RECONSTRUCTIFY AI

PROJECT SUPERVISOR

Dr. Muhammad Atif Tahir

PROJECT TEAM

Azaan Nabi Khan K21-3208

Asad ullah Khan K21-4945

Muhammad Arif K21-3416

Submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science.

FAST SCHOOL OF COMPUTING
NATIONAL UNIVERSITY OF COMPUTER AND EMERGING SCIENCES KARACHI CAMPUS
May 2025

Project Supervisor	Dr. Muhammad Atif Tahir
Project Team	Azaan Nabi Khan K21-3208 Asad ullah Khan K21 4945 Muahmmad Arif K21-3416
Submission Date	May 15, 2025

Dr Muhammad Atif Tahir - **Supervisor**

Dr. Ghufran Ahmed - **Head of Department**

Acknowledgement:

All thanks to the supervisor Dr. Atif Tahir and the members of the project Azaan Nabi Khan, Asad ullah Khan, Muhammad Arif and people who cooperated in providing the data for the project. All the mentioned people have contributed to the project and helped us on this journey. Without their help this fyp would not have been completed.

Table of Contents:

Abstract:

Reconstructify AI is an application that tackles a key problem in forensic investigations: partial or unclear fingerprints found at crime scenes. These low-quality prints are often difficult to use for accurate identification. To solve this, we use Diffusion Models to reconstruct incomplete fingerprints. Once the reconstruction is done, our system matches the enhanced fingerprint against a database of known prints using a fast and reliable matching algorithm (ORB). This accelerates the process, supporting quicker and more accurate forensic investigations.

Introduction:

Our final year project focuses on solving a major problem in crime scene investigations: dealing with partial or poor-quality fingerprints. Often, fingerprints found at crime scenes are incomplete or not clear, making it difficult for forensic experts to analyze them properly. To address this, we've used advanced technology called diffusion models, which are a type of AI that can generate missing parts of an image. In our case, these models help complete partial fingerprints, making them more useful for matching and analysis.

Our project is a step-by-step process where the AI improves incomplete fingerprint images over time. It works by adding and then removing "noise" (randomness) in a controlled way, gradually filling in the missing details of the fingerprint. This makes the fingerprint clearer and more complete, which is crucial for accurate forensic analysis.

Our solution is designed to be practical and easy to integrate into the existing forensic workflow. It automates the traditionally slow and manual process of enhancing fingerprints, saving time for law enforcement agencies. This can speed up investigations and help solve cases more efficiently. We tested our model using both artificial and real fingerprint datasets, and the results showed that it can recover important details even from very low-quality fingerprints.

This project is a real-world example of how deep learning can be applied in forensic science. By improving the accuracy and speed of fingerprint analysis, our system can contribute to solving crimes faster, ensuring justice, and enhancing public safety. It's a small but meaningful step toward making forensic investigations more effective.

Literature Review:

The field of fingerprint analysis has undergone development over time, due to progress enhancing identification methods.This review of literature delves into facets of fingerprint restoration practices and the application of intelligence in forensic science as well as the obstacles encountered by law enforcement in Pakistan.

Analysis of Fingerprints Techniques:
In the past fingerprint identification methods mainly depended upon comparing fingerprint patterns with the help of experts who were trained for this task. However these methods tend to be ineffective when dealing with deteriorated prints that are frequently found at crime scenes. Recent research has emphasized the requirement for techniques that can effectively reconstruct incomplete fingerprint data. [1]

Generative AI Models in Forensics:
Ai models like Generative Adversarial Networks (GAN) Variational Autoencoders (VAEs) and Diffusion Models have displayed potential in the realm of image creation and reconstruction. For example Variational Autoencoders (VAEs) have been employed across areas to produce top notch images from lower resolution sources. When analyzing fingerprints, in forensic investigations these models can be adjusted to reconstruct sections of prints which improves the process of identification. [3]

Challenges in Forensic Fingerprint Analysis:
In Pakistan, the challenges faced by forensic teams are compounded by limited resources and outdated technologies. As per research findings numerous forensic labs in Pakistan are ill equipped and inadequately trained in handling fingerprint data forensics efficiently which leads to overreliance on conventional techniques that may fall short in meeting contemporary investigative demands. [2]

Deep Learning in Image Reconstruction:
Our method, for partial fingerprint analysis relies on a stage framework that integrates sophisticated deep learning methods with cutting edge generative AI models. This approach includes preparing fingerprint data before training AI models on fingerprint datasets and using them to fill in areas in partial prints for precise identification purposes. The system is crafted to manage degrees of fingerprint deterioration and function effectively in a range of settings, like those found in Pakistan. [4]

Ethical Considerations in AI Applications:
As we explore the use of AI in forensic science, it is important to address the ethical implications associated with these technologies. The potential for bias in AI algorithms and the importance of transparency in AI decision-making processes have been emphasized in recent literature.. Ensuring that our system adheres to ethical standards will be a key consideration in the development of our fingerprint regeneration technology. [5]

Methodology:

- **Data Collection & Preprocessing**
  Collected fingerprint datasets from various online sources and generated corresponding partial fingerprints. Preprocessed data for training by applying noise reduction and image enhancement techniques.

- **Model Training & Selection**
  Trained multiple AI models (GANs, VAEs, CNNs, Diffusion) and compared their reconstruction accuracy using MSE loss. The Diffusion Model performed best, especially at a learning rate of 0.001.

- **Fingerprint Matching**
  Implemented five algorithms: Template Search, Histogram Search, ORB Matching, SSIM, and SIFT. Evaluated each on runtime and accuracy. ORB Matching provided the best performance in large-scale testing (6000+ images).

- **Web Application Development**
  Built the frontend with Next.js and backend with FastAPI for model inference. Users upload a dataset and a partial fingerprint. The system reconstructs and matches it using the trained Diffusion Model and ORB. All data is stored in MongoDB.

System Diagram:

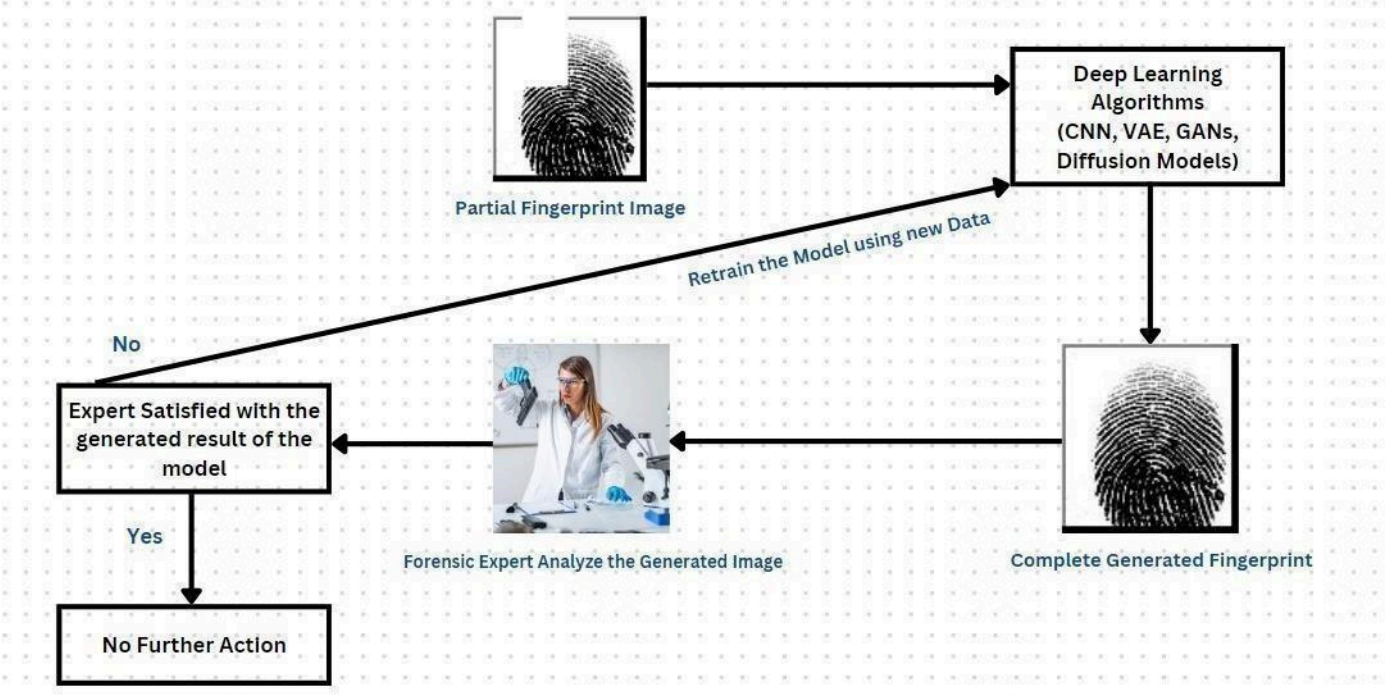
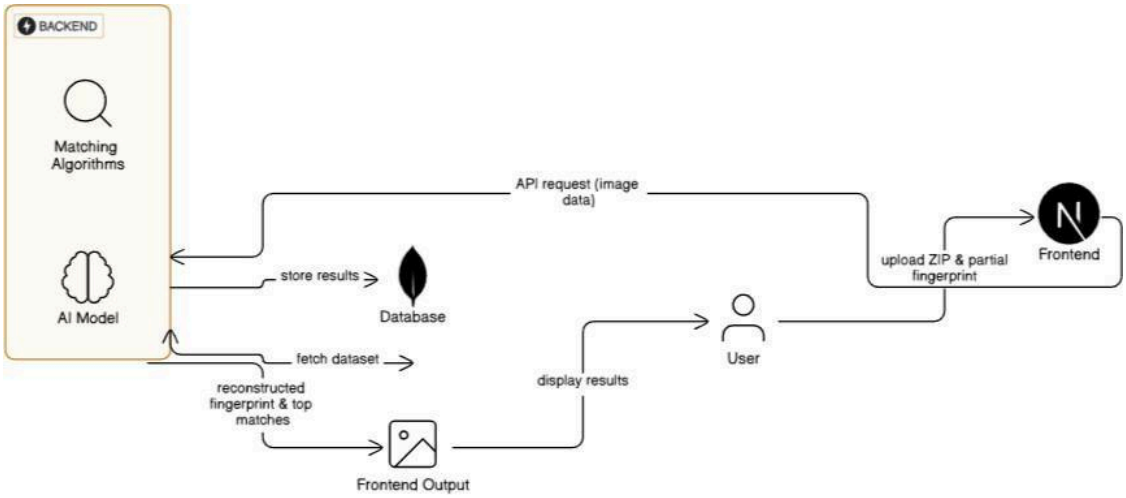


Figure 1: System Diagram

System Architecture:



Requirements:

Use Cases:

1. **UC1: Upload Fingerprint Database**

UC1: Upload Fingerprint Database		
Use case Id:	*Uc1*	
Actors: *User (Forensic Analyst, Investigator)*		
Feature: *Upload Fingerprint Dataset*		
Pre-condition:	*Dataset must be in a valid ZIP format*	
Scenarios: *User uploads a ZIP file containing full fingerprints to the system, which stores the images in the MongoDB database.*		
Step#	***Action***	***Software Reaction***
1.	*User opens the website*	*System displays homepage with upload option*
2.	*User clicks on "Upload Dataset"*	*File browser opens for file selection*
3.	*User selects a ZIP file*	*System checks file format and content*
4.	*User clicks "upload"*	*ZIP is extracted and images are validated*
5.	*System saves images to MongoDB*	*Upload success message is shown*
6.	*Admin clicks the "Register" button*	*User is created and added to the admin's organization*
Alternate Scenarios:		
1: *User uploads a file that is not in ZIP format* ***2:*** *ZIP file is empty or contains unsupported files* ***3:*** *MongoDB is not reachable at the time of upload*		
Post Conditions: *Complete fingerprint dataset is successfully stored in MongoDB and ready for reconstruction and matching.*		
Step#	***Description***	
Use Case Cross referenced	-	

2. **Upload Partial Fingerprint**

UC2: Upload Partial Fingerprint		
Use case Id:	*Uc2*	
Actors: *User (Forensic Analyst, Investigator)*		
Feature: *Upload Partial Fingerprint*		
Pre-condition:	*A complete fingerprint dataset must already be uploaded*	
Scenarios: *User uploads a single partial fingerprint image to be reconstructed and matched*		
Step#	***Action***	***Software Reaction***
1.	*User opens the website*	*System displays homepage with "Upload Partial Fingerprint" option*
2.	*User clicks on "Upload Partial Fingerprint"*	*File browser opens for image selection*
3.	*User selects an image file*	*System checks image format and quality*
4.	*System prepares the image for reconstruction*	*Reconstructed is shown*
Alternate Scenarios:		
1 : *User uploads a non-image file* ***2:*** *No full fingerprint dataset exists for matching*		
Post Conditions: *The partial fingerprint is saved and ready to be processed by the reconstruction model.*		
Step#	***Description***	
	Enables system to initiate fingerprint reconstruction.	
Use Case Cross referenced	*Uc1*	

3. **Reconstruct Partial Fingerprint:**

UC3: Reconstruct Partial Fingerprint		
Use case Id:	*Uc3*	
Actors: *System*		
Feature: *Reconstruct Fingerprint using Diffusion Model*		
Pre-condition:	*A partial fingerprint must be uploaded*	
Scenarios: *System uses trained Diffusion Model to reconstruct the full fingerprint from the partial input*		
Step#	***Action***	***Software Reaction***
1.	*System receives partial fingerprint*	*Model loading begins*
2.	*Diffusion Model adds noise and learns to denoise*	*Intermediate fingerprints generated*
3.	*Model refines fingerprint step by step*	*High-quality reconstruction is formed*
4.	*Final fingerprint image is generated*	*Saved in MongoDB and ready for matching*
Alternate Scenarios:		
1: Model fails to load properly *2: Input fingerprint is too degraded to reconstruct* *3: Timeout occurs during inference*		
Post Conditions: *A reconstructed version of the partial fingerprint is created and saved.*		
Step#	***Description***	
-	*Key AI process enabling fingerprint recovery*	

4. **Match Reconstructed Fingerprint:**

UC4: Match Reconstructed Fingerprint		
Use case Id:	*Uc4*	
Actors: *System*		
Feature: *Match Reconstructed Fingerprint with Database*		
Pre-condition:	*Reconstructed fingerprint must be available*	
Scenarios: *System compares reconstructed fingerprint with all prints in database using ORB algorithm and returns top matches*		
Step#	***Action***	***Software Reaction***
1.	*System loads reconstructed fingerprint*	*Ready for comparison*
2.	*ORB Matching algorithm runs*	*Matches are calculated*
3.	*System finds top k similar fingerprints*	*Image is Matched*
4.	*Results are displayed on UI*	*Matched images and similarity scores shown*
5.	*Uploaded documents are available for queries (User) or for fine-tuning (Admin)*	*System updates interface based on user role*
Alternate Scenarios: *1: No matches are found* *2: ORB algorithm throws an error* *3: MongoDB connection fails*		
Post Conditions: *Top matching fingerprints are shown alongside the reconstructed print for analysis.*		
Step#	***Description***	
1	*Allows user to identify and verify fingerprint from matches*	

Project Implementation:

Reconstructify AI is a privacy-aware, AI-powered fingerprint regeneration and matching system designed to assist in forensic investigations where partial or degraded fingerprints are encountered. The system follows a multi-phase pipeline focused on fingerprint reconstruction using Diffusion Models, followed by fast and accurate matching using ORB algorithms, all delivered through a user-friendly web platform.

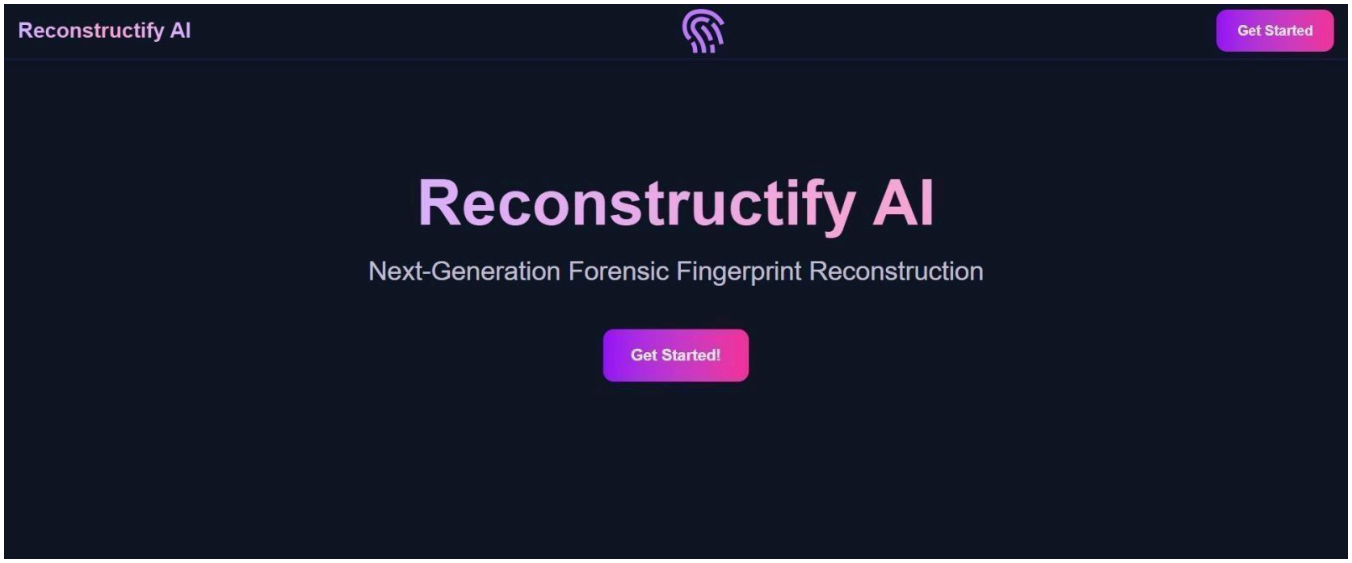
At its core, the system uses state-of-the-art Generative AI models including GANs, VAEs, and Diffusion Models—trained on a curated dataset of full and partial fingerprints. Data was collected from publicly available fingerprint repositories, with a focus on incorporating real-world degraded prints. Preprocessing included noise reduction, contrast enhancement, and normalization to prepare the data for model training.

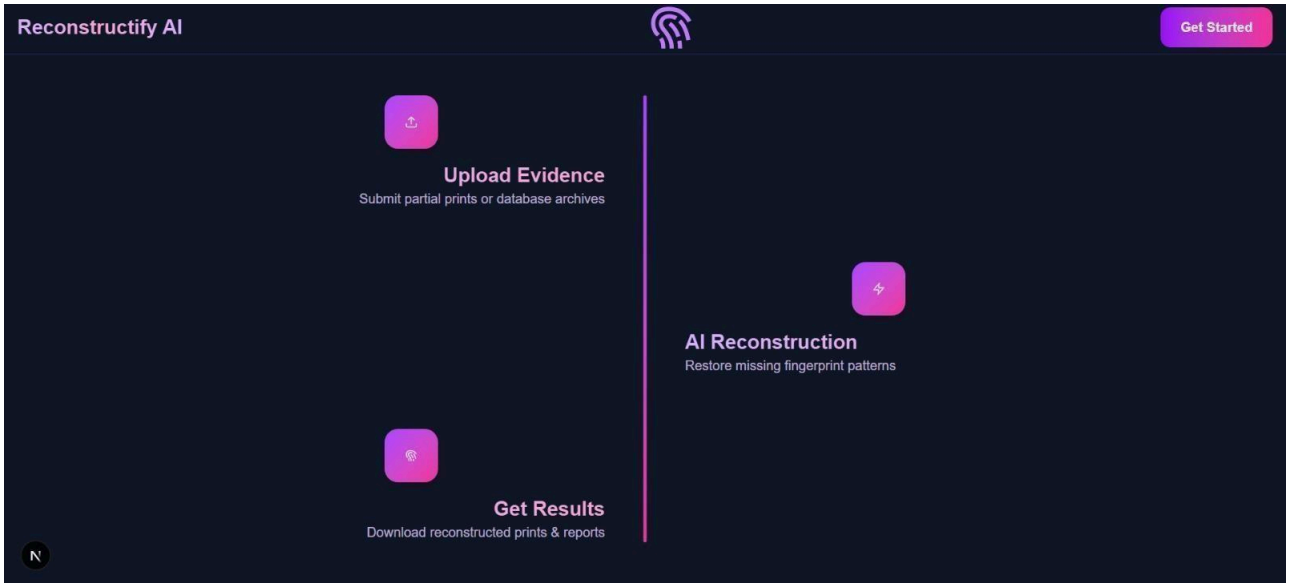
A comprehensive model evaluation process compared multiple architectures using MSE loss for reconstruction accuracy. Diffusion Models outperformed other methods, particularly at a learning rate of 0.001, offering highly accurate reconstructions even for severely damaged prints.

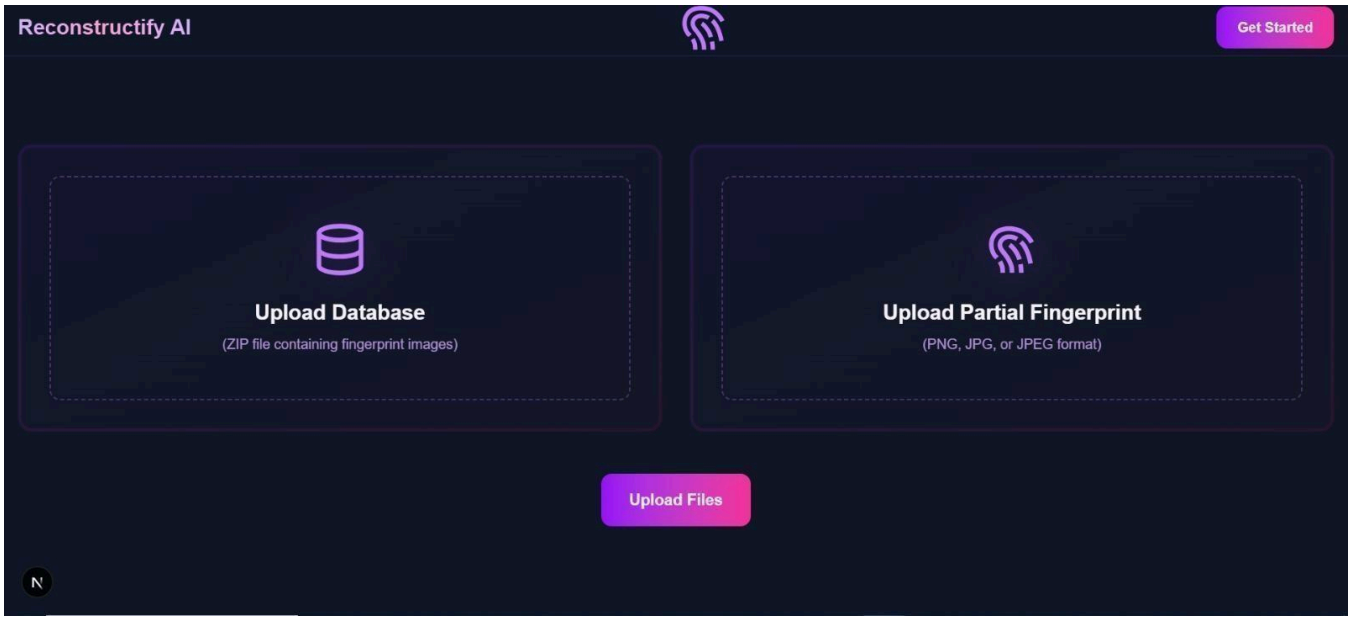
To enable identification, five search algorithms were developed and tested Template Matching, Histogram Search, SSIM, SIFT, and ORB. These were evaluated on runtime and accuracy using datasets of over 6000 images. ORB Matching delivered the best performance, allowing top-k (k=5) fingerprint retrievals in real-time.

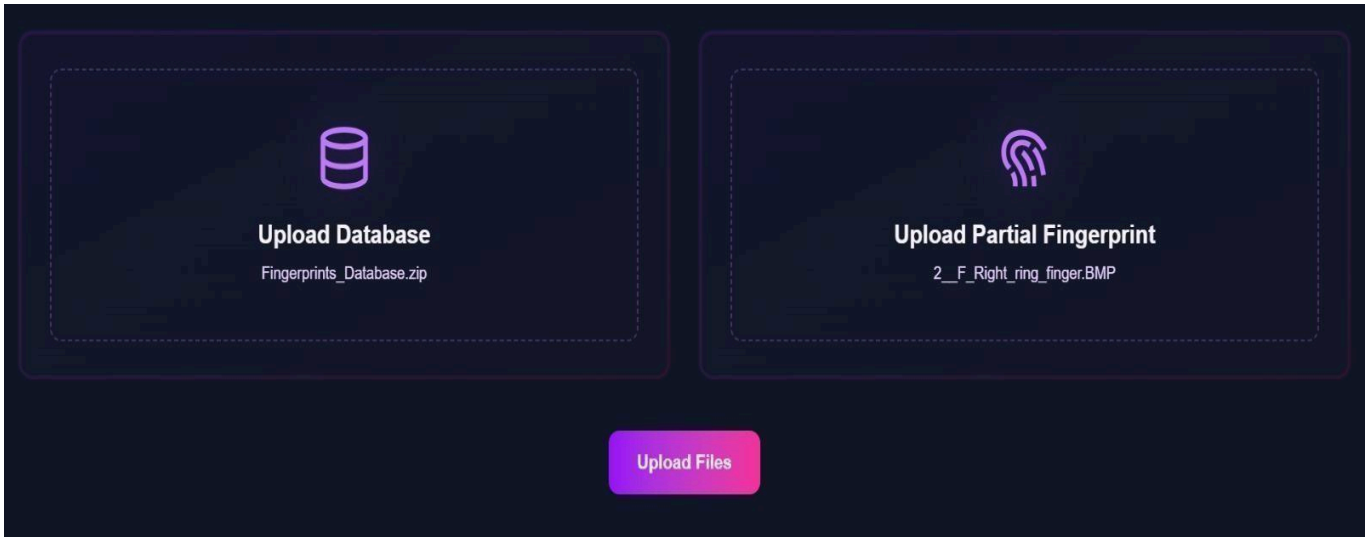
The system is deployed as a web-based application, developed using Next.js for the frontend and FastAPI for backend model inference. Users upload a fingerprint dataset (in ZIP format) and a partial print. The system reconstructs the print and searches for matches. Fingerprint data and user uploads are managed securely using MongoDB.

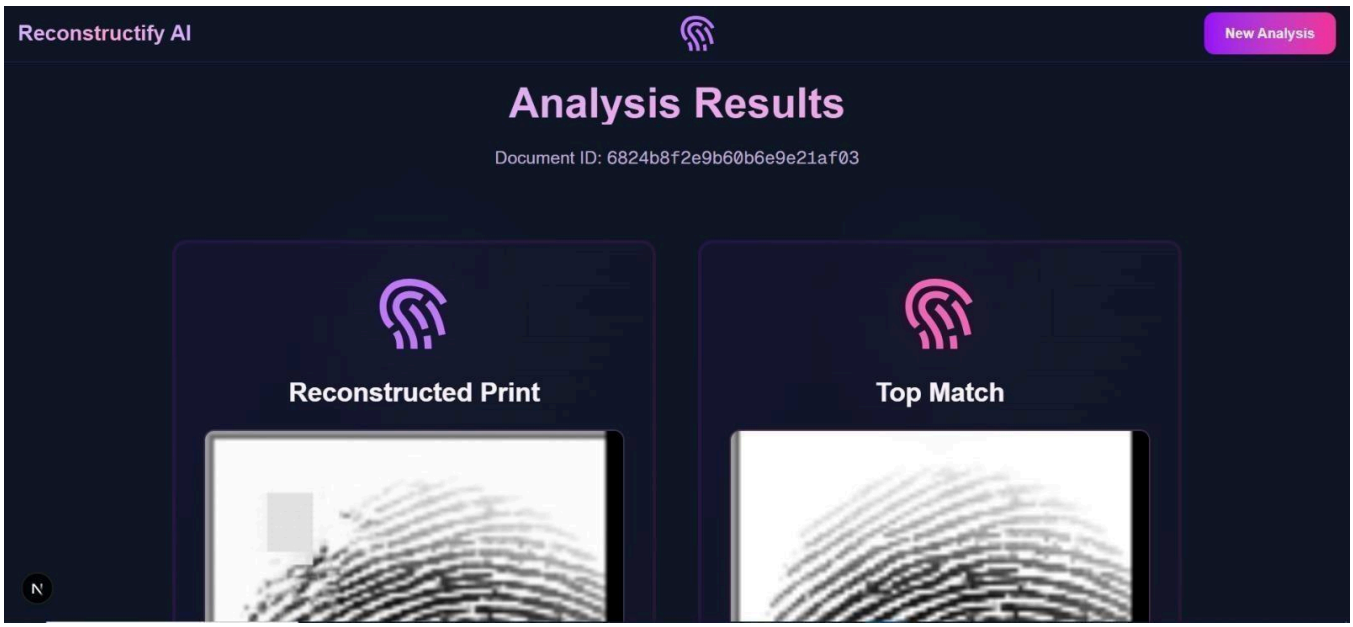
Design:

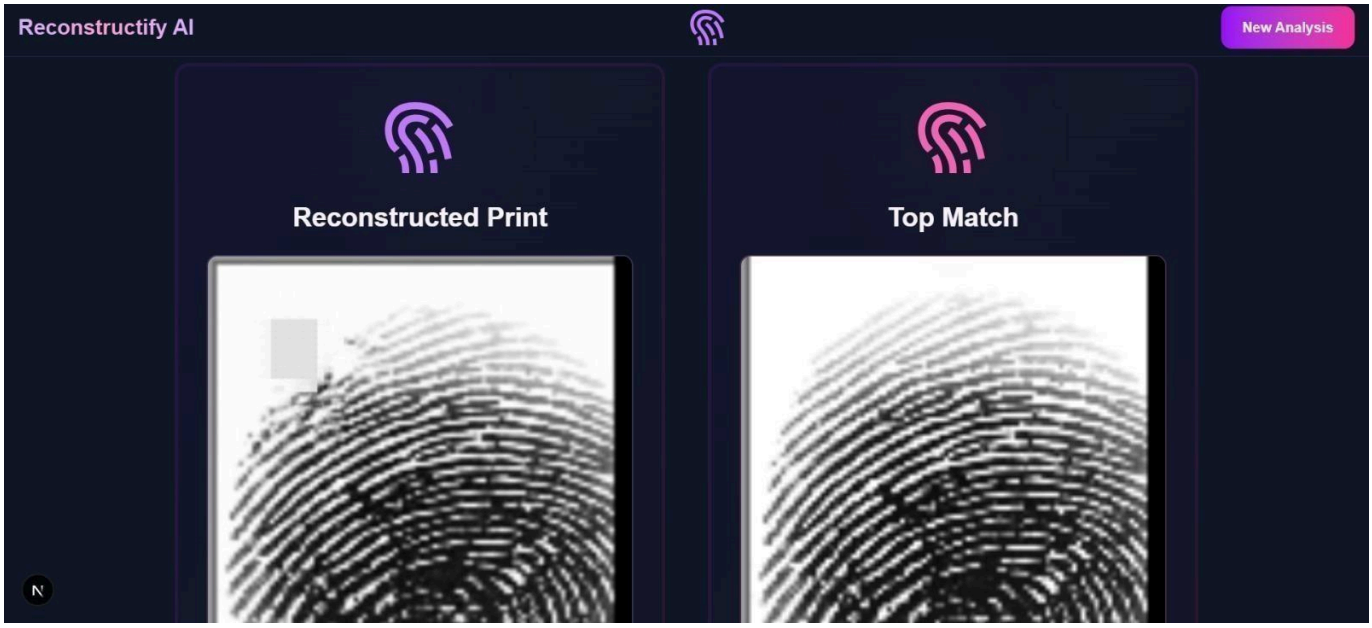

Reconstructify AI
Get Started
Reconstructify AI
Next-Generation Forensic Fingerprint Reconstruction
Get Started!

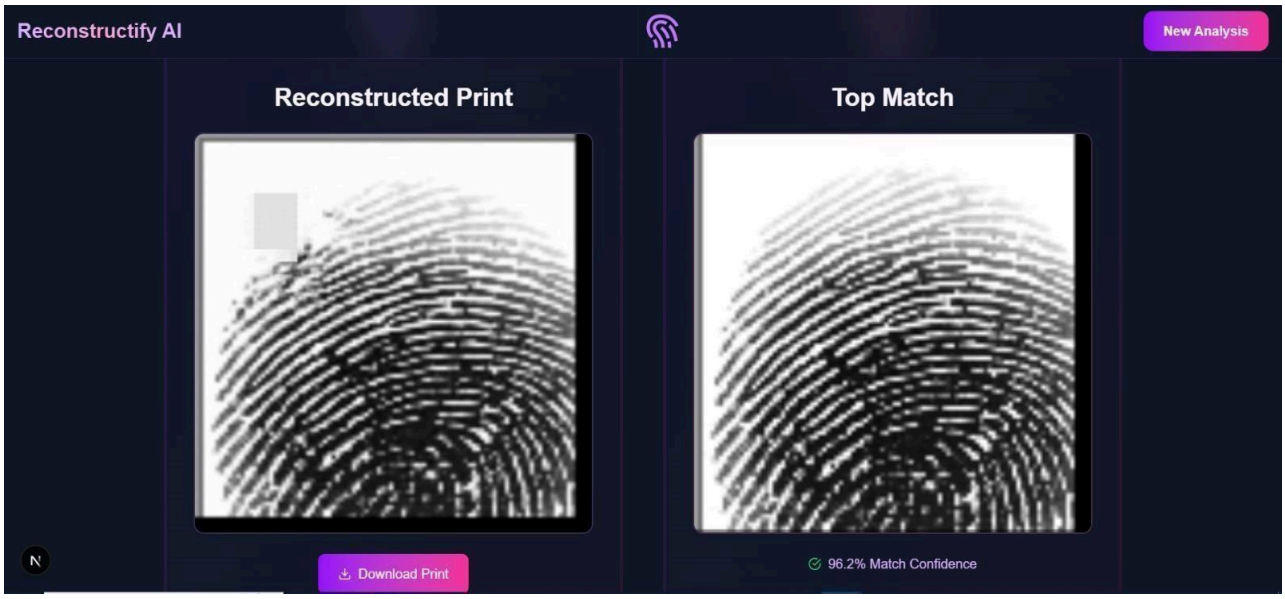

Reconstructify AI
Get Started
Upload Evidence
Submit partial prints or database archives
AI Reconstruction
Restore missing fingerprint patterns
Get Results
Download reconstructed prints & reports


Reconstructify AI
Get Started
Upload Database
(ZIP file containing fingerprint images)
Upload Partial Fingerprint
(PNG, JPG, or JPEG format)
Upload Files


Upload Database
Fingerprints_Database.zip
Upload Partial Fingerprint
2__F_Right_ring_finger.BMP
Upload Files


Reconstructify AI
New Analysis
Analysis Results
Document ID: 6824b8f2e9b60b6e9e21af03
Reconstructed Print
Top Match


Reconstructify AI
New Analysis
Reconstructed Print
Top Match


Reconstructify AI
New Analysis
Reconstructed Print
Top Match
Download Print
96.2% Match Confidence

Results:

Extracting minutiae points:

Figure 1: Minutiae points

CNN Results:

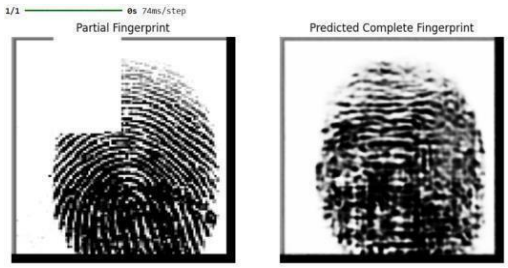


Figure 3: CNN Results

Pixel CNN Results:

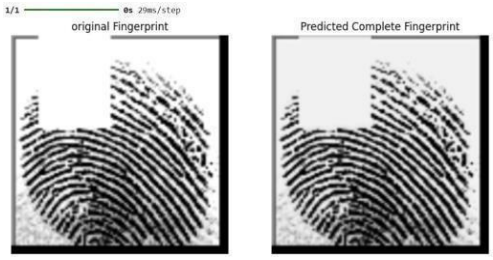


Figure 4: Pixel CNN Results

VAE Results:

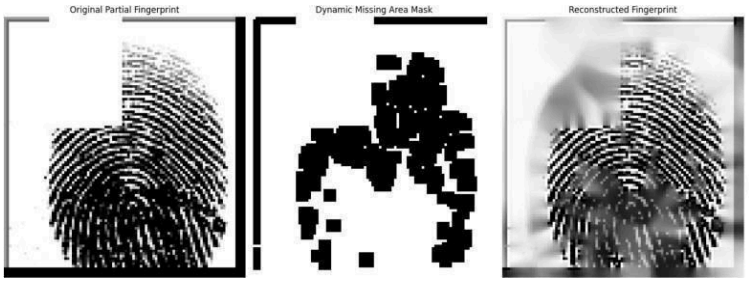


Figure 5: VAE Results

GANs without Minutiae points:

Figure 6: GANS without Minutiae Points

U-Net Model:

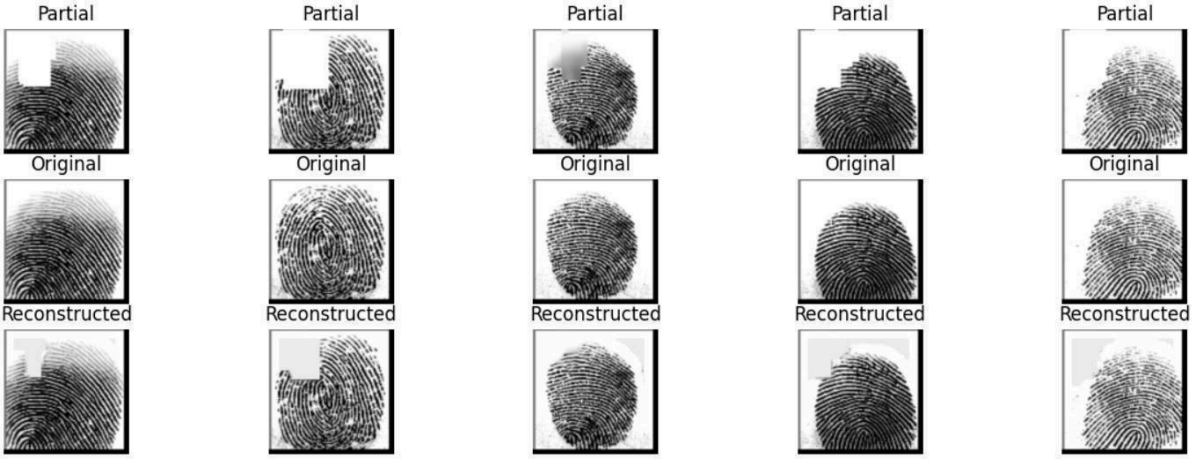


Figure 7: UNET Results

GANs with Minutiae points:

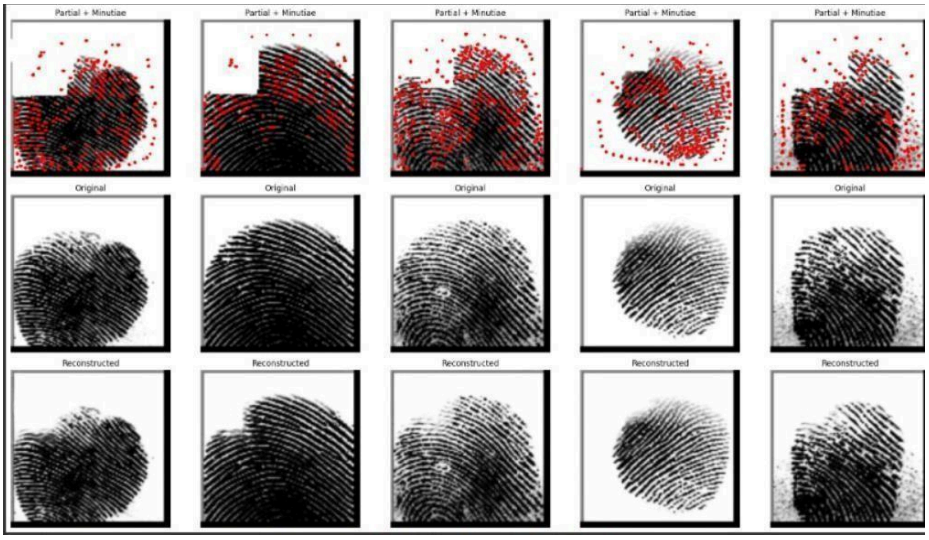


Figure 8: GANS with Minutiae Points

Diffusion Models:

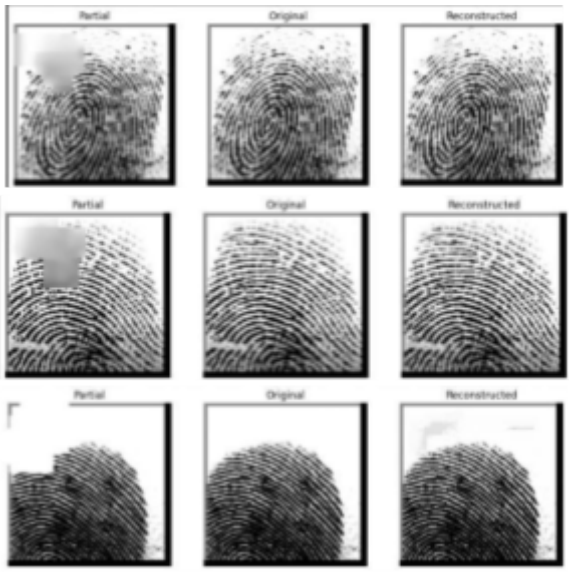
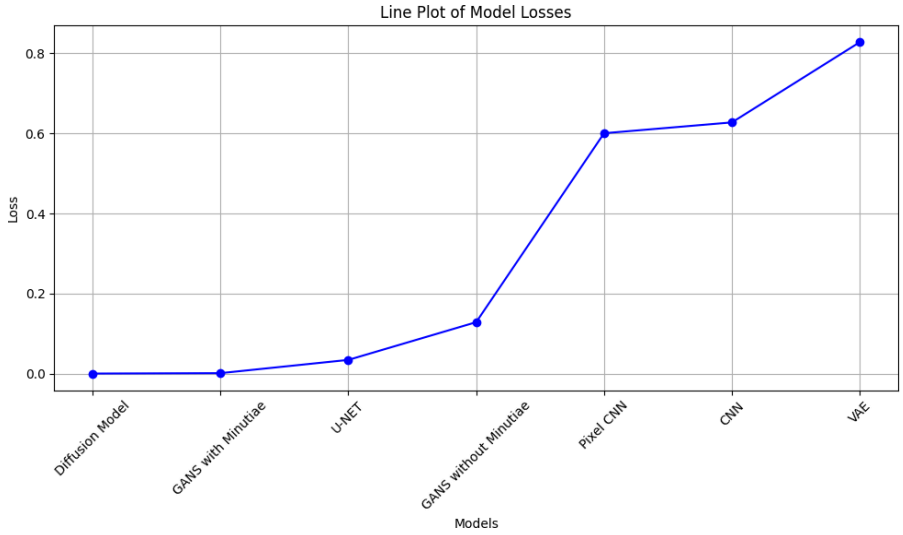
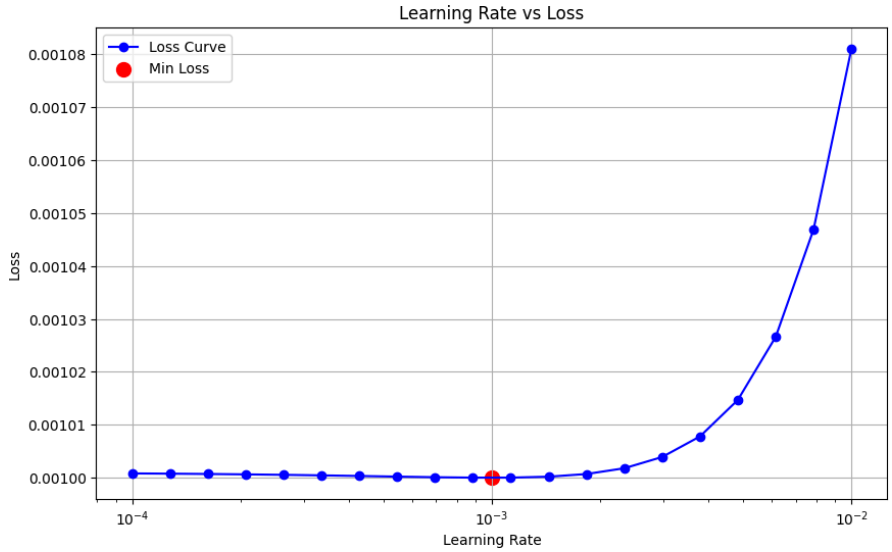


Figure 9: Diffusion Model Results

Model vs Loss:



Diffusion Model Learning Rate Comparison and Selection:



Findings:

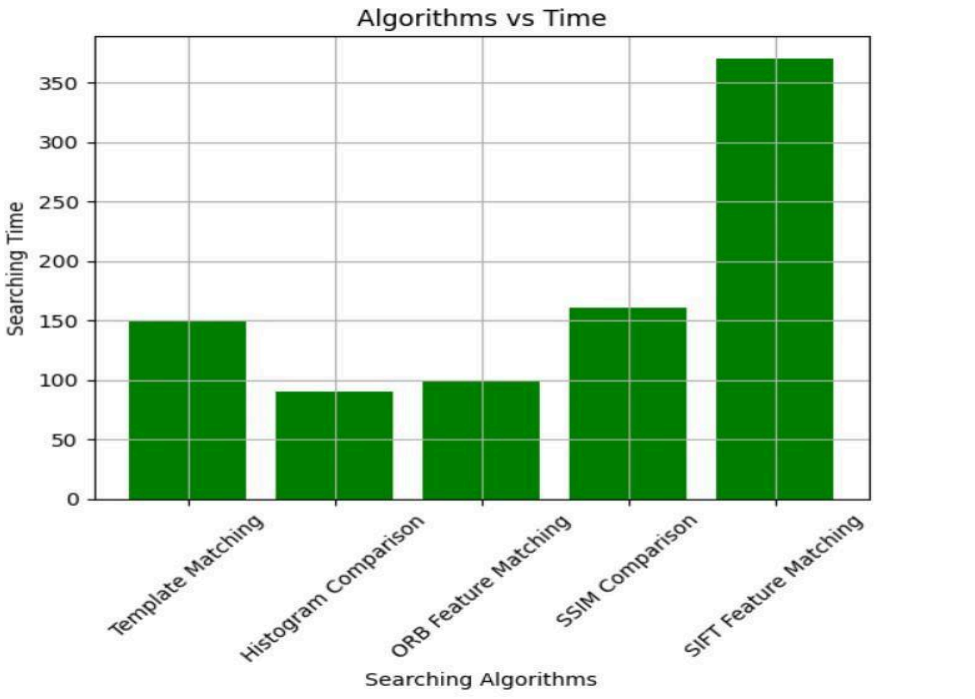
We conducted an extensive analysis of multiple different Ai models. We compared the loss of each model (mse) for fingerprint reconstruction and arrived at the conclusion that diffusion model produced the best fingerprint reconstruction results.

After Selecting Diffusion model we tuned it at different learning rates, and upon analyzing loss at each learning rate, we concluded that diffusion model reconstructed fingerprints best at learning rate of 0.001.

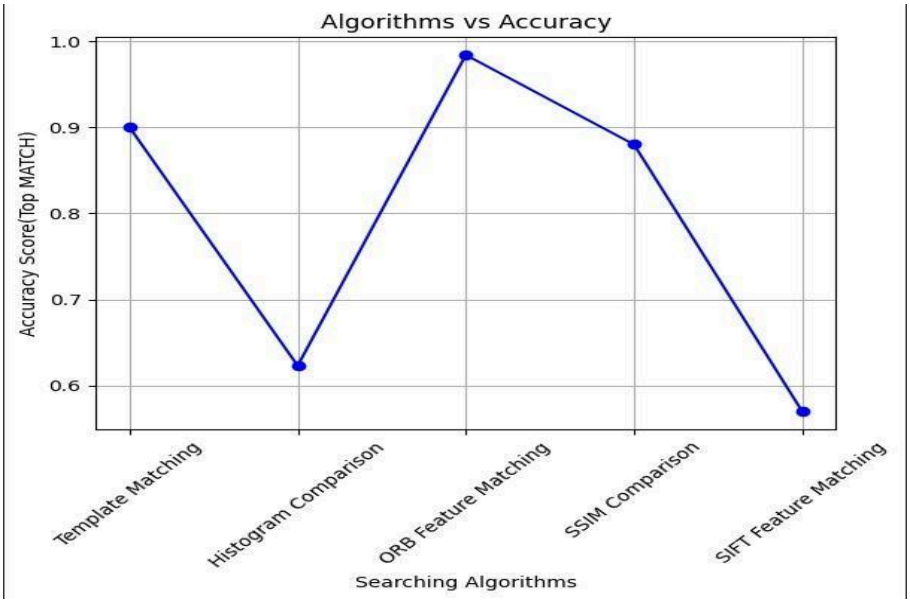
Matching Algorithms:

Method	Pros	Cons
SSIM (Structural Similarity Index)	- Measures structural similarity, useful for slight variations. - Fast and computationally efficient.	- Sensitive to illumination changes. - Struggles with geometric transformations (rotation, translation).
SIFT (Scale-Invariant Feature Transform)	- Robust to scale and rotation variations. - Detects distinctive keypoints.	- Computationally expensive for a dataset of 6000 images. - Slower matching process.
Template Matching	- Simple and easy to implement. - Works well when fingerprints are aligned properly.	- Fails with misaligned or rotated images. - Requires exact positioning.
ORB (Oriented FAST and Rotated BRIEF)	- Fast and efficient for large datasets. - Performs well under rotation and scale variations.	- Can be sensitive to noise.
Histogram Matching	- Works well for global color/intensity distributions. - Fast and efficient for large datasets.	- Ineffective for detailed fingerprint features. - Does not capture spatial information.

Algorithms VS Time:

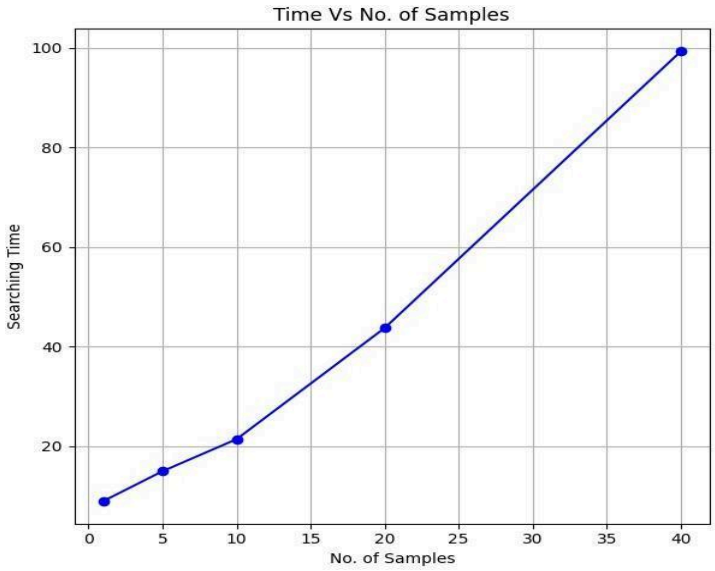


Algorithms vs Accuracy:



Findings:

- **Sample testing for ORB**



WHY ORB PERFORMED BEST?

- Faster than SIFT while maintaining good accuracy.
- Works well for fingerprint images, even with rotation and slight distortions.
- Efficient for large datasets (6000 images)

Conclusion:

Reconstructify AI demonstrates the effective integration of generative AI and advanced search algorithms to solve the critical challenge of partial fingerprint recognition in forensic investigations. Through the use of Diffusion Models, we achieved accurate reconstruction of incomplete or degraded fingerprints. Combined with the efficiency of the ORB Matching algorithm, the system ensures fast and reliable identification. Our web-based platform further enhances accessibility, offering a practical, scalable solution for real-world forensic applications. As development progresses, Reconstructify AI continues to move toward becoming a powerful tool for modern investigative workflows.

References:

[1] 1. Kai Cao, Anil Kumar Jain, “Learning Fingerprint Reconstruction: From Minutiae to Image”, IEEE (Transactions on Information Forensics), December 2014.

[2] 2. Andrey Makrushin, Venkata Srinath Mannam, and Jana Dittman, “Data-Driven Fingerprint Reconstruction from Minutiae Based on Real and Synthetic Training Data”,
Dept of CS, Otto von Geuricke University, 2022

[3] 3. Nuno Martins, José Silvestre, and Alexandre Bernardino, “Fingerprint Recognition in Forensic Scenarios”, Instituto Superior Técnico, Universidade de Lisboa, 20 January 2024.

[4] 4. Milind B Bhilavade, Dr.K.S. Shivaprakasha, Dr. Meenakshi R. Patil, and Dr. Lalita S Admuthe, “Fingerprint Reconstruction: Approaches to Improve Fingerprint Images”, C M R Institute of Technology, March 30 2024

[5] 5. Mohammad Kharulli Bin Othman, “Fingerprint Reconstruction Based on Improved Directional Image”,