A Hybrid Digital Twins Framework for Personalized Dementia Care: A Proof-of-Concept Study

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INTRODUCTION

- Dementia is heterogeneous, with individuals experiencing different rates and patterns of cognitive decline. Longitudinal, multimodal health data may help capture these individual trajectories and support more personalized care [1].
- Digital twins (DTs) technology offers a promising approach to personalized dementia care by integrating longitudinal, multimodal health data to model individual trajectories and support clinical decision-making [2].
- Existing dementia-focused DTs applications remain largely conceptual or early-stage, with limited integration of longitudinal prediction, patient stratification, and individualized outcome modelling [2-3].

OBJECTIVE

- To develop a proof-of-concept Digital Twin framework for dementia care that integrates multiple machine learning approaches to support individualized disease monitoring and clinical decision support.

DIGITAL TWINS MODELLING FRAMEWORK

We integrate longitudinal, multimodal data to predict disease progression, discover cognitive trajectories, and provide similar-patient recommendations.

Longitudinal Data (ADNI)

- 12,023 visits
- 3,025 participants

Model A: Predict

What happens next?

- Predict future ADAS-Cog13 scores and diagnostic status
- Disease Progression

Model B: Trajectory

What Pattern exisist?

- Identify distinct cognitive trajectories over time
- Lognitudinal Progression

Model C: Reccomend

What happened to similar patients?

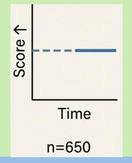
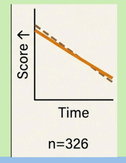
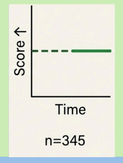
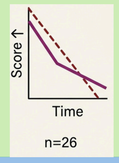
- Find clinically similar patients and examine their outcomes
- Similarity-Based Recommendation

MODEL A: DISEASE PREDICTION

- **Learned From:** 7,608 patient-visits, across all phases of the ADNI study.
- **Output:** Predicts future ADAS-13 score and next visit diagnosis status
- **Results** are from 5-fold cross-validation

MODEL B: LOGNITUDINAL PATTERNS

- **Learned From:** 1,347 patients who had at least 3 visits.
- **Output:** 4 distinct patient groups

Group 0 - Stable	Group 1 - Steady decline	Group 2 - Long-followed	Group 3 - Fast decline
Low scores; stable over time.	Worse baseline + faster decline; more carry **APOE4**.	Longest follow-up (~8 visits; ~9 years); relatively stable	Worst baseline; steepest decline; ~77% carry **APOE4**
			
n=650	n=326	n=345	n=26

DISCUSSION

- **Distinct trajectories:** Four longitudinal patterns highlight the heterogeneity of cognitive change across patients.
- **Personalized insights:** Clinical measures associated with outcomes may support more individualized monitoring and prediction.
- **Patient-centered predictions:** The recommendation model shows what happened to people with similar health profiles, making the results easier to understand and share.
- **DT potential:** Integrating trajectory modelling + patient stratification + similar-patient prediction provides a foundation for a personalized dementia decision support tool.

RESULTS

90.3%	0.786	4	0.798
Diagnostic Accuracy for ADAS-Cog13 prediction	**R^2** for ADAS-Cog13 prediction	**Distinct trajectories** from longitudinal clustering	**AUC** for worsening prediction (MAE = 2.430)

MODEL C: RECCOMMENDATION

Protective Factors associated with better outcomes:

- BP and pulse
- Baseline memory
- MoCA score

- **Learned From:** 925 patients with the richest set of measurements (Mo-CA required)
- **What it does:** Identifies 20 similar patients and summarizes their outcomes.

Example Output: A risk profile; "Among the 20 most similar patients: 80% stayed stable, 10% worsened, 10% improved."

CONCLUSION & FUTURE WORK

- Our results demonstrate the feasibility of integrating complementary predictive models within a DT framework for dementia care.
- The proposed architecture provides a foundation for incorporating multimodal real-world data and intervention exposure to support adaptive, personalized monitoring and decision-making.
- **Future Work:** Prospective validation is needed to assess clinical utility, fairness, interpretability, and generalizability.

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