End-to-End ML Pipeline for Loan Default Prediction

A comprehensive system orchestrating data processing, model training, inference, and automated governance using Airflow, Docker, and Python to predict loan defaults at application time with continuous monitoring and drift detection.

Overview: End-to-End ML Pipeline (3 DAGs)

Goal

Predict loan default at application time, monitor performance & drift, and enforce automated governance.

Tech Stack

Airflow (3 DAGs), Docker, Python (pandas, scikit-learn, XGBoost), Parquet (pyarrow).

Data Layers

Bronze → Silver → Gold; Model artifacts in model_store; results in results/.

Temporal Integrity

- Features at application time (MOB=0), labels at +6 months (MOB=6).
- Windows: Train 2023-01→12, Val 2024-01→03, Test 2024-04→05, OOT 2024-06.

Selection

Best model chosen by AUC, used for inference across a date range.

Monitoring

Performance metrics + PSI, saved monthly; visualizations generated.

DAG 1: Data Processing (Bronze → Silver → Gold)

Schedule

Monthly backfillable; orchestrates per-snapshot processing.

Inputs (Bronze)

clickstream, attributes, financials, and lms_loan_daily snapshots.

Outputs

> ### Silver
>
> cleaned, standardized, de-duplicated tables (clickstream/attributes/financials/loan_daily).

> ### Gold
>
> - feature_store_YYYY_MM_DD.parquet (MOB=0)
> - label_store_YYYY_MM_DD.parquet (MOB=6; DPD threshold configured)

Silver Data Cleaning (Highlights)

Type Standardization

- Cast numeric columns
- coerce invalid values
- handle ±inf
- consistent date types

Missing Values

- Impute numeric columns (median), safe coercion.
- Drop/flag records missing core identifiers (loan_id, Customer_ID).

De-duplication

stable keys (loan_id, Customer_ID, snapshot_date).

Sanity Checks

non-negative amounts/tenure; valid income ranges (truncate or clip if needed).

Join Readiness

conforming column names and keys for downstream merges to Gold.

Feature Engineering (Gold Feature Store @ MOB=0)

Feature groups included (config-driven, leakage-safe at application time):

Loan Features

tenure, loan_amt

Demographics

customer_age

Financials

Annual_Income, Monthly_Inhand_Salary, Num_Bank_Accounts, Num_Credit_Card, Interest_Rate, Num_of_Loan, Num_of_Delayed_Payment, Outstanding_Debt, Credit_Utilization_Ratio, Total_EMI_per_month, Amount_invested_monthly, Monthly_Balance, debt_to_income_ratio

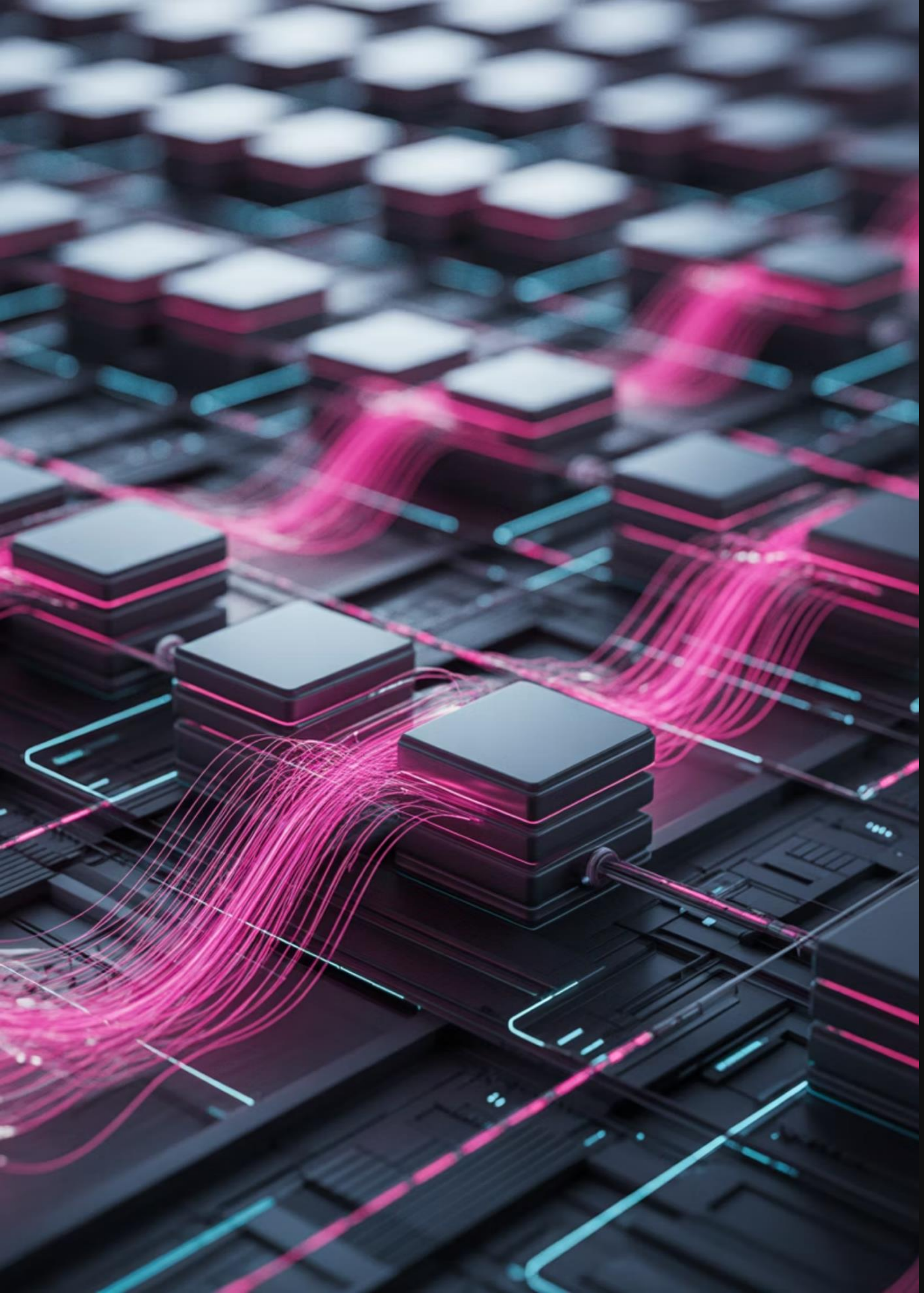
Clickstream

fe_1 ... fe_20

Label Engineering

label_store at MOB=6 using DPD_THRESHOLD=30; aligned to features via snapshot_date + 6 months.

Leakage guardrails: strict MOB filtering (features: t, labels: t+6) to mirror real-time availability.



DAG 2: Model Training (Manual, Readiness-Gated)

Readiness Checks

full feature months + aligned label months available for Train/Val/Test.

Models

LogisticRegression, RandomForest, XGBoost (balanced handling; XGB tuned via scale awareness).

Splits (absolute)

- Train: 2023-01→12, Val: 2024-01→03, Test: 2024-04→05.

Selection

Best model by AUC

Saves

model.pkl, scaler.pkl, metadata.json

Writes

model_config.json and model_evaluation.json

Stability: forbids empty splits; robust metrics (nan-safe log_loss/AUC in degenerate cases).

DAG 3: Inference & Monitoring (Range-Aware)

Inference

- Check Data Availability.
- Loads best model; features in trained order; numeric coercion; safe imputation.
- Output: predictions_<MODEL>_<YYYY_MM_DD>.parquet with prediction_proba, prediction_label, threshold, model_name, inference timestamps.

Monitoring

- Merges predictions with labels at snapshot_date + 6 months on loan_id + Customer_ID.
- Metrics per month: AUC, Accuracy, Precision, Recall, F1, Log Loss, Confusion Matrix.
- Drift: PSI vs baseline (first available predictions); saved monthly JSON + Parquet; cumulative model_monitoring.json.
- Robust: handles empty joins, missing labels (PSI-only mode), flexible file schemas, JSON-safe outputs.

Visualizations & Reporting (Gold → Results)

Inputs: cumulative monitoring history + monthly predictions in Gold.

Charts saved to results/monitoring_visualizations

- Performance Metrics Over Time

  (AUC, Acc, Prec, Rec, F1, Log Loss) with thresholds.

- PSI Trend

  with warning/critical bands (0.1/0.2).

- Confusion Components Trend

  (TP/FP/TN/FN).

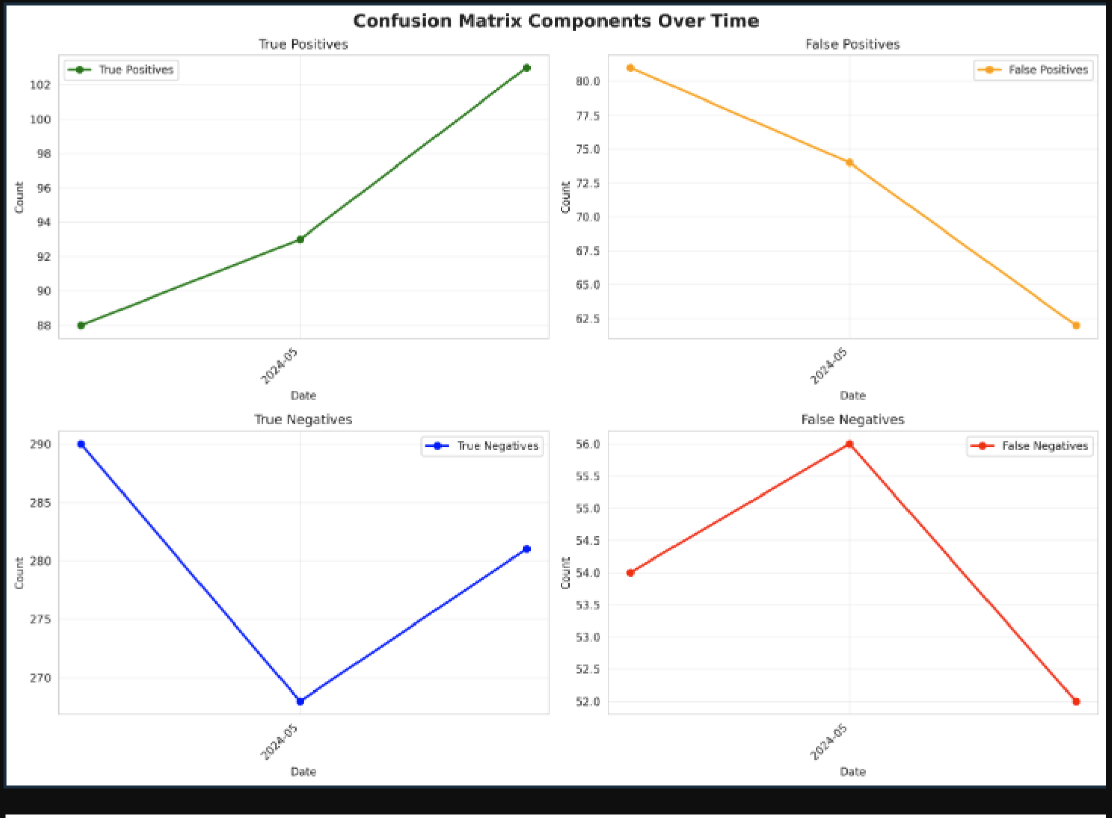
- Threshold Compliance Trend

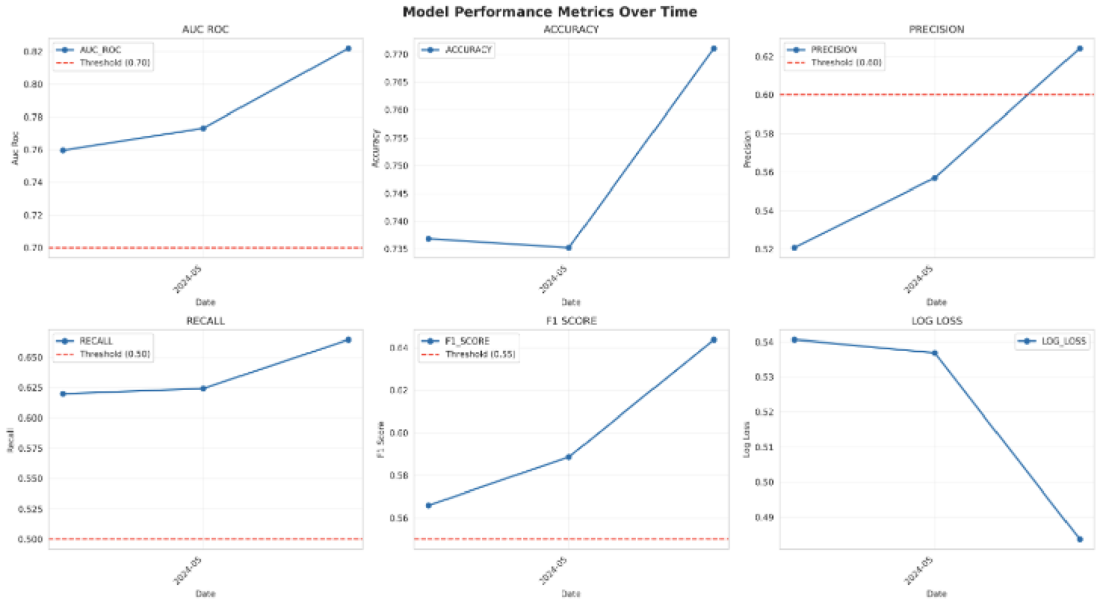
  (pass rate across AUC/Precision/Recall/F1).

- Prediction Distribution Over Time

  (normalized to prediction_proba).

Summary report: monitoring_summary_report.txt (latest + averages, compliance).





Governance: Automated Monitoring & Retraining

A critical feedback loop ensuring model performance and data integrity are continuously upheld through automated checks and re-triggering of the training pipeline.

Governance Triggers (Configurable)

Performance Degradation

AUC < 0.70 Precision < 0.60 Recall < 0.50

Priority Levels

P0 : ROC-AUC (Critical Business Metrics)

P1 : Accuracy (Important but not critical)

P2 : F1, Precision, Recall

Data Drift

PSI (Population Stability Index) ≥ 0.20

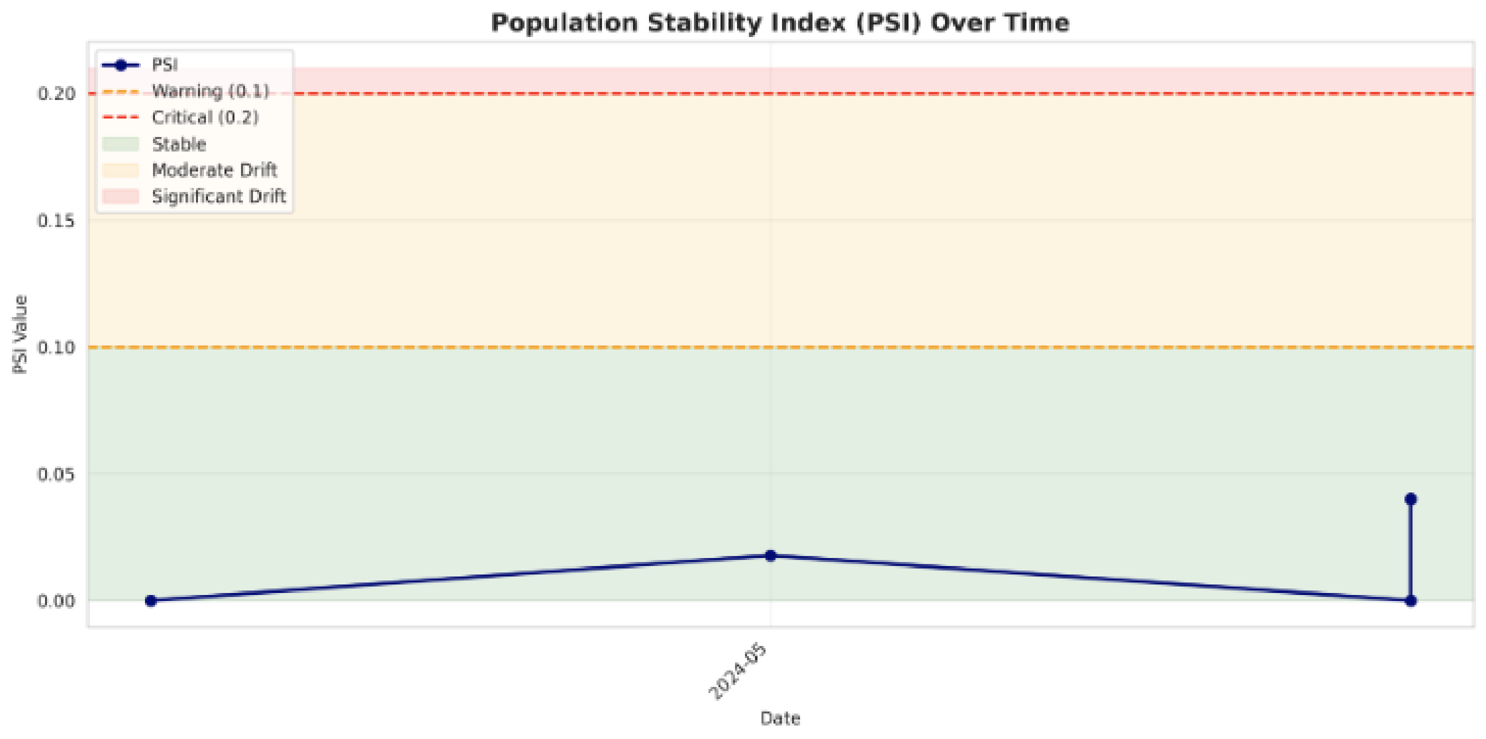
Automated Actions

A `BranchPythonOperator` checks these rules monthly after monitoring:

- If all rules pass: The pipeline concludes with no action.
- If any rule fails: The full Training pipeline (DAG 2) is automatically re-triggered, followed by deployment of the best model and resumption of inference/monitoring.

Guardrails

- MOB integrity enforced (`MOB=0` for features, `MOB=6` for labels).
- Range-aware execution: Only months with aligned labels contribute to performance metrics.
- Cumulative audit trail in `model_monitoring.json` for traceability.


Population Stability Index (PSI) Over Time
PSI
Warning (0.1)
Critical (0.2)
Stable
Moderate Drift
Significant Drift
PSI Value
Date