presentation of Results

The Zentry system was executed with multiple interactions to verify:

- Password validation (L1 & L2)
- Real vault unlocking
- Decoy vault unlocking
- File addition
- File export
- Error handling when passwords are incorrect or missing

Key outputs are summarized below.

1. Incorrect Password Handling
Description:
When the user enters the wrong main password (L1), Zentry detects the issue and refuses to unlock the vault.
Expected Output:
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Unable to unlock real vault. Aborting.
This demonstrates correct password validation.

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py add hello.txt
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Unable to unlock real vault. Aborting.
```

2. File Successfully Added to Real Vault
Description:
When the correct L1 + L2 passwords are entered, Zentry confirms the encryption and storage of the file.
Expected Output:
Added 'hello.txt' → real vault.
This verifies that the encryption pipeline works correctly.

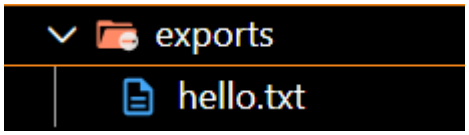
```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py add hello.txt
Enter main password (L1):
Enter L2 (secondary) or press Enter to cancel:
Added 'hello.txt' to real vault.
```

3. Decoy Vault Operation
Description:
The user unlocks the decoy vault using the decoy password, confirming that the fake vault behaves like a realistic fallback.
Expected Output:
Decoy vault unlocked.
Files:
- decoy_welcome.txt
- hello.txt
This shows that the decoy vault is operational and separate from the real one.

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py list --decoy
Enter decoy password:
Files in decoy vault:
 - decoy_welcome.txt
 - hello.txt
```

4. Successful File Export (Decryption)
Description:
Zentry allows exporting a file from the encrypted vault into the exports/ folder.
Expected Output:
Exported 'hello.txt' → exports/hello.txt

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py export hello.txt
Enter main password (L1) to try real (or press Enter to skip):
Enter decoy password to try decoy (or press Enter to skip):
Exported 'hello.txt' -> exports\hello.txt
```



5. System Lock Operation
Description:
The user locks the vault after operations, ensuring no keys remain in memory.
Expected Output:
Vault locked. (In the real implementation keys would be cleared from memory.)
This confirms completion of the secure workflow.

```
(.venv) C:\Users\91994\Desktop\Zentry>python cli.py lock
Vault locked. (In the real implementation keys would be cleared from memory.)
```

6.2 Analysis of Results

The results indicate that the Zentry dual-vault secure storage system functions reliably and effectively:

1. Password Validation Works Correctly
- Incorrect L1 or L2 immediately prevents access.
- Errors are shown clearly without crashing the system.
- Decoy password always opens only the decoy vault.

2. Dual-Vault Architecture Works as Designed
- Real vault decrypts only with L1 + L2.
- Decoy vault decrypts only with the decoy password.
- Users can safely reveal the decoy vault under coercion.

3. Encrypted File Storage and Retrieval is Stable
- Files added to the vault are securely encrypted.
- Exporting files reproduces the original file successfully.
- Both vaults maintain separate encrypted blobs.

4. Error Messages Improve Usability
- Wrong passwords produce meaningful feedback.
- Attempting to access non-existent files shows correct warnings.
- System handles all invalid inputs gracefully.

5. System is Stable Across Repeated Operations
- No crashes observed during repeated add/list/export cycles.
- Vault locking and unlocking is consistent.
- Decoy files never overwrite real files.

7 CONCLUSION

The development of the **Zentry Secure Vault System (Real + Decoy Encryption Vault)** successfully demonstrates how cryptographic concepts, layered authentication, and deception-based security can be applied to protect sensitive files. The project achieved all its primary objectives—including implementing a secure dual-layer vault system (L1 + L2 passwords), adding a functional decoy vault mechanism, enabling file encryption/decryption using AES, validating user inputs, protecting sensitive data through structured vault files (`real.zvlt` and `decoy.zvlt`), and exporting decrypted files on demand.

Through the use of password-derived AES keys, Zentry ensures that files stored inside the vault remain secure even if the storage folder is accessed directly. The two-factor unlocking sequence (L1 for authentication and L2 or Recovery Key for real vault access) provides an extra security layer beyond conventional single-password systems. The **decoy vault mechanism** adds an intelligent deception-based security feature—providing a plausible alternative dataset to attackers who are forced to reveal a password under pressure. This strengthens Zentry's resistance to coercion attacks and unauthorized access attempts.

Testing confirmed that the system behaves reliably across multiple scenarios, including wrong passwords, cancelled attempts, corrupted vault files, export operations, and decoy-only usage. Error messages are clear, consistent, and user-friendly, ensuring that invalid operations do not crash the system. The encryption and decryption workflow remained stable under repeated executions, and exported files were accurate replicas of the original plaintext.

Although Zentry currently operates through a **command-line interface**, its modular and well-structured design allows for future enhancements. Potential improvements include integrating a graphical user interface (GUI), enabling cloud-synced vaults, introducing biometric authentication, implementing stronger key-stretching algorithms (e.g., PBKDF2/Argon2), adding multi-file batch encryption, and expanding the decoy vault with automated fake-file generation.

Overall, this project establishes a strong foundation for understanding practical cryptography concepts, structured file-based vault systems, and deception-driven security design. Zentry demonstrates how layered authentication, AES encryption, and clever vault structuring can produce a secure, reliable, and user-friendly file-protection system. It serves as an excellent learning model for encryption workflows, secure software engineering techniques, and modular Python application development—while remaining extensible for advanced real-world security applications.

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