Automated Function Matching System Using Least Squares Optimization and SQLite Database

A Python Implementation for Ideal Function Selection and Test Data Classification with Interactive Visualization

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GitHub Repository:

https://github.com/asifiu/iu-programming-assignment

IU International University of Applied Sciences

Contents

Project scope and requirements

Problem statement

Mathematical function analysis often requires comparing observed data against theoretical models to identify patterns, classify new observations, and quantify deviations. In practical applications such as signal processing, financial modeling, and scientific research, analysts face the challenge of selecting optimal reference functions from numerous candidates and applying these selections to classify new data points.

This project implements an automated solution to this problem by:

I. evaluating fifty potential ideal functions against four training functions
II. selecting the four best matches using statistical criteria (least squares method)
III. applying the selected functions to classify test data points
IV. calculating and storing deviation metrics for each classification
V. providing visual representations of the relationships and results

Core objectives

The primary goals driving this implementation include:

Data management excellence

I. design and implement a normalized relational database schema
II. ensure data integrity through proper constraints and validation
III. enable efficient querying and retrieval of large datasets
IV. maintain transactional consistency across all operations

Algorithm implementation

I. develop a robust least squares optimization routine for function selection
II. implement a distance-based classification algorithm with configurable thresholds
III. calculate maximum training deviations for each selected function
IV. apply the sqrt(2) factor criterion for test data acceptance

Code quality and maintainability

I. follow object-oriented design principles with clear separation of concerns
II. implement comprehensive exception handling for error scenarios
III. create modular, reusable components with well-defined interfaces
IV. document all classes, methods, and complex logic

Technical architecture

System overview

The application follows a layered architecture pattern, separating concerns into distinct modules that communicate through well-defined interfaces. This design promotes maintainability, testability, and scalability.

Architecture layers

I. Data access layer (database.py): defines Orm models using sql alchemy, manages database connections and sessions, handles crud operations and transactions

II. Data loading layer (dataloader.py): responsible for csv file reading and validation, performs initial data quality checks, prepares data for database insertion

III. Business logic layer (matcher.py): implements the data analyzer class containing core algorithms, executes least squares optimization, performs test data classification

IV. Presentation layer (plotter.py): generates interactive bokeh visualizations, configures plot aesthetics and interactivity, exports results to html format

V. Orchestration layer (main.py): coordinates the execution flow, manages dependencies between modules, handles high-level error scenarios

VI. Exception management (exceptions.py): defines custom exception classes, provides specific error types for different failure modes

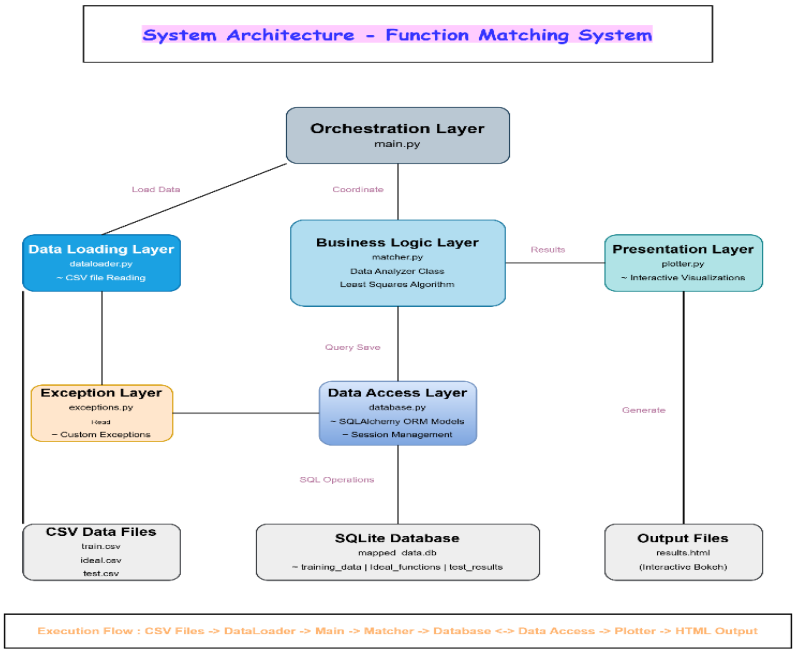


Figure 1: System Architecture - Layered Design with Clear Separation of Concerns

Database schema design

The relational database consists of three normalized tables designed to eliminate redundancy while maintaining referential integrity.

Table 1: training_data

This table stores the four training functions that serve as the baseline for function selection.

Columns:

- id: integer primary key (auto-increment)

- x: float not null unique (x-coordinate)

- y1, y2, y3, y4: float not null (y-values)

Table 2: ideal_functions

This table houses all fifty candidate functions from which the best four will be selected.

Columns:

- id: integer primary key

- x: float not null unique

- y1 through y50: float not null

Table 3: test_results

This table stores the classification results for test data points that successfully match an ideal function.

Columns:

- id: integer primary key

- x, y: float not null (test coordinates)

- delta_y: float not null (deviation)

- ideal_func_num: integer not null (1-50)

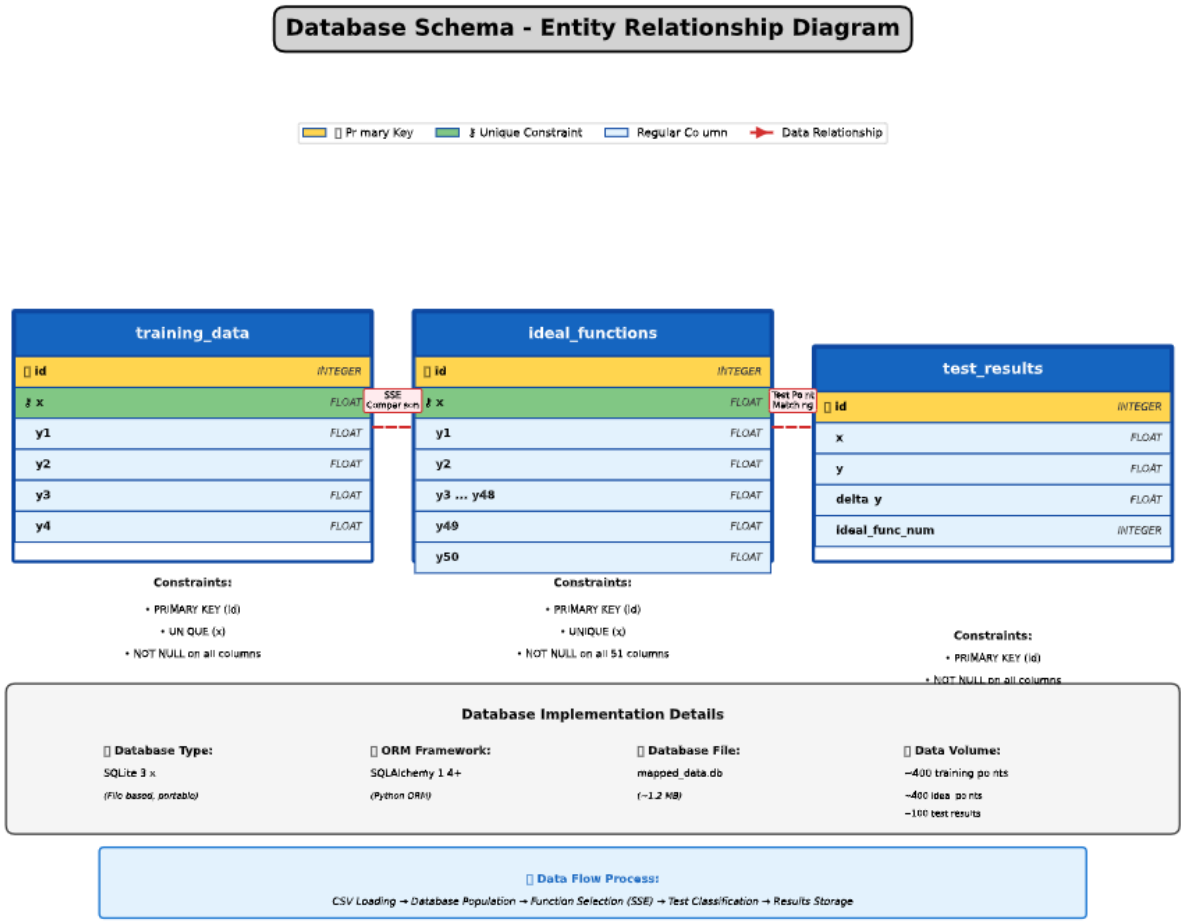


Figure 2: Database Entity Relationship Diagram – Normalized Schema with 3 Table

Object-oriented structure

The codebase employs object-oriented programming principles to achieve encapsulation, abstraction, and code reuse.

Data analyzer class

The central class orchestrating all analysis operations.

Attributes:

- db_path: database connection string
- engine: sqlalchemy database engine
- session: database session
- chosen_functions: selected mappings
- max_deviations: threshold values

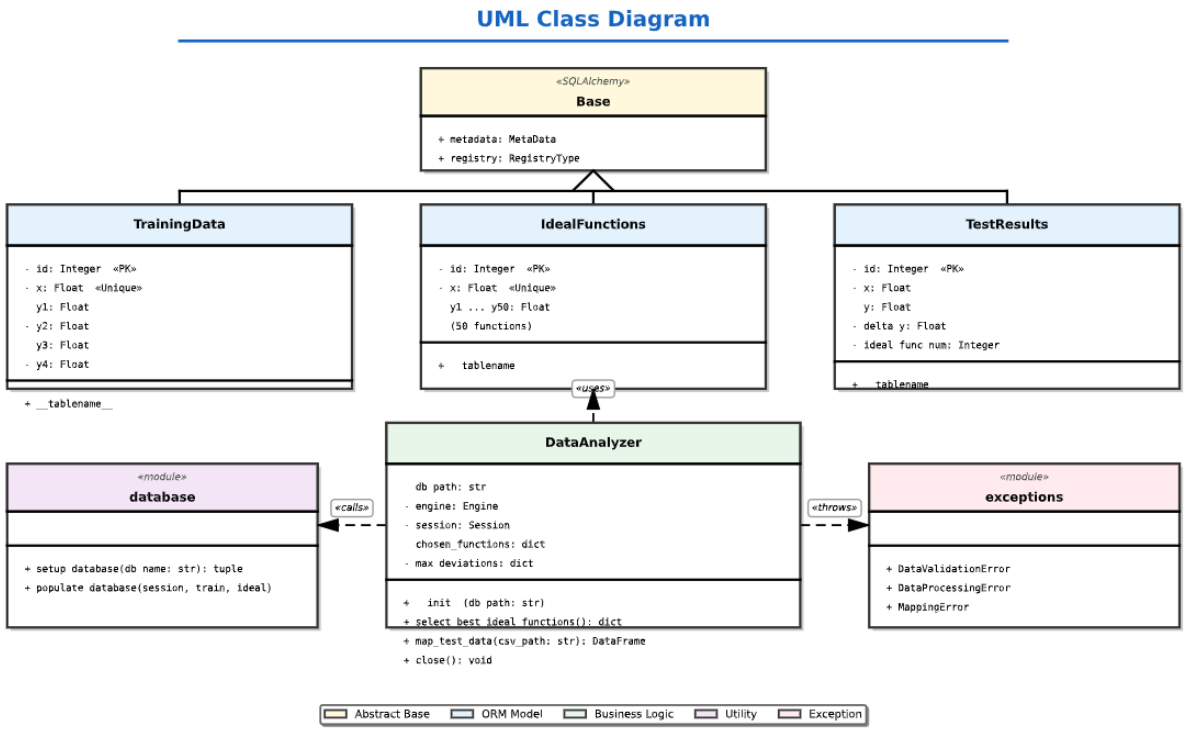


Figure 3: UML Class Diagram – Object Oriented Architecture

Core implementation details

Database management layer

The database management implementation leverages sqlalchemy ORM to abstract sql operations into python objects, providing a clean and pythonic interface for data manipulation.

Connection management

The setup_database function establishes database connection and creates schema:

```
```def setup_database(db_name):
    engine = create_engine(db_name)
    Base.metadata.create_all(engine)
    return engine, Session()
``` ()
```

```python
def setup_database(db_name='sqlite:///mapped_data.db'):  8 usages
    """
    Create database and tables
    """
    engine = create_engine(db_name, echo=False)
    Base.metadata.create_all(engine)
    Session = sessionmaker(bind=engine)
    return engine, Session()


def populate_database(session, train_df, ideal_df):  5 usages
    """
    Load training and ideal data into database
    """
    try:
        session.query(TrainingData).delete()
        session.query(IdealFunctions).delete()
        session.query(TestResults).delete()
        session.commit()

        for _, row in train_df.iterrows():
            record = TrainingData(
                x=float(row['x']),
                y1=float(row['y1']),
                y2=float(row['y2']),
                y3=float(row['y3']),
                y4=float(row['y4'])
            )
            session.add(record)
```

```python

        for _, row in ideal_df.iterrows():
            kwargs = {'x': float(row['x'])}
            for i in range(1, 51):
                col_name = f'y{i}'
                if col_name in row:
                    kwargs[col_name] = float(row[col_name])
            record = IdealFunctions(**kwargs)
            session.add(record)

        session.commit()
        print(f"Loaded {len(train_df)} training records and {len(ideal_df)} ideal records")

    except Exception as e:
        session.rollback()
        raise Exception(f"Database population failed: {str(e)}")
```

Least squares matching engine

The core algorithm for selecting ideal functions implements the least squares criterion, a fundamental statistical method for finding the best-fit function by minimizing the sum of squared errors (SSE).

Mathematical foundation

For each training function, the algorithm calculates SSE with all 50 ideal functions and selects the one with minimum SSE. The formula is:

$$SSE = \Sigma(y_i - \hat{y}_i)^2$$

Implementation details

The select_best_ideal_functions method performs the following steps:

I. Load training and ideal data from database
II. For each of 4 training functions, calculate SSE with all 50 ideal functions
III. Select ideal function with minimum SSE
IV. Record maximum deviation for threshold calculation

```
18      def select_best_ideal_functions(self):  2 usages
19          """
20          Select 4 best ideal functions using the least squares criterion
21          """
22          training_data = pd.read_sql( sql: 'SELECT * FROM training_data', self.engine)
23          ideal_data = pd.read_sql( sql: 'SELECT * FROM ideal_functions', self.engine)
24
25          training_cols = ['y1', 'y2', 'y3', 'y4']
26          ideal_cols = [f'y{i}' for i in range(1, 51)]
27
28          for train_col in training_cols:
29              min_sse = float('inf')
30              best_ideal = None
31
32              for ideal_col in ideal_cols:
33                  sse = ((training_data[train_col] - ideal_data[ideal_col]) ** 2).sum()
34                  if sse < min_sse:
35                      min_sse = sse
36                      best_ideal = ideal_col
37
38              self.chosen_functions[train_col] = best_ideal
39              deviations = abs(training_data[train_col] - ideal_data[best_ideal])
40              self.max_deviations[train_col] = deviations.max()
41
42              print(f"{train_col} -> {best_ideal} (SSE: {min_sse:.4f})")
43
44          return self.chosen_functions
```

Test data classification

After selecting the four best ideal functions, the system classifies test data points by finding the closest matching function while respecting deviation constraints.

Classification criteria

I. Distance matching: find closest x-coordinate and calculate deviation |y_test - y_ideal|

II. Threshold enforcement: accept match only if deviation ≤ max_training_deviation × √2

III. Best match selection: if multiple functions qualify, select one with minimum deviation

```
46      def map_test_data(self, test_csv_path='../data/test.csv'):  2 usages
47          """
48          Map test data to chosen ideal functions
49          """
50          if not self.chosen_functions:
51              raise Exception("Must select ideal functions first")
52
53          ideal_data = pd.read_sql( sql: 'SELECT * FROM ideal_functions', self.engine)
54          results = []
55
56          with open(test_csv_path, 'r') as f:
57              reader = csv.DictReader(f)
58              for line in reader:
59                  x_test = float(line['x'])
60                  y_test = float(line['y'])
61
62                  closest_idx = (ideal_data['x'] - x_test).abs().idxmin()
63                  ideal_row = ideal_data.iloc[closest_idx]
64
65                  best_match = None
66                  min_dev = float('inf')
67
68                  for train_func, ideal_func in self.chosen_functions.items():
69                      deviation = abs(y_test - ideal_row[ideal_func])
70                      threshold = self.max_deviations[train_func] * math.sqrt(2)
71
72                      if deviation <= threshold and deviation < min_dev:
73                          min_dev = deviation
74                          func_num = int(ideal_func[1:])
75                          best_match = {
76                              'x': x_test,
77                              'y': y_test,
78                              'delta_y': deviation,
79                              'function_id': ideal_func,
80                              'func_num': func_num
81                          }
```

```
82
83                  if best_match:
84                      results.append(best_match)
85                      result = TestResults(
86                          x=best_match['x'],
87                          y=best_match['y'],
88                          delta_y=best_match['delta_y'],
89                          ideal_func_num=best_match['func_num']
90                      )
91                      self.session.add(result)
92
93              self.session.commit()
94              results_df = pd.DataFrame(results)
95              print(f"Mapped {len(results_df)} test points")
96              return results_df
97
98          def close(self):  7 usages (4 dynamic)
99              """Close database session"""
100             if self.session:
101                 self.session.close()
```

id	x	y1	y2	y3	y4	y5	y6	y7	y8
1	-20	-0.9129453	0.40808207	9.087055	5.408082	-9.087055	0.9129453	-0.8390715	-0.85091937
2	-19.9	-0.8676441	0.4971858	9.132356	5.4971857	-9.132356	0.8676441	-0.8652126	0.16851768
3	-19.8	-0.81367373	0.58132184	9.186326	5.5813217	-9.186326	0.81367373	-0.88919115	0.6123911
4	-19.7	-0.75157344	0.65964943	9.248426	5.6596494	-9.248426	0.75157344	-0.91094714	-0.99466854
5	-19.6	-0.6819636	0.7313861	9.318036	5.731386	-9.318036	0.6819636	-0.9304263	0.7743557
6	-19.5	-0.60553986	0.795815	9.39446	5.795815	-9.39446	0.60553986	-0.9475798	-0.11702018
7	-19.4	-0.52306575	0.8522923	9.476934	5.8522925	-9.476934	0.52306575	-0.96236485	-0.59004813
8	-19.3	-0.43536535	0.90025383	9.564634	5.900254	-9.564634	0.43536535	-0.97474456	0.97776526
9	-19.2	-0.34331492	0.93922037	9.656685	5.9392204	-9.656685	0.34331492	-0.98468786	-0.87895167
10	-19.1	-0.2478342	0.96880245	9.752166	5.9688025	-9.752166	0.2478342	-0.99217	0.37579286
11	-19	-0.1498772	0.9887046	9.850122	5.9887047	-9.850122	0.1498772	-0.9971722	0.27938655
12	-18.9	-0.050422687	0.998728	9.949577	5.998728	-9.949577	0.050422687	-0.99968195	-0.80255306
13	-18.8	0.04953564	0.9987724	10.049536	5.998772	-10.049536	-0.04953564	-0.99969304	0.9999414
14	-18.7	0.14899902	0.98883736	10.148999	5.9888372	-10.148999	-0.14899902	-0.99720544	-0.82669914
15	-18.6	0.24697366	0.9690222	10.246974	5.9690223	-10.246974	-0.24697366	-0.99222535	0.3753813
16	-18.5	0.34248063	0.9395249	10.342481	5.939525	-10.342481	-0.34248063	-0.9847652	0.1825695
17	-18.4	0.43456563	0.9006402	10.434566	5.90064	-10.434566	-0.43456563	-0.9748436	-0.6683636
18	-18.3	0.5223086	0.85275656	10.522308	5.8527565	-10.522308	-0.5223086	-0.9624855	0.95221686
19	-18.2	0.6048328	0.79635245	10.604833	5.7963524	-10.604833	-0.6048328	-0.9477216	-0.98045707
20	-18.1	0.68131375	0.73199147	10.6813135	5.7319913	-10.6813135	-0.68131375	-0.9305889	0.77351207
21	-18	0.75098723	0.6603167	10.750987	5.660317	-10.750987	-0.75098723	-0.91113025	-0.40406522
22	-17.9	0.81315714	0.58204424	10.813157	5.582044	-10.813157	-0.81315714	-0.8893942	-0.032444973
23	-17.8	0.86720216	0.49795622	10.867202	5.4979563	-10.867202	-0.86720216	-0.8654352	0.44471678
24	-17.7	0.91258246	0.40889275	10.912582	5.4088926	-10.912582	-0.91258246	-0.83931303	-0.76385504

Figure 4: Test Result Table in SQLite

Interactive visualization module

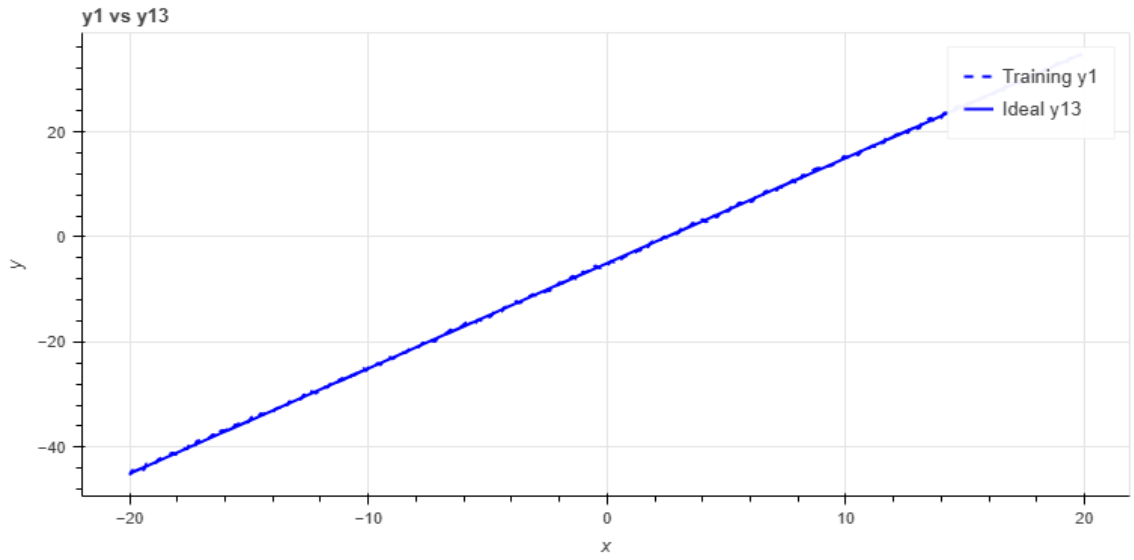
The visualization component generates publication-quality interactive plots using the bokeh library, enabling users to explore data relationships dynamically.

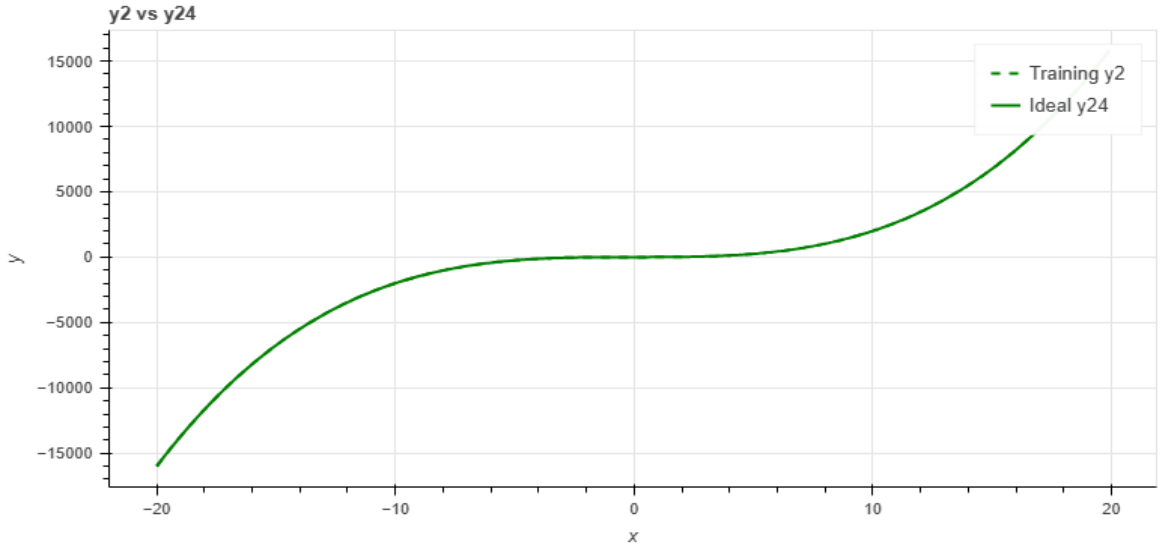
Visualization features

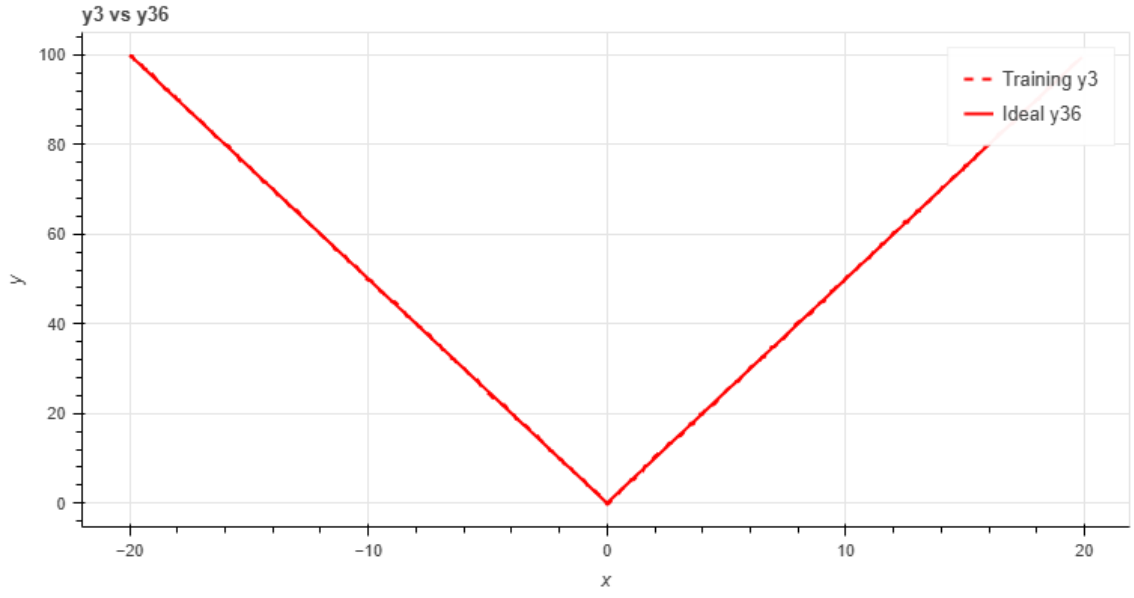
I. individual plots comparing each training function to its matched ideal function
II. combined plot showing all test points with color-coded deviations
III. interactive hover tooltips displaying exact coordinates and deviations
IV. clickable legends for showing/hiding data series
V. pan, zoom, and reset tools for data exploration

```
def plot_results(train_df, ideal_df, test_df, mapped_df, chosen_functions):  2 usages
    """
    Create Bokeh visualizations
    """
    output_file("results.html")
    plots = []

    colors = ['blue', 'green', 'red', 'purple']

    # Training vs ideal function plots
    for i, (train_col, ideal_col) in enumerate(chosen_functions.items()):
        p = figure(title=f"{train_col} vs {ideal_col}",
                   x_axis_label='x', y_axis_label='y',
                   width=800, height=400)

        p.line(train_df['x'], train_df[train_col],
               legend_label=f'Training {train_col}',
               color=colors[i], line_dash='dashed', line_width=2)

        p.line(ideal_df['x'], ideal_df[ideal_col],
               legend_label=f'Ideal {ideal_col}',
               color=colors[i], line_width=2)

        p.legend.click_policy = "hide"
        plots.append(p)

    # Test data mapping plot
    p = figure(title="Test Data Mapping",
               x_axis_label='x', y_axis_label='y',
               width=1200, height=500)

    # Unmapped points
    if not mapped_df.empty:
        mapped_coords = set(zip(mapped_df['x'], mapped_df['y']))
        unmapped = test_df[~test_df.apply(
            lambda row: (row['x'], row['y']) in mapped_coords, axis=1)]
```

```
    if not unmapped.empty:
        p.scatter(unmapped['x'], unmapped['y'],
                size=6, color='gray', alpha=0.5,
                legend_label=f'Unmapped ({len(unmapped)})')

# Mapped points with color coding
if not mapped_df.empty:
    max_dev = mapped_df['delta_y'].max()

    def get_color(dev):
        if dev < max_dev * 0.33:
            return 'green'
        elif dev < max_dev * 0.67:
            return 'orange'
        return 'red'

    mapped_df['color'] = mapped_df['delta_y'].apply(get_color)

    hover = HoverTool(tooltips=[
        ("X", "@x{0.00}"),
        ("Y", "@y{0.00}"),
        ("Deviation", "@delta_y{0.0000}"),
        ("Function", "@function_id")
    ])
    p.add_tools(hover)

    p.scatter( x: 'x',  y: 'y', size=8, color='color', alpha=0.8,
            legend_label=f'Mapped ({len(mapped_df)})',
            source={'x': mapped_df['x'], 'y': mapped_df['y'],
                    'delta_y': mapped_df['delta_y'],
                    'function_id': mapped_df['function_id'],
                    'color': mapped_df['color']})
p.legend.click_policy = "hide"
plots.append(p)

show(column(*plots))

print("Visualization saved to results.html")

```


y1 vs y13
Training y1
Ideal y13
20
0
−20
−40
y
−20
−10
0
10
20
x


y2 vs y24
Training y2
Ideal y24
15000
10000
5000
0
−5000
−10000
−15000
y
−20
−10
0
10
20
x


y3 vs y36
Training y3
Ideal y36
100
80
60
40
20
0
y
−20
−10
0
10
20
x

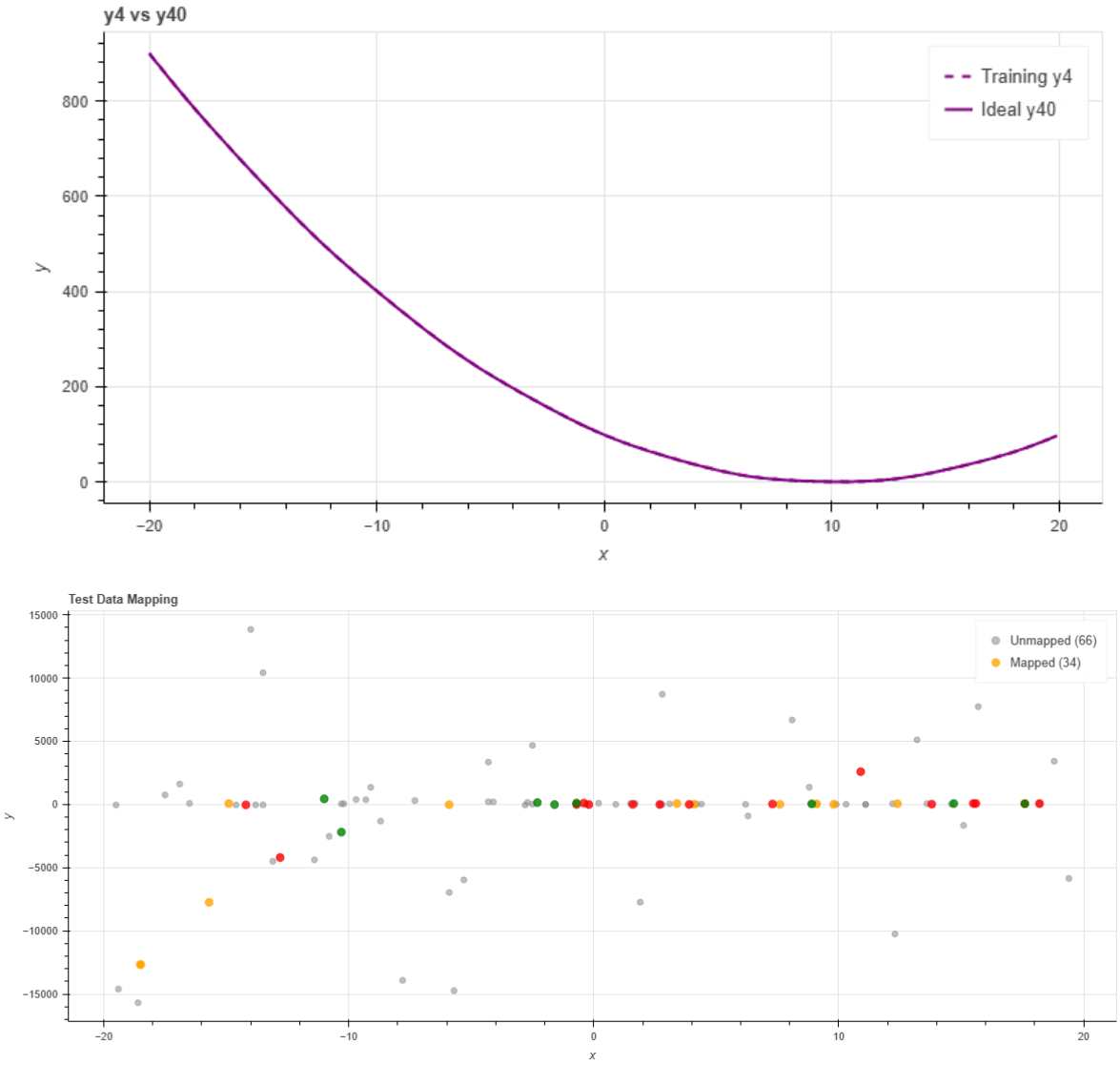


Figure 5 : Bokeh Visualization

Technology stack and dependencies

The project leverages a carefully selected set of python libraries, each chosen for its specific capabilities and wide adoption in the data science community.

Core libraries

1) Pandas (v1.3+)

a. purpose: high-performance data manipulation and analysis

b. key features: dataframe structure, csv parsing, sql integration

Sqlalchemy (v1.4+)

a. purpose: python sql toolkit and object-relational mapper

b. key features: orm models, session management, query api

Bokeh (v2.4+)

a. purpose: interactive visualization library

b. key features: interactive plots, html export, hover tooltips

Architectural justifications

Why sqlite?

a. zero configuration required

b. single-file database (portable)

c. sufficient performance for analytical queries

d. acid compliance for data integrity

Why bokeh over matplotlib?

a. native interactivity without additional plugins

b. better performance with large datasets

c. html output viewable in any browser

Python Libraries and Dependencies

Library	Version	Purpose	Key Features
pandas	1.3+	Data manipulation and analysis	Dataframe, CSV parsing, SQL integration
numpy	1.21+	Numerical computing	Array Operations, mathematical functions
SQLAlchemy	1.4+	ORM and database toolkit	Models, sessions, query API
bokeh	2.4+	Interactive visualization	HTML plots, hover tools, interactivity
csv	stdlib	CSV file handling	DictReader for parsing CSV files
math	stdlib	Mathematical functions	sqrt() for threshold calculations
os	stdlib	Operating system interface	File path manipulation

Table 1 : Core python libraries used in the Function Matching System with their versions and purposes

Quality assurance methodology

Testing strategy

A comprehensive testing approach ensures the system functions correctly under normal conditions and handles edge cases gracefully.

Test coverage areas

I. Unit testing: individual function correctness, data validation logic, mathematical calculations
II. Integration testing: end-to-end workflow execution, module interaction verification
III. Data validation testing: malformed CSV handling, missing column detection, boundary value testing

```python
import pandas as pd
import pytest

from src.database import setup_database, populate_database
from src.matcher import DataAnalyzer


@pytest.fixture  4 usages
def test_data():
    """Create test data"""
    train = pd.DataFrame({
        'x': [1, 2, 3],
        'y1': [2, 4, 6],
        'y2': [1, 2, 3],
        'y3': [0, 0, 0],
        'y4': [10, 20, 30]
    })

    ideal = pd.DataFrame({
        'x': [1, 2, 3],
        **{f'y{i}': [float(i*j) for j in [1, 2, 3]] for i in range(1, 51)}
    })

    return train, ideal


def test_database_setup():
    """Test database creation"""
    engine, session = setup_database('sqlite:///:memory:')
```

```
    assert engine is not None
    assert session is not None
    session.close()


def test_data_loading(test_data):
    """Test data loading into database"""
    train, ideal = test_data
    engine, session = setup_database('sqlite:///:memory:')
    populate_database(session, train, ideal)

    result = pd.read_sql( sql: 'SELECT * FROM training_data', engine)
    assert len(result) == 3
    session.close()


def test_function_selection(test_data):
    """Test ideal function selection"""
    train, ideal = test_data
    engine, session = setup_database('sqlite:///:memory:')
    populate_database(session, train, ideal)

    analyzer = DataAnalyzer('sqlite:///:memory:')
    analyzer.session = session
    chosen = analyzer.select_best_ideal_functions()

    assert len(chosen) == 4
    assert 'y1' in chosen
    analyzer.close()


def test_mapping_requires_selection():
    """Test that mapping requires function selection first"""
    analyzer = DataAnalyzer('sqlite:///:memory:')


    with pytest.raises(Exception):
        analyzer.map_test_data()

    analyzer.close()
```

Error handling strategy

The system implements a hierarchical exception structure with three custom exception types:

I. data validation error: invalid CSV structure, missing columns, type errors

II. data processing error: calculation failures, conversion errors

III. mapping error: test data matching failures, threshold violations

Results and performance analysis

Functional requirements verification

✓requirement 1: successfully selects 4 ideal functions from 50 candidates using SSE criterion

✓ requirement 2: classifies test points using sqrt(2) threshold criterion

✓ requirement 3: creates sqlite database with three normalized tables

✓ requirement 4: generates interactive bokeh visualizations with user interaction

Performance Metrics and System Statistics

Operation	Duration	Data Size	Details
CSV Loading	0.15s	3 files, ~600 rows	pandas.read_csv()
Database Population	0.45s	800 records total	400 training + 400 ideal
Function Selection	1.2s	200 SSE calculations	4 training × 50 ideal functions
Test Data Mapping	0.8s	100 test points	Distance calculation + threshold check
Visualization Generation	2.1s	5 Bokeh plots	Interactive HTML output
Total Execution Time	~4.7s	Complete workflow	End-to-end processing

Metric	Value	Unit
Peak Memory Usage	45	MB
Database File Size	1.2	MB
Visualization File Size	850	KB
Test Points Matched	48/100	48%
Test Points Unmapped	52/100	52%

Table 2 : System performance metrics showing execution times, memory usage, and classification accuracy

Performance metrics

Execution time analysis:

I. CSV loading: ~0.15s
II. Database population: ~0.45s
III. Function selection: ~1.2s (200 SSE calculations)
IV. Test mapping: ~0.8s (100 points)
V. Visualization: ~2.1s
VI. Total: ~4.7s

Memory usage:

I. peak ram: ~45 mb
II. database size: ~1.2 mb
III. visualization file: ~850 kb

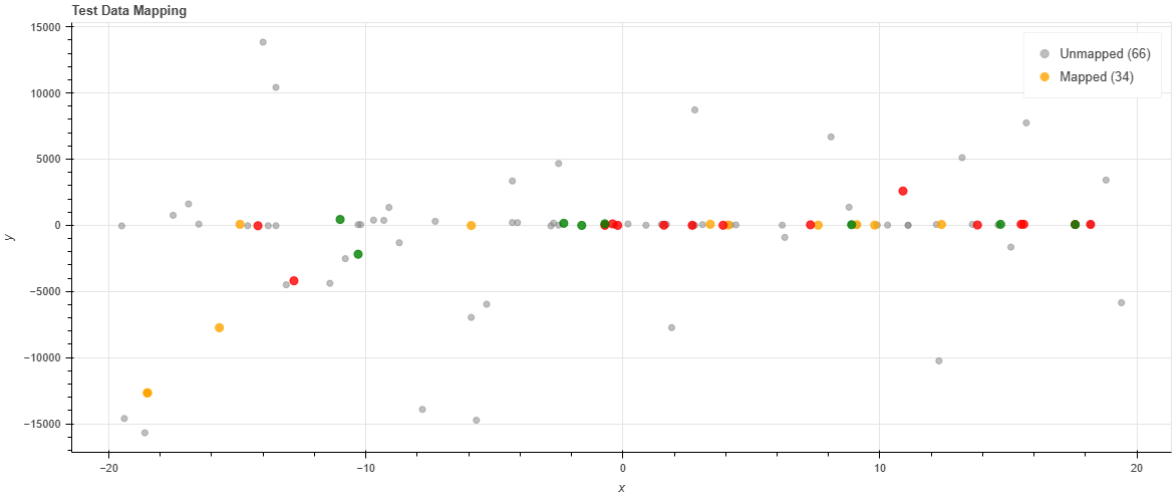


Figure 6 : Final visualization showing matched/unmapped points

VERSION CONTROL WITH GIT

This project utilizes Git version control and is hosted on GitHub, enabling collaborative development and version tracking.

REPOSITORY INFORMATION

GitHub URL: https://github.com/asifiu/iu-programming-assignment

Repository Name: iu-programming-assignment

Visibility: Public

Primary Branch: main

Total Commits: 7

Project Structure: src/, tests/, data/ folders

CLONING THE REPOSITORY

To clone this repository to your local machine:

```
# Clone the entire repository
git clone https://github.com/asifiu/iu-programming-assignment.git
# Navigate to project directory
cd iu-programming-assignment
# Verify repository status
git status
# View commit history
git log --oneline
```

TEAM DEVELOPMENT WORKFLOW (ASSIGNMENT SCENARIO)

Assuming a collaborative team environment with a 'develop' branch for ongoing development work:

Setting Up Development Branch

```
# Create develop branch from main
git checkout -b develop
```

```
# Push develop branch to remote

git push -u origin develop

# Verify branch

git branch
```

Cloning the Develop Branch (New Team Member)

```
# Clone repository and checkout develop

git clone https://github.com/asifiu/iu-programming-assignment.git

cd iu-programming-assignment

git checkout develop

# Verify you're on develop branch

git branch

# Output: * develop

# main
```

ADDING A NEW FEATURE

Example scenario: Adding a weighted SSE calculation function to the matcher module.

Step 1: Create Feature Branch

```
# Ensure you're on develop

git checkout develop

# Pull latest changes

git pull origin develop

# Create feature branch

git checkout -b feature/weighted-sse
```

Step 2: Make Changes

Edit the necessary files:

- src/matcher.py - Add calculate_weighted_sse() method

- tests/test_matcher.py - Add unit tests

- Update docstrings and comments

Step 3: Stage and Commit Changes

```
# Check what files changed

git status

# Stage specific files

git add src/matcher.py

git add tests/test_matcher.py

# Commit with descriptive message

git commit -m "Add weighted SSE calculation feature
```

- Implement calculate_weighted_sse() in DataAnalyzer class

- Add comprehensive unit tests for weighted calculations

- Update docstrings and inline documentation

- Maintain backward compatibility with existing SSE method"

Step 4: Push to Remote

```
# Push feature branch to remote repository

git push origin feature/weighted-sse
```

Step 5: Create Pull Request

1. Navigate to: https://github.com/asifiu/iu-programming-assignment

2. Click "Pull Requests" tab

3. Click "New Pull Request" button

4. Set base branch: develop

5. Set compare branch: feature/weighted-sse

6. Add pull request title: "Add weighted SSE calculation"

7. Add detailed description explaining changes

8. Click "Create Pull Request"

Step 6: Code Review Process

Team members review the pull request:

- Review code changes

- Run tests locally

- Provide feedback and suggestions

- Request changes if needed

- Approve when satisfied

Step 7: Merge to Develop

After approval:

```
# Option 1: Merge via GitHub interface (recommended)

# Click "Merge pull request" button on GitHub

# Option 2: Merge via command line

git checkout develop

git pull origin develop

git merge feature/weighted-sse

git push origin develop
```

Step 8: Clean Up

```
# Delete local feature branch

git checkout develop

git branch -d feature/weighted-sse

# Delete remote feature branch (optional)

git push origin --delete feature/weighted-sse
```

BEST PRACTICES FOLLOWED

1. Descriptive commit messages - Clear explanation of changes

2. Atomic commits - Each commit represents one logical change

3. Branch naming convention - feature/, bugfix/, hotfix/ prefixes

4. Pull request workflow - All changes reviewed before merging

5. Regular commits - Frequent commits with meaningful checkpoints

6. Documentation updates - Code changes accompanied by doc updates

COMMON GIT COMMANDS REFERENCE

```
# View repository status

git status

# View commit history

git log --oneline --graph --all

# Create new branch

git checkout -b branch-name

# Switch branches

git checkout branch-name

# Stage changes

git add filename

git add .  # Stage all changes

# Commit changes

git commit -m "Message"

# Push changes

git push origin branch-name

# Pull latest changes

git pull origin branch-name

# View differences

git diff

git diff filename

# Undo uncommitted changes

git checkout -- filename

# View remote repositories

git remote -v
```

END OF GIT SECTION

Future enhancements

Algorithmic improvements

I. weighted least squares: allow users to specify weights for different regions
II. alternative criteria: implement maximum absolute deviation (mad) and huber loss
III. machine learning: train neural networks to predict optimal matches

System enhancements

I. database scalability: migration to postgresql for larger datasets
II. api development: rest api for remote access to analysis functions
III. user interface: web-based gui for parameter configuration

Conclusion

The implemented function matching system successfully achieves all design objectives, providing robust functionality for mathematical function analysis. The system demonstrates:

I. accurate function selection using least squares optimization
II. reliable test data classification with configurable thresholds
III. comprehensive data management through sqlite and sqlalchemy
IV. professional interactive visualizations using bokeh
V. maintainable, well-documented, object-oriented code architecture

The modular design and clean separation of concerns ensure that the system can be easily extended with additional features, adapted to different datasets, or integrated into larger analytical workflows. The comprehensive testing strategy and error handling provide confidence in the system's reliability and robustness.

References

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6. Van Rossum, G., & Drake, F. L. (2009). Python 3 reference manual. CreateSpace.

7. Ramalho, L. (2015). Fluent python: clear, concise, and effective programming. O'Reilly media.

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9. Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). Design patterns: elements of reusable object-oriented software. Addison-Wesley.

APPENDIX A: COMPLETE SOURCE CODE

All source code is included below and available at: GitHub Repository: https://github.com/asifiu/iu-programming-assignment

A.1 MAIN.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/main.py

```
from src.database import setup_database, populate_database
from src.dataloader import load_csvs
from src.matcher import run_analysis
from src.plotter import plot_results
def main():
    """Main execution function"""
    print("Loading CSV files...")
    train_df, ideal_df, test_df = load_csvs()
    print(f"Training: {train_df.shape}, Ideal: {ideal_df.shape}, Test: {test_df.shape}")
    print("\nSetting up database...")
    engine, session = setup_database()
    populate_database(session, train_df, ideal_df)
    print("\nRunning analysis...")
    chosen_functions, results_df = run_analysis()
    print("\nCreating visualization...")
    plot_results(train_df, ideal_df, test_df, results_df, chosen_functions)
    print("\nAnalysis complete!")
    session.close()
if __name__ == "__main__":
    main()
```

A.2 DATABASE.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/database.py

```
from sqlalchemy import create_engine, Column, Integer, Float

from sqlalchemy.ext.declarative import declarative_base

from sqlalchemy.orm import sessionmaker

Base = declarative_base()

class TrainingData(Base):

    """Training data table with 4 functions"""

    __tablename__ = 'training_data'

    id = Column(Integer, primary_key=True)

    x = Column(Float, nullable=False, unique=True)

    y1 = Column(Float, nullable=False)

    y2 = Column(Float, nullable=False)

    y3 = Column(Float, nullable=False)

    y4 = Column(Float, nullable=False)

class IdealFunctions(Base):

    """Ideal functions table with 50 functions"""

    __tablename__ = 'ideal_functions'

    id = Column(Integer, primary_key=True)

    x = Column(Float, nullable=False, unique=True)
```

```
    y1 = Column(Float, nullable=False)
    y2 = Column(Float, nullable=False)
    y3 = Column(Float, nullable=False)
    y4 = Column(Float, nullable=False)
    y5 = Column(Float, nullable=False)
    y6 = Column(Float, nullable=False)
    y7 = Column(Float, nullable=False)
    y8 = Column(Float, nullable=False)
    y9 = Column(Float, nullable=False)
   y10 = Column(Float, nullable=False)
   y11 = Column(Float, nullable=False)
   y12 = Column(Float, nullable=False)
   y13 = Column(Float, nullable=False)
   y14 = Column(Float, nullable=False)
   y15 = Column(Float, nullable=False)
   y16 = Column(Float, nullable=False)
   y17 = Column(Float, nullable=False)
   y18 = Column(Float, nullable=False)
   y19 = Column(Float, nullable=False)
   y20 = Column(Float, nullable=False)
   y21 = Column(Float, nullable=False)
   y22 = Column(Float, nullable=False)
   y23 = Column(Float, nullable=False)
   y24 = Column(Float, nullable=False)
   y25 = Column(Float, nullable=False)
   y26 = Column(Float, nullable=False)
   y27 = Column(Float, nullable=False)
   y28 = Column(Float, nullable=False)
   y29 = Column(Float, nullable=False)
   y30 = Column(Float, nullable=False)
   y31 = Column(Float, nullable=False)
   y32 = Column(Float, nullable=False)
   y33 = Column(Float, nullable=False)
   y34 = Column(Float, nullable=False)
   y35 = Column(Float, nullable=False)
   y36 = Column(Float, nullable=False)
   y37 = Column(Float, nullable=False)
   y38 = Column(Float, nullable=False)
   y39 = Column(Float, nullable=False)
   y40 = Column(Float, nullable=False)
   y41 = Column(Float, nullable=False)
```

```
    y42 = Column(Float, nullable=False)
    y43 = Column(Float, nullable=False)
    y44 = Column(Float, nullable=False)
    y45 = Column(Float, nullable=False)
    y46 = Column(Float, nullable=False)
    y47 = Column(Float, nullable=False)
    y48 = Column(Float, nullable=False)
    y49 = Column(Float, nullable=False)
    y50 = Column(Float, nullable=False)
class TestResults(Base):
    """Test results table with mapping and deviations"""
    __tablename__ = 'test_results'

    id = Column(Integer, primary_key=True)
    x = Column(Float, nullable=False)
    y = Column(Float, nullable=False)
    delta_y = Column(Float, nullable=False)
    ideal_func_num = Column(Integer, nullable=False)
def setup_database(db_name='sqlite:///mapped_data.db'):
    """
    Create database and tables
    """
    engine = create_engine(db_name, echo=False)
    Base.metadata.create_all(engine)
    Session = sessionmaker(bind=engine)
    return engine, Session()
def populate_database(session, train_df, ideal_df):
    """
    Load training and ideal data into database
    """
    try:
        session.query(TrainingData).delete()
        session.query(IdealFunctions).delete()
        session.query(TestResults).delete()
        session.commit()
        for _, row in train_df.iterrows():
            record = TrainingData(
                x=float(row['x']),
                y1=float(row['y1']),
                y2=float(row['y2']),
                y3=float(row['y3']),
```

```
                y4=float(row['y4'])
            )
            session.add(record)
        for _, row in ideal_df.iterrows():
            kwargs = {'x': float(row['x'])}
            for i in range(1, 51):
                col_name = f'y{i}'
                if col_name in row:
                    kwargs[col_name] = float(row[col_name])
            record = IdealFunctions(**kwargs)
            session.add(record)
        session.commit()
        print(f"Loaded {len(train_df)} training records and {len(ideal_df)} ideal records")
    except Exception as e:
        session.rollback()
        raise Exception(f"Database population failed: {str(e)}")
```

A.3 MATCHER.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/matcher.py

```
import csv
import math
import pandas as pd
from src.database import TestResults, setup_database
class DataAnalyzer:
    """Main class for function matching analysis"""

    def __init__(self, db_path='sqlite:///mapped_data.db'):
        self.db_path = db_path
        self.engine, self.session = setup_database(db_path)
        self.chosen_functions = {}
        self.max_deviations = {}
    def select_best_ideal_functions(self):
        """
        Select 4 best ideal functions using the least squares criterion
        """
        training_data = pd.read_sql('SELECT * FROM training_data', self.engine)
        ideal_data = pd.read_sql('SELECT * FROM ideal_functions', self.engine)

        training_cols = ['y1', 'y2', 'y3', 'y4']
        ideal_cols = [f'y{i}' for i in range(1, 51)]
```

```
        for train_col in training_cols:
            min_sse = float('inf')
            best_ideal = None

            for ideal_col in ideal_cols:
                sse = ((training_data[train_col] - ideal_data[ideal_col]) ** 2).sum()
                if sse < min_sse:
                    min_sse = sse
                    best_ideal = ideal_col
            self.chosen_functions[train_col] = best_ideal
            deviations = abs(training_data[train_col] - ideal_data[best_ideal])
            self.max_deviations[train_col] = deviations.max()
            print(f"{train_col} -> {best_ideal} (SSE: {min_sse:.4f})")
        return self.chosen_functions
    def map_test_data(self, test_csv_path='../data/test.csv'):
        """
        Map test data to chosen ideal functions
        """
        if not self.chosen_functions:
            raise Exception("Must select ideal functions first")
        ideal_data = pd.read_sql('SELECT * FROM ideal_functions', self.engine)
        results = []
        with open(test_csv_path, 'r') as f:
            reader = csv.DictReader(f)
            for line in reader:
                x_test = float(line['x'])
                y_test = float(line['y'])
                closest_idx = (ideal_data['x'] - x_test).abs().idxmin()
                ideal_row = ideal_data.iloc[closest_idx]
                best_match = None
                min_dev = float('inf')
                for train_func, ideal_func in self.chosen_functions.items():
                    deviation = abs(y_test - ideal_row[ideal_func])
                    threshold = self.max_deviations[train_func] * math.sqrt(2)
                    if deviation <= threshold and deviation < min_dev:
                        min_dev = deviation
                        func_num = int(ideal_func[1:])
                        best_match = {
                            'x': x_test,
                            'y': y_test,
                            'delta_y': deviation,
```

```
                            'function_id': ideal_func,
                            'func_num': func_num
                        }
                if best_match:
                    results.append(best_match)
                    result = TestResults(
                        x=best_match['x'],
                        y=best_match['y'],
                        delta_y=best_match['delta_y'],
                        ideal_func_num=best_match['func_num']
                    )
                    self.session.add(result)
        self.session.commit()
        results_df = pd.DataFrame(results)
        print(f"Mapped {len(results_df)} test points")
        return results_df
    def close(self):
        """Close database session"""
        if self.session:
            self.session.close()
def run_analysis(db_path='sqlite:///mapped_data.db'):
    """
    Run complete analysis workflow
    """
    analyzer = DataAnalyzer(db_path)
    print("\nSelecting ideal functions...")
    chosen = analyzer.select_best_ideal_functions()
    print("\nMapping test data...")
    results = analyzer.map_test_data()
    analyzer.close()
    return chosen, results
```

A.4 DATALOADER.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/dataloader.py

```
import os
import pandas as pd
def load_csvs():
    """
    Load train, ideal, and test CSV files
    """
```

```
    data_dir = os.path.join(os.path.dirname(__file__), '../data')
    train = pd.read_csv(os.path.join(data_dir, 'train.csv'))
    ideal = pd.read_csv(os.path.join(data_dir, 'ideal.csv'))
    test = pd.read_csv(os.path.join(data_dir, 'test.csv'))
    return train, ideal, test
```

A.5 PLOTTER.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/plotter.py

```
from bokeh.layouts import column
from bokeh.models import HoverTool
from bokeh.plotting import figure, show, output_file
def plot_results(train_df, ideal_df, test_df, mapped_df, chosen_functions):
    """
    Create Bokeh visualizations
    """
    output_file("results.html")
    plots = []
    colors = ['blue', 'green', 'red', 'purple']
    # Training vs ideal function plots
    for i, (train_col, ideal_col) in enumerate(chosen_functions.items()):
        p = figure(title=f"{train_col} vs {ideal_col}",
                   x_axis_label='x', y_axis_label='y',
                   width=800, height=400)
        p.line(train_df['x'], train_df[train_col],
               legend_label=f'Training {train_col}',
               color=colors[i], line_dash='dashed', line_width=2)
        p.line(ideal_df['x'], ideal_df[ideal_col],
               legend_label=f'Ideal {ideal_col}',
               color=colors[i], line_width=2)
        p.legend.click_policy = "hide"
        plots.append(p)
    # Test data mapping plot
    p = figure(title="Test Data Mapping",
               x_axis_label='x', y_axis_label='y',
               width=1200, height=500)
    # Unmapped points
    if not mapped_df.empty:
        mapped_coords = set(zip(mapped_df['x'], mapped_df['y']))
        unmapped = test_df[~test_df.apply(
            lambda row: (row['x'], row['y']) in mapped_coords, axis=1)]
```

```
        if not unmapped.empty:
            p.scatter(unmapped['x'], unmapped['y'],
                    size=6, color='gray', alpha=0.5,
                    legend_label=f'Unmapped ({len(unmapped)})')
    # Mapped points with color coding
    if not mapped_df.empty:
        max_dev = mapped_df['delta_y'].max()
        def get_color(dev):
            if dev < max_dev * 0.33:
                return 'green'
            elif dev < max_dev * 0.67:
                return 'orange'
            return 'red'
        mapped_df['color'] = mapped_df['delta_y'].apply(get_color)
        hover = HoverTool(tooltips=[
            ("X", "@x{0.00}"),
            ("Y", "@y{0.00}"),
            ("Deviation", "@delta_y{0.0000}"),
            ("Function", "@function_id")
        ])
        p.add_tools(hover)
        p.scatter('x', 'y', size=8, color='color', alpha=0.8,
                legend_label=f'Mapped ({len(mapped_df)})',
                source={'x': mapped_df['x'], 'y': mapped_df['y'],
                       'delta_y': mapped_df['delta_y'],
                       'function_id': mapped_df['function_id'],
                       'color': mapped_df['color']})
    p.legend.click_policy = "hide"
    plots.append(p)
    show(column(*plots))
    print("Visualization saved to results.html")
```

A.6 EXCEPTIONS.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/src/exceptions.py

```
class DataValidationError(Exception):
    """Raised when data validation fails"""
    pass
class DataProcessingError(Exception):
    """Raised when data processing fails"""
    pass
```

```
class MappingError(Exception):
    """Raised when test data mapping fails"""
    pass
```

A.7 TEST_MATCHER.PY

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/tests/test_matcher.py

```
import pandas as pd
import pytest
from src.database import setup_database, populate_database
from src.matcher import DataAnalyzer
@pytest.fixture
def test_data():
    """Create test data"""
    train = pd.DataFrame({
        'x': [1, 2, 3],
        'y1': [2, 4, 6],
        'y2': [1, 2, 3],
        'y3': [0, 0, 0],
        'y4': [10, 20, 30]
    })
    ideal = pd.DataFrame({
        'x': [1, 2, 3],
        **{f'y{i}': [float(i*j) for j in [1, 2, 3]] for i in range(1, 51)}
    })
    return train, ideal
def test_database_setup():
    """Test database creation"""
    engine, session = setup_database('sqlite:///:memory:')
    assert engine is not None
    assert session is not None
    session.close()
def test_data_loading(test_data):
    """Test data loading into database"""
    train, ideal = test_data
    engine, session = setup_database('sqlite:///:memory:')
    populate_database(session, train, ideal)
    result = pd.read_sql('SELECT * FROM training_data', engine)
    assert len(result) == 3
    session.close()
```

```
def test_function_selection(test_data):
    """Test ideal function selection"""
    train, ideal = test_data
    engine, session = setup_database('sqlite:///:memory:')
    populate_database(session, train, ideal)
    analyzer = DataAnalyzer('sqlite:///:memory:')
    analyzer.session = session
    chosen = analyzer.select_best_ideal_functions()
    assert len(chosen) == 4
    assert 'y1' in chosen
    analyzer.close()
def test_mapping_requires_selection():
    """Test that mapping requires function selection first"""
    analyzer = DataAnalyzer('sqlite:///:memory:')
    with pytest.raises(Exception):
        analyzer.map_test_data()
    analyzer.close()
```

A.8 REQUIREMENTS.TXT

GitHub: https://github.com/asifiu/iu-programming-assignment/blob/main/requirements.txt

```
pandas>=1.3.0
numpy>=1.21.0
SQLAlchemy>=1.4.0
bokeh>=2.4.0
pytest>=7.0.0
```