Machine Learning-based Multi-Step Ahead Handover Prediction for Stand-Alone 5G Systems in Maritime Environments

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Outline

- Motivation
- Data Collection
- Machine Learning
- Results
- Conclusion

Motivation

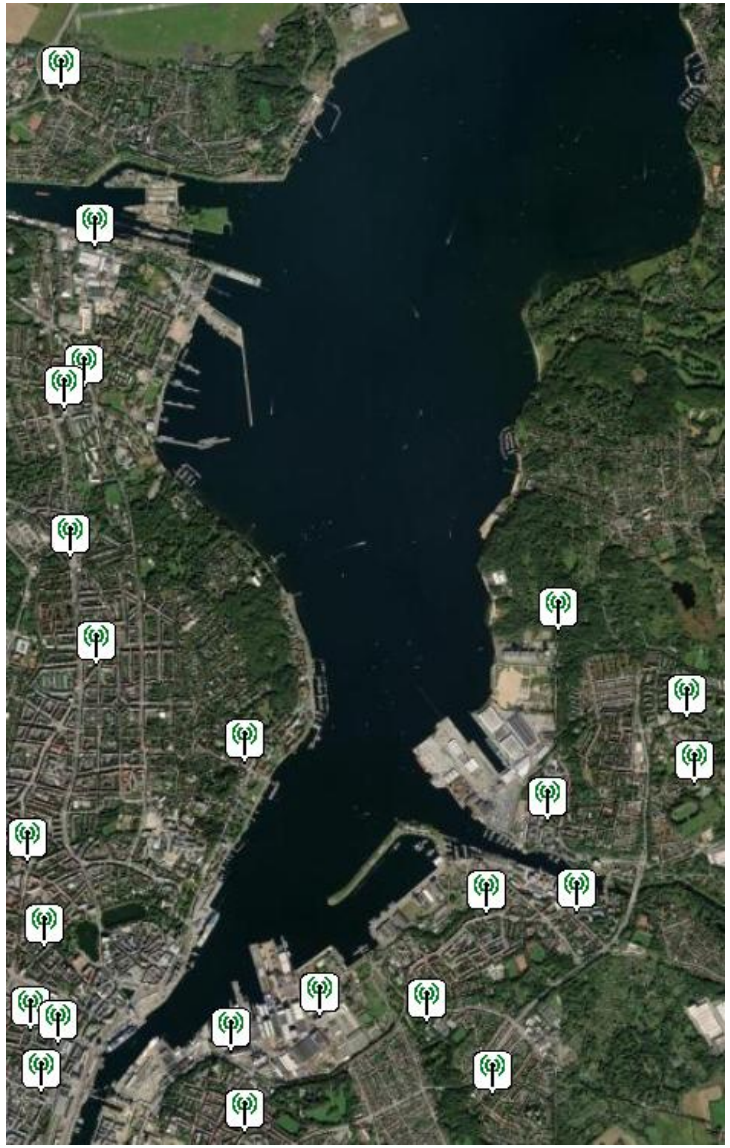
- Autonomous and remotely controlled vehicles in maritime traffic scenario
  - More freedom regarding movement → Less controlled environment
  - Increased distance to base stations → Higher likelihood of latencies and connection interruption
- <u>Challenge:</u> Handover between base stations
  - Increased vulnerability to additional latencies and even total connection loss

→ Predict handover on client side early enough to make reaction possible

WAVELAB research vessel

Experimental Data Collection

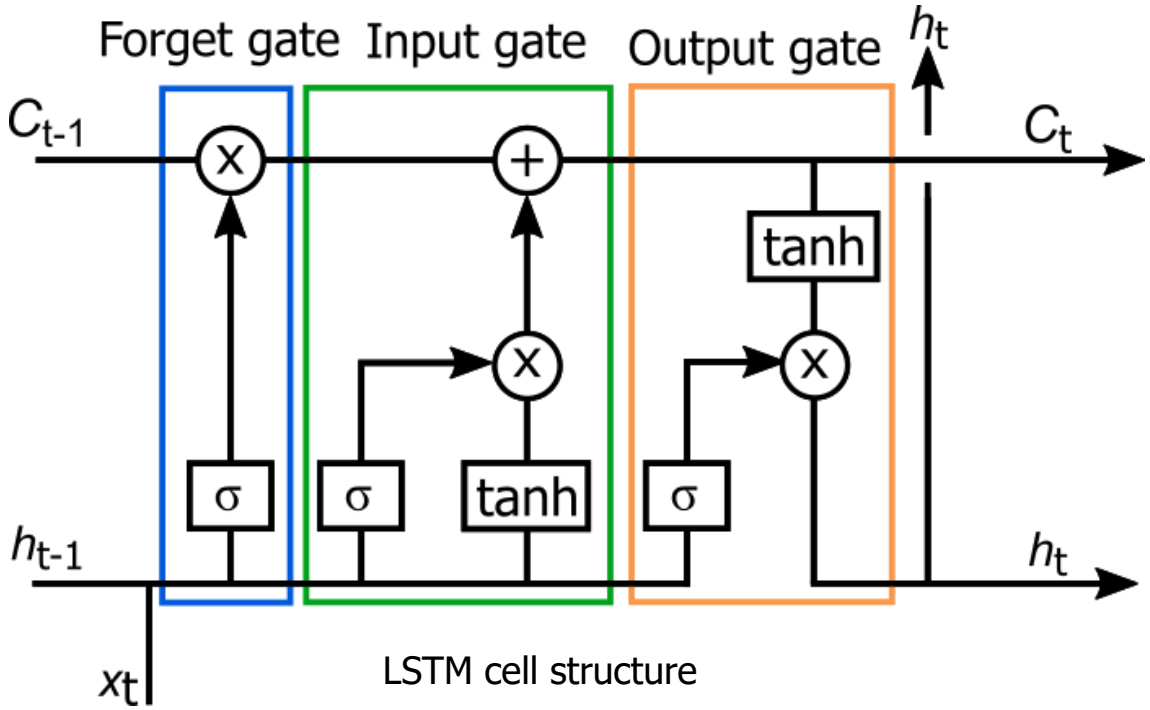
- Measurement period: ~1 year
- Measurement interval: 1 second
- Measurement method: Router on board of WAVELAB ship
- Total number of base stations connected: 23
- Parameters measured:
  - Latitude
  - Longitude
  - Cell ID
  - Channel quality indicator (CQI)
  - Signal-to-interference-and-noise ratio (SINR)
  - Reference signal receive power (RSRP)
- Only data measured at client side available



Data collection scenario along Kiel Fjord

Machine Learning - LSTM

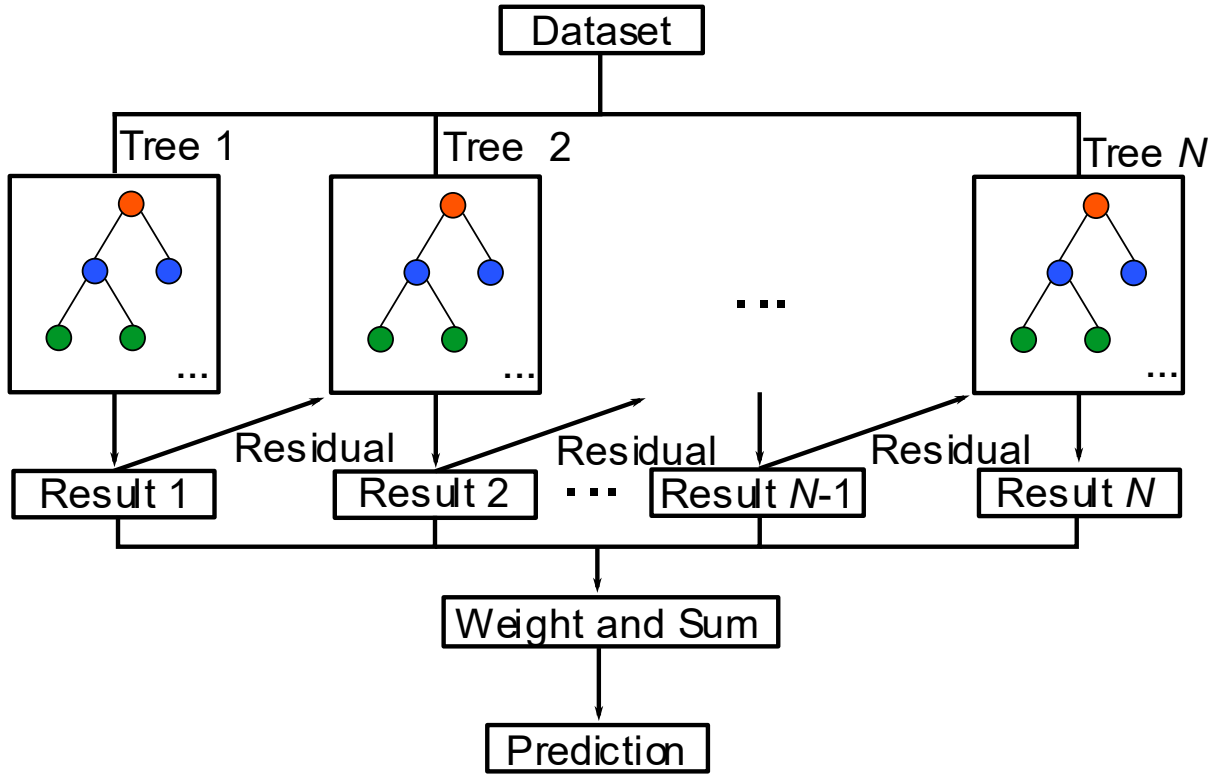
- Type of recurrent neural network (RNN) with gated structure
- 3 types of gates:
  - Forget gate: information from previous cell state forgotten
  - Input gate: new information used to update current state
  - Output gate: parts of the cell state serve as the output
- Gated structure to avoid exploding or vanishing gradient problem



LSTM cell structure

Machine Learning - XGBoost

- Extension of the decision tree
- Trees created using residual distances
- Output of one tree as new residuals for next tree
- Continues until maximum number/set threshold reached
- Final prediction using sum of outputs of all trees



XGBoost structure

Machine Learning - Setup

- Total dataset size: 300,000 entries
- Dataset is scaled with Keras' standard scaler and split into 75% training set and 25% testing set
- Highly imbalanced data, only 2% handovers
- Batch generator to rebalance data during training
- Predicted time steps: 1, 3, 5 and 10 seconds

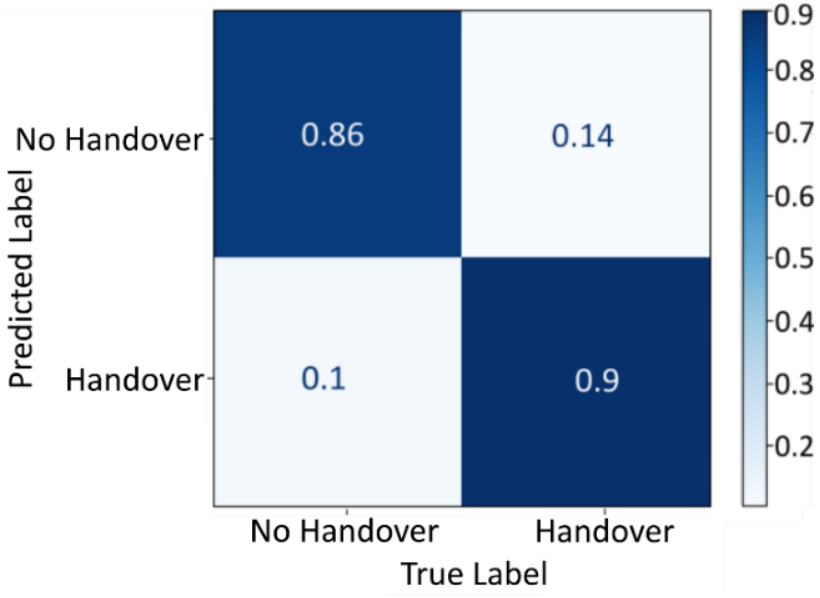
LSTM	
Implementation	Python using Keras
Structure	2 LSTM layers with 10 cells + Fully connected layer with sigmoid activation
Number of features	9 (cell ID encoded into binary vector)
Training	50 epochs
Batch Size	100
History	100 samples

XGBoost	
Implementation	Python using XGBoost library
Structure	80 trees with maximum depth 16
Number of features	10 (9 + Timestep feature for temporal context)
Learning rate	0.25
Regularization parameter	1

Results – Prediction 1 Second ahead

- Both algorithms perform similarly for the prediction of a handover exactly one second in the future
- LSTM: Prediction accuracy of 90% and 86%
- XGBoost: Prediction accuracy of 89% and 86%

LSTM

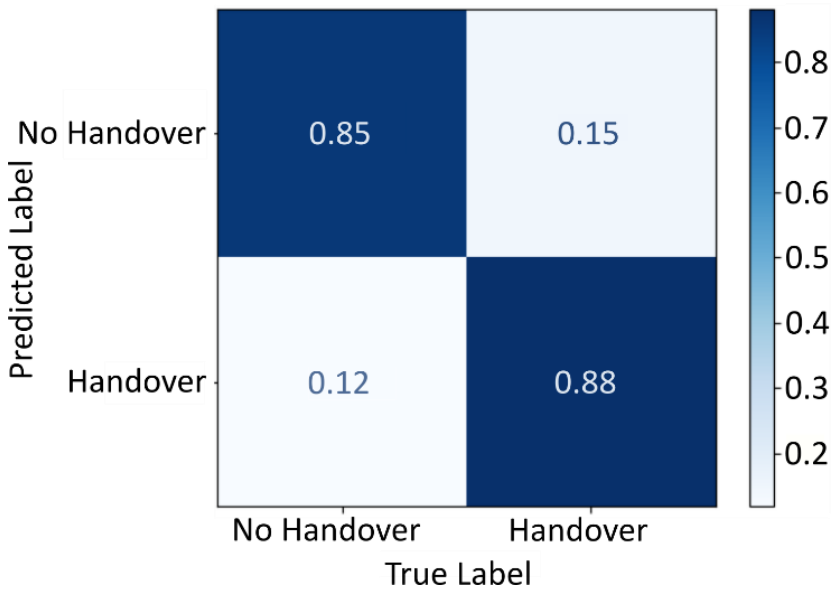


XGBoost

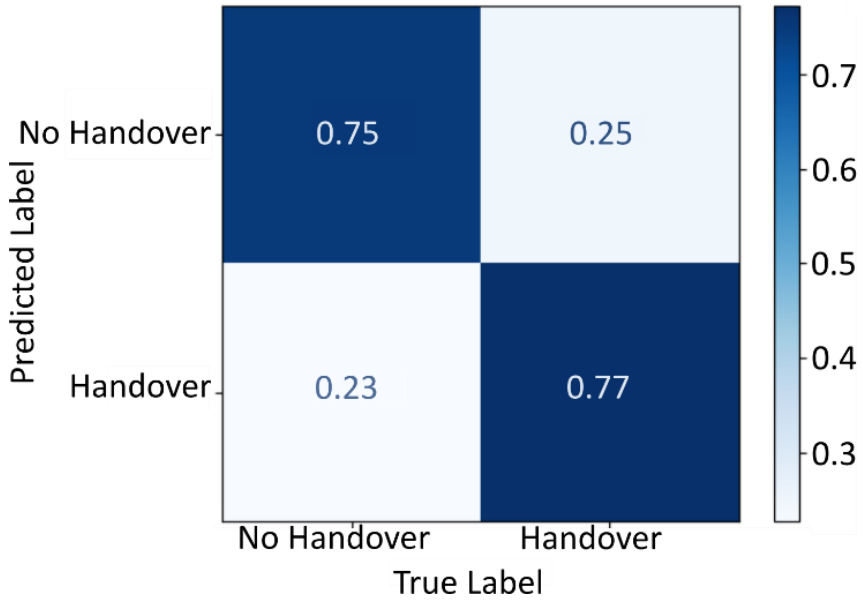
Results – Prediction 10 Seconds ahead

- LSTM maintains similar performance while XGBoost shows significant accuracy loss
- LSTM: Prediction accuracy of 88% and 85%
- XGBoost: Prediction accuracy of 77% and 75%

LSTM

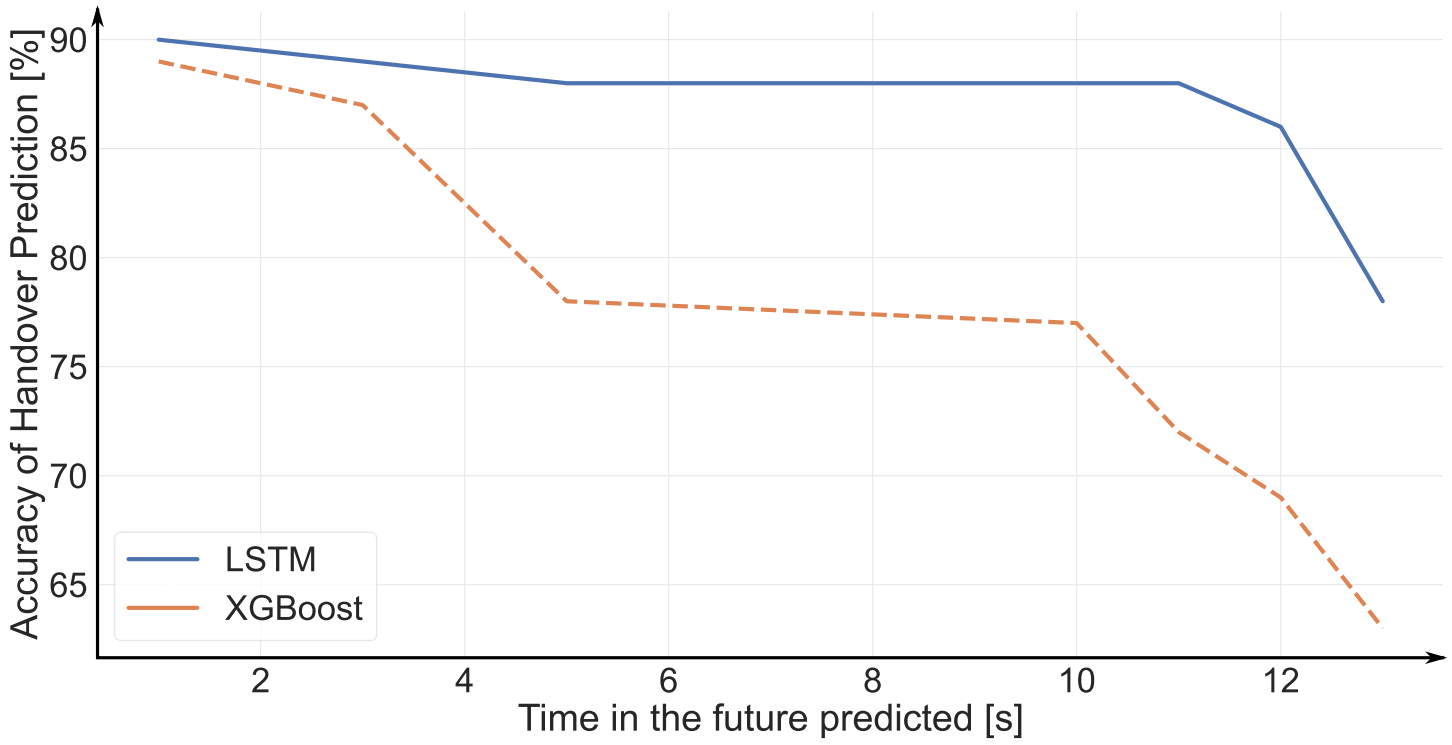


XGBoost



Results – Accuracy Progression

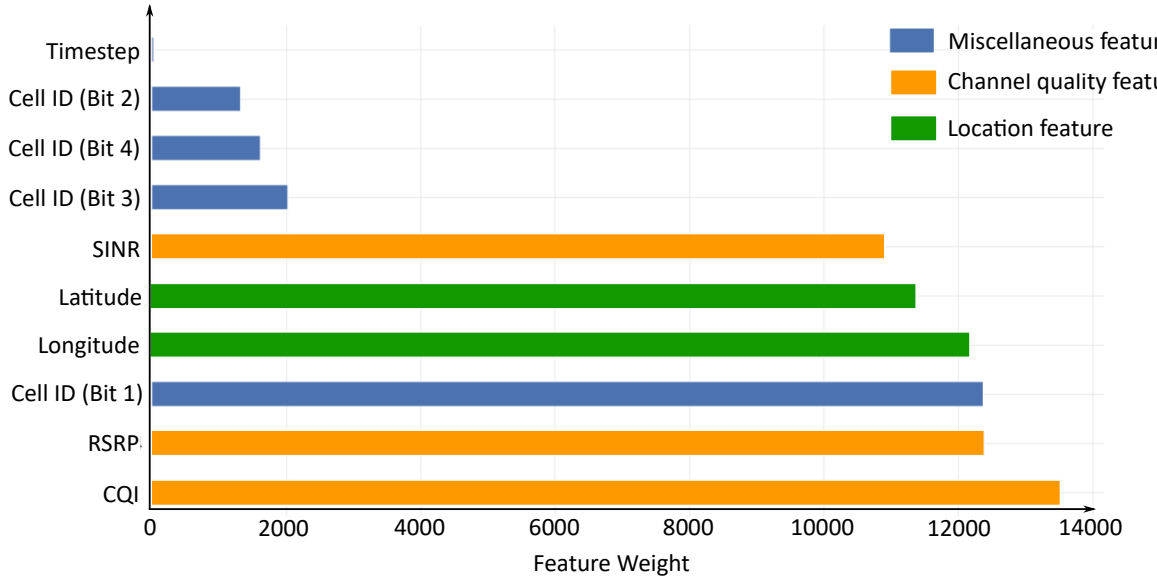
- LSTM shows only minimal accuracy reduction for any of the observed points until 10 seconds
- XGBoost shows similar progression 3 seconds into future but shows several large accuracy drops for further time steps



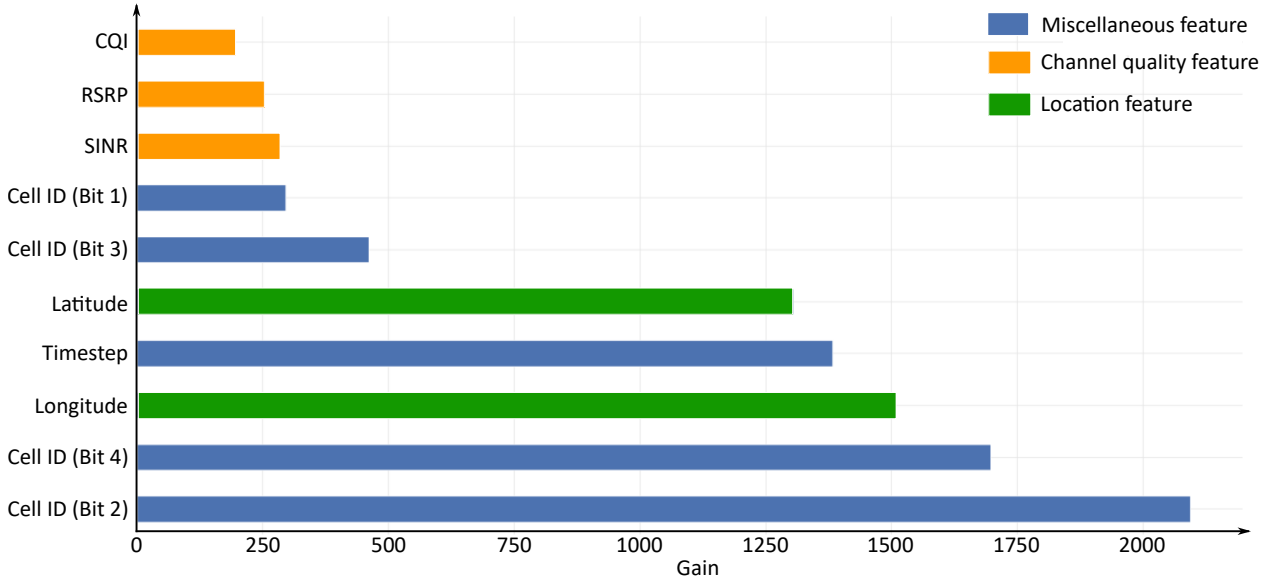
Results – Feature Importance

- Feature importance metrics
  - Weight (number of times a feature is used to split data across all trees)
  - Gain (reduction in training error by each split in all trees)
- Location features create highest gain but low weight
- Channel quality features show high weight but low gain

Weight



Gain



Conclusion

- Both algorithms achieve high accuracy for 1 second prediction
- LSTM only minor accuracy loss for over 10 seconds into the future
- XGBoost loses accuracy quickly, losing over 10% accuracy for 10 seconds into future
- All features significantly impact either gain or weight

Thank you for the attention!

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