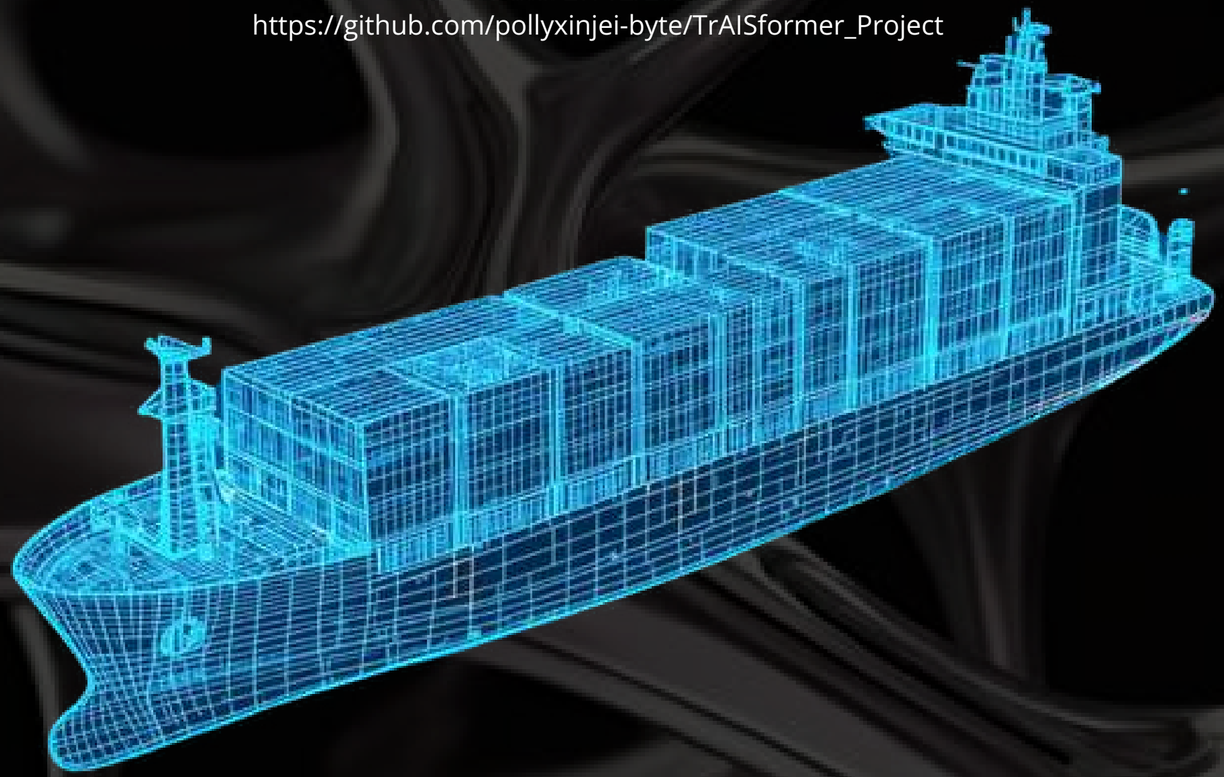
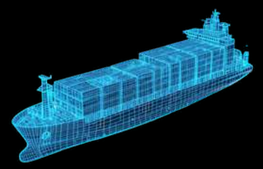
Reproducing TrAISformer for Vessel Trajectory Prediction

Moving from Regression to Classification in Maritime Situational Awareness

Author: Polly Chen-GOUJARD
MSc AI for Business (Neoma/INSA de ROUEN)
Date: 27/12/2025
https://github.com/pollyxinjei-byte/TrAISformer_Project





The Challenge: The "Average" Trap

- **Goal:** Predict future trajectory to prevent collisions.

- **The Reality:**

Vessels often face distinct choices (e.g., turning Left or Right around an island). This is called Multimodality.

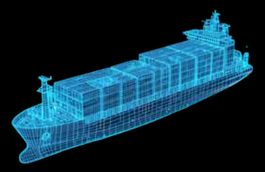
- **The Failure:** Traditional models (LSTMs) use Regression (MSE).

- **The Result:**

To minimize error, MSE predicts the mathematical average of two valid paths.

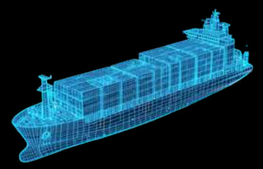
- **Consequence:**

The predicted path goes straight through the island. (Physically Invalid).



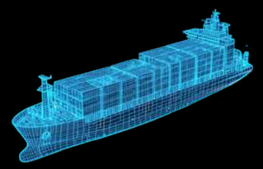
The Solution: TrAISformer
Treating Trajectories like Language

- **Core Shift:** We move from Regression (predicting a number) to Classification (predicting a probability).
- **The Input ("Four-hot"):** Instead of raw numbers, we discretize data into tokens: Lat + Lon + Speed (SOG) + Course (COG)
- **The Engine:** A Transformer Decoder (GPT-style).
- **Uses Self-Attention to look at the entire history at once.**
- **The Output:** A probability map over a grid (e.g., "70% chance Left, 30% chance Right").



Experimental Setup
Reproduction Environment

DATASET CONFIGURATION	COMPUTE ENVIRONMENT	IMPLEMENTATION DETAILS
Source: Danish Maritime Authority (DMA) **Training Data:** 9,144 Trajectories **Test Data:** 1,453 Trajectories	**Hardware:** Google Colab Pro (T4 GPU) **Framework:** PyTorch / Python 3.12 **Training Time:** ~100 Minutes (50 Epochs)	**Optimizer:** AdamW + Cyclic LR **Critical Fixes:** Refactored .__next__() Fixed Deprecated Iterators **Persistence:** Google Drive Integration

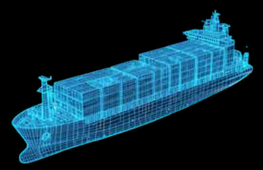


Successful Reproduction of State-of-the-Art Benchmarks
Reproduction Results: Exact Match

- **Primary Success:** Achieved 0.48 nautical miles (nmi) error at the critical 1-hour horizon.
- **Direct Comparison:** This result is an exact match with the original TrAISformer paper [Table I], confirming the validity of the architecture.
- **Unit Consistency:** All metrics were converted from Kilometers to Nautical Miles
- **Trend:** The error grows linearly over time (2h, 3h), which is consistent with the unpredictable nature of long-term vessel movement.

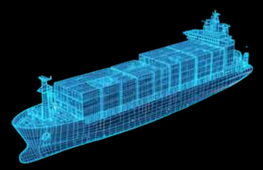
Prediction Horizon	My Reproduction (nmi)	Original Paper (nmi)	Original Paper (nmi)
1 Hour	**0.48**	**0.48**	✅ **Exact Match**
2 Hours	0.92	0.94	✅ Validated
3 Hours	1.51	1.64	✅ Validated

Observation: Error increases linearly with time, consistent with trajectory prediction physics

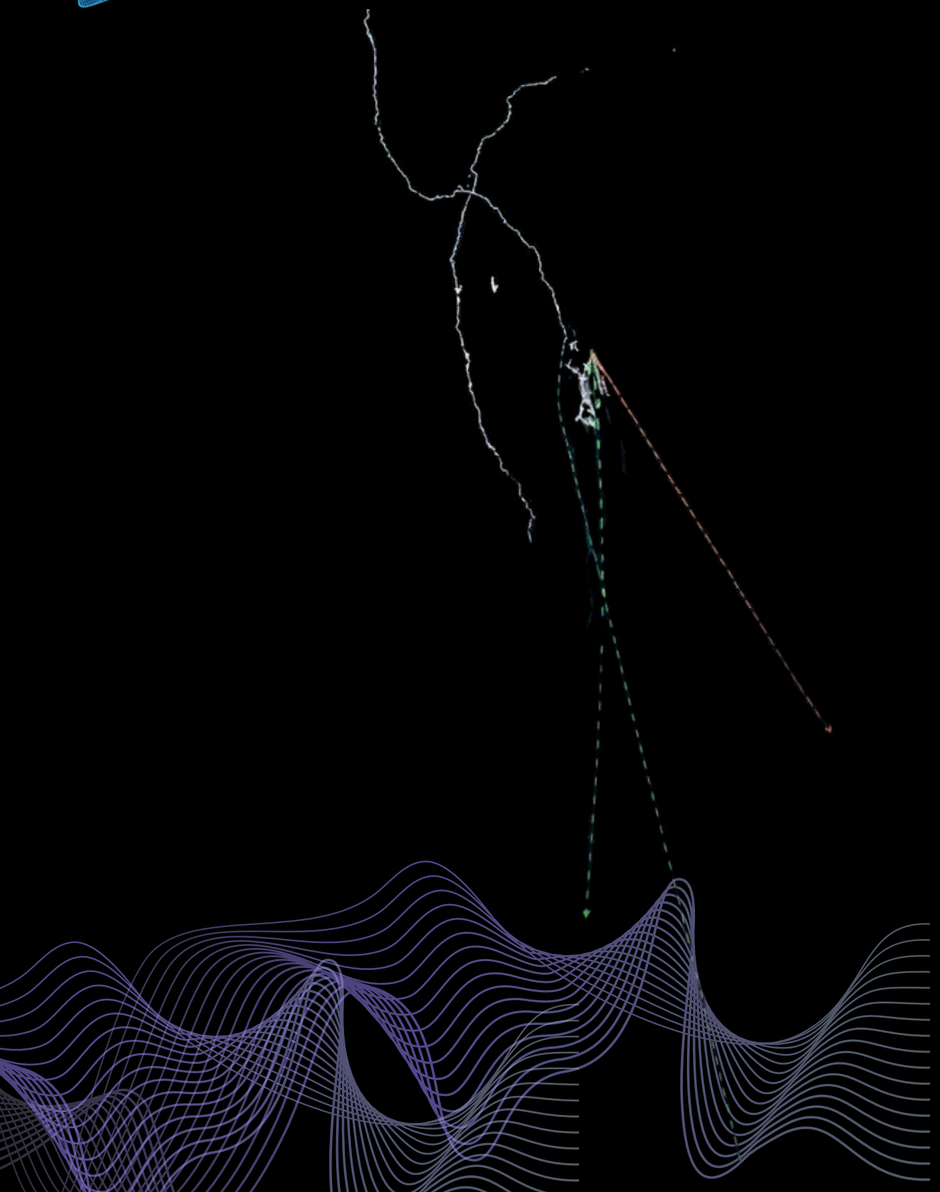


Training Analysis
Training Dynamics & Overfitting

TRAINING PHASE	METRICS OBSERVED	ANALYSIS & ACTION
OPTIMAL CONVERGENCE (Epoch 0 - 10)	**Validation Loss:** 1.38 (Minimum) **Training Loss:** 0.75	**Status: Optimal Performance** The model learned core trajectory patterns rapidly. Epoch 10 was identified as the "Best Checkpoint."
OVERFITTING ZONE (Epoch 11 - 50)	**Validation Loss:** 1.38 -> **3.91 (Spike)** **Training Loss:** 0.75 → **-1.68**	**Status: Generalization Failure** The divergence between training and validation metrics indicates the model began memorizing data.
STRATEGIC DECISION (Final Selection)	**Selected Epoch:** 10 **Rejected Epoch:** 50	**Action: Early Stopping Applied** Selected the Epoch 10 checkpoint to prevent overfitting, validating the paper's methodology.

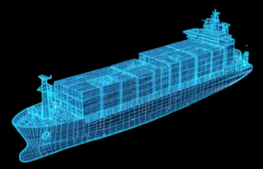


Qualitative Analysis: Prediction Accuracy



- **Scenario:** A vessel executing a navigational change (turn) in a coastal region.
- **Performance:** The model demonstrates the ability to capture complex maneuvers, not just linear movement.
- **Ground Truth (Green):** The actual path taken by the vessel.
- **Prediction (Orange):** The path generated by TrAISformer.
- **Result:** The strong overlap between the two lines visually confirms the low error rate (0.48 nmi) recorded in the quantitative analysis.

Figure 2: Representative visualization of prediction accuracy at the 1-hour horizon. The model successfully anticipates the vessel's turn



Conclusion & Future Outlook

- **Reproduction Successful ✅**

I successfully implemented the TrAISformer architecture on the DMA dataset.
Achieved 0.48 nmi error at 1-hour, matching the State-of-the-Art (SOTA) benchmark exactly.

- **Methodological Validation ✅**

Confirmed that treating trajectory prediction as a Classification task (token generation) is superior to Regression for complex maritime environments.
Validated the effectiveness of Early Stopping (Epoch 10) to mitigate overfitting.

- **Future Work 🚀**

Weather Integration: Incorporate wind and current data to improve accuracy for lighter vessels.
Vessel Interaction: Model ship-to-ship interactions for collision avoidance in crowded ports.