HYBRID ARCHITECTURE FOR EPIDEMIC FORECASTING: INTEGRATING DATA-DRIVEN ML AND SPATIAL CELLULAR AUTOMATA

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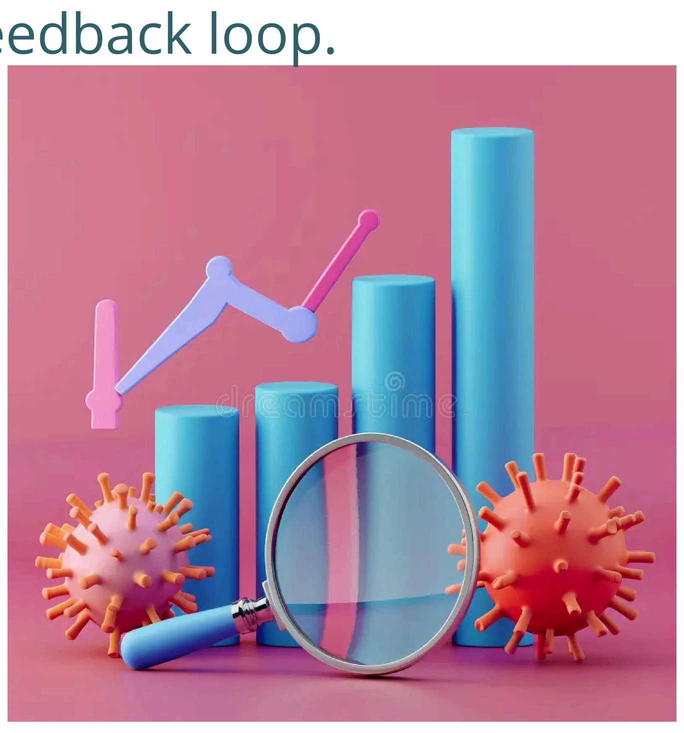
INTRODUCTION

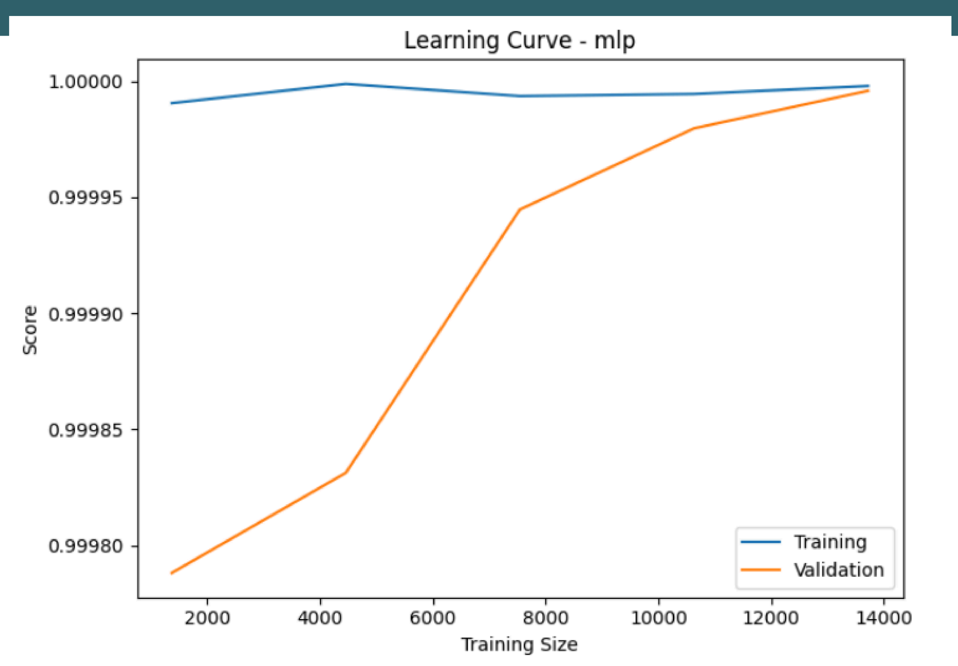
This project addresses the global need for transparent forecasting by implementing a modular system grounded in ***Systems Engineering principles.*** The solution integrates a data-driven pipeline ***(Scenario 1)*** using Machine Learning and an event-based simulation using ***Cellular Automata (Scenario 2).*** The system processes global data to predict cumulative COVID-19 cases, ensuring ***reproducibility, scalability, and stability*** through a validated feedback loop.



GOAL

To develop and validate a ***robust forecasting architecture*** that combines statistical learning ***(MLP, Random Forest)*** with spatial dynamics modeling. The primary goal is to ensure prediction stability under perturbations and demonstrate the technical feasibility of a ***feedback-driven pipeline*** for epidemiological modeling.

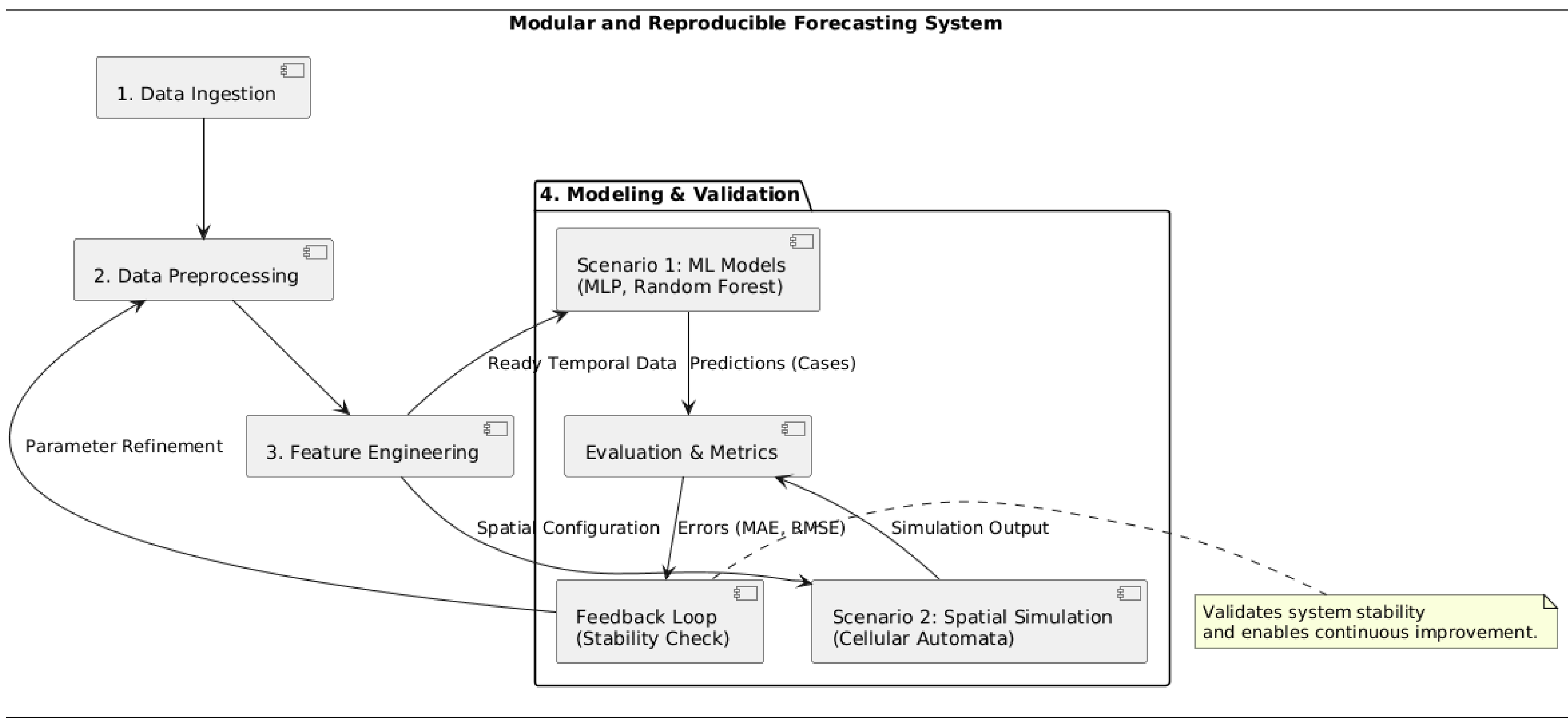
RESULTS



Quantitative Metrics:
MLP Model: MAE = 1.16, RMSE = 10.56 (Most Accurate).
Random Forest: MAE = 3.04, RMSE = 75.91 (High Variance).

Stability Analysis:
Robustness: The ML models showed high resilience to ***±5% input perturbations.***
Feedback Loop: Demonstrated ***convergence*** without oscillatory instability.
Cellular Automata: Exhibited ***high sensitivity*** and emergent spatial patterns, contrasting with the numerical stability of the ML models.

PROPOSED SOLUTION



EXPERIMENTS

Scenario 1: Machine Learning Performance Three models were evaluated using RMSE and MAE metrics. The ***Multi-Layer Perceptron (MLP)*** achieved the best balance of accuracy and stability, significantly outperforming ***Random Forest*** and Linear Regression.

Scenario 2: Spatial Simulation A 25x25 grid Cellular Automata was simulated. The experiment tested the system's sensitivity to initial conditions and infection probabilities, observing ***rapid convergence*** to homogeneous states, contrasting with the gradual trends of the ML models.

CONCLUSIONS

The project successfully validated a ***hybrid forecasting system.*** Results demonstrate that ***Machine Learning models (MLP)*** provide numerical stability and precision for trend forecasting, while ***Cellular Automata*** offer insights into non-linear spatial dynamics and emergence the ***modular architecture*** proved effective for handling real-world data, ensuring reproducibility and enabling continuous refinement through ***feedback loops.***

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