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S4M:S4 for multivariate time series forecasting with Missing values

Addressing the challenge of missing observation in time series forecasting

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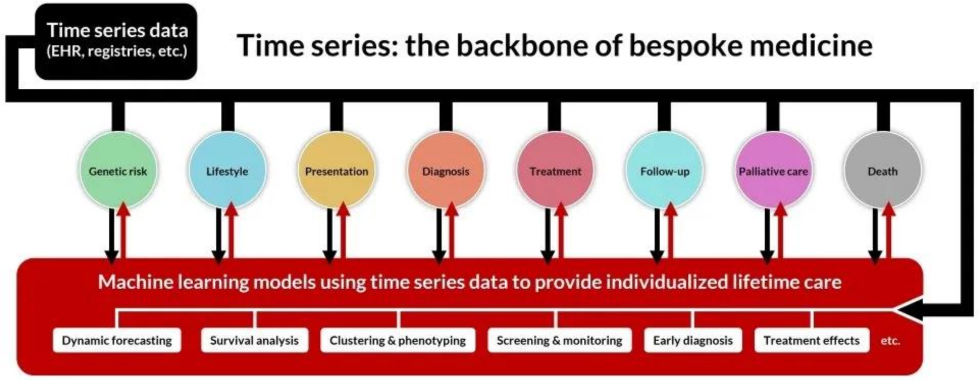
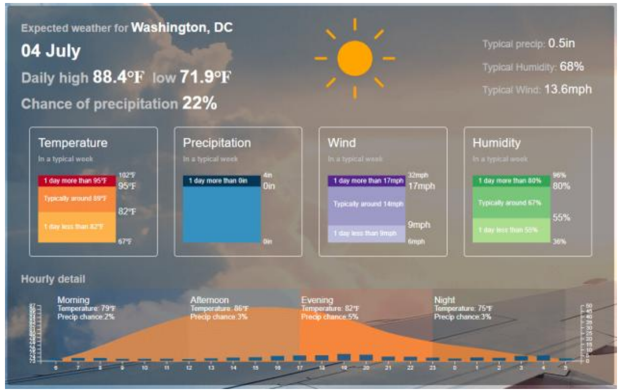
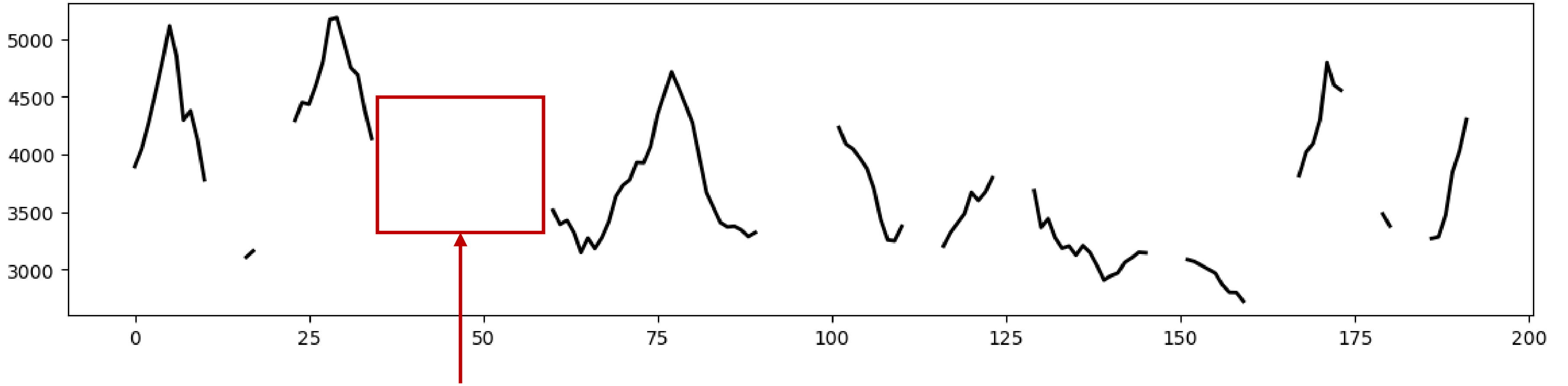
Background

Multivariate time series forecasting are ubiquitous







Consecutive missing: sensor failures, data collection issues, or external disruption

Existing work

Transformer-based

Autoformer (Wu et al.,2021)
iTransformer(Liu et al.,2023)
CARD(Xue et al.,2023)

Not designed for missing data

Two step: Impute then forecast

SAITS (Du et al., 2023)

Accumulated errors
Imputation in high-D

RNN-based

GRU-D (Che et al., 2018)
BRITS (Cao et al., 2018)

Long training time
Poor performance

ODE-based

Neural ODE (Chen et al., 2018)
GraFITi (Yalavarthi et al., 2024)
CRUs (Schirmer et al., 2022)

Expensive computation

Graph model-based

BiTGraph (Chen et al., 2023)

High memory

Our method

Low memory
Low computation
Good performance

Motivation for our design

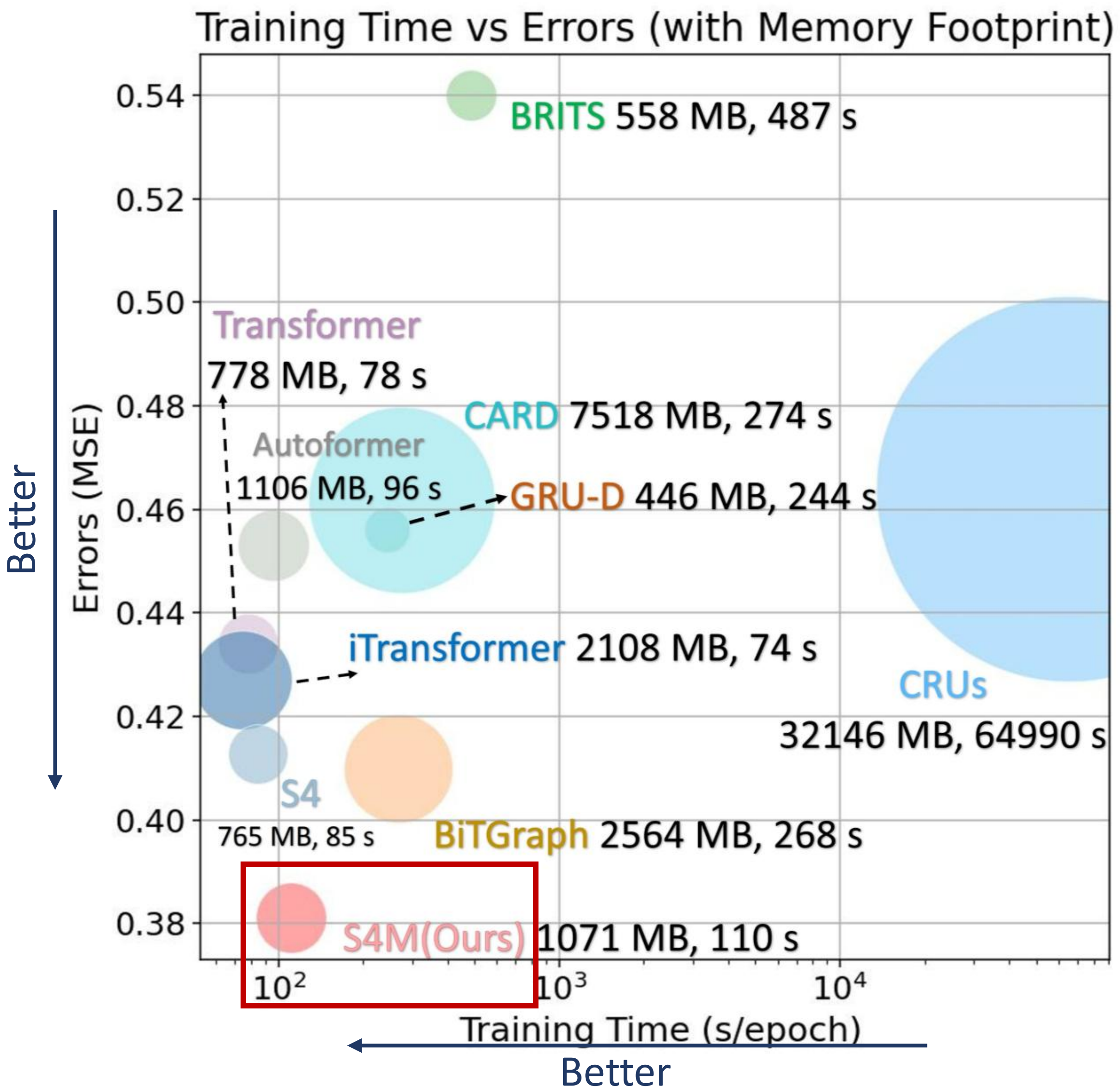
Q: Impute then forecast lead to accumulated errors
S: End-to-end

Q: Imputation in high-dim. is difficult
S: Imputation in lower-dim latent space

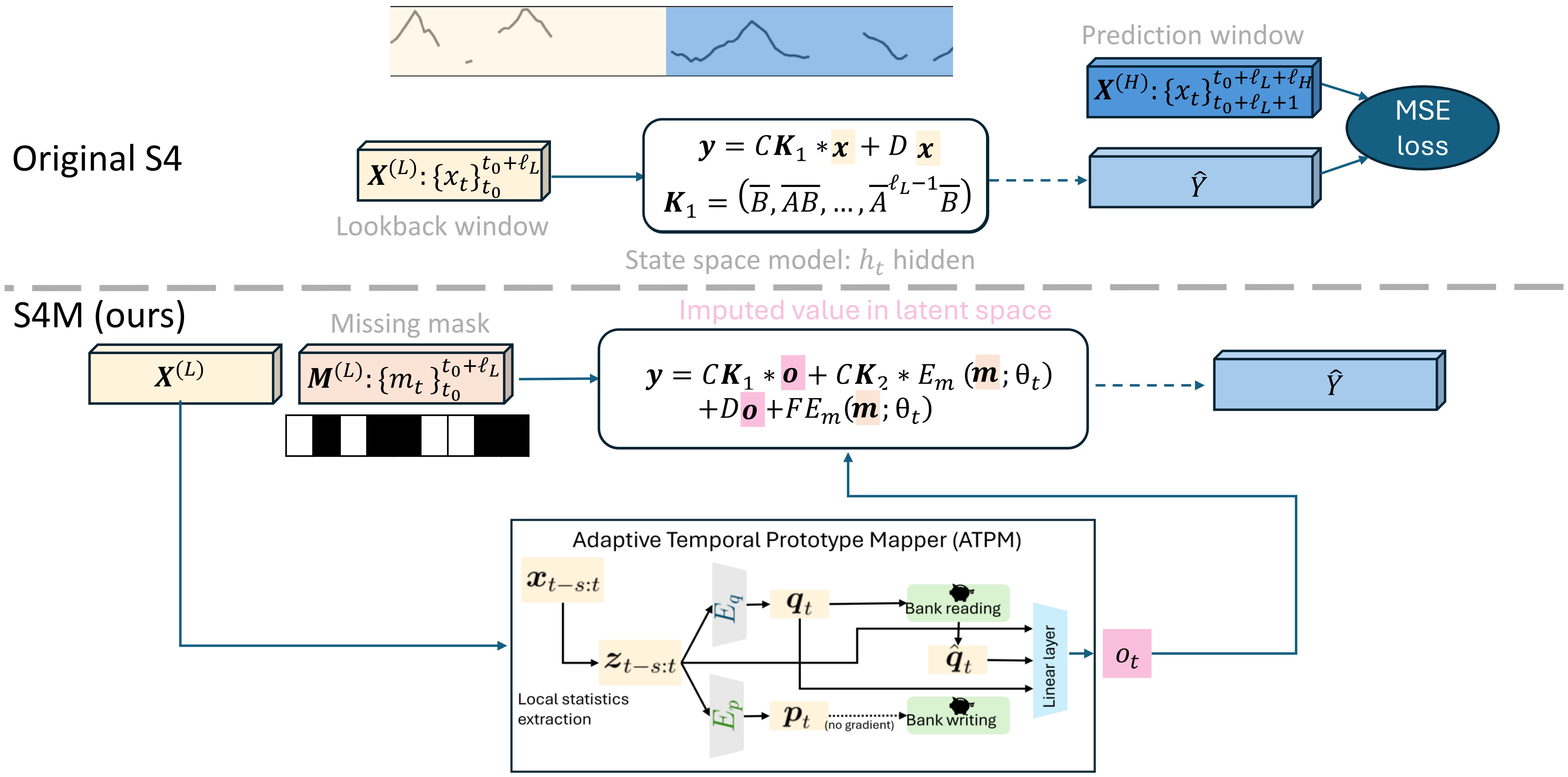
Q: Limited historical patterns for reference
S: Prototype bank to store rich representations

Q: High memory, computation
S: S4 (Structured State Space Sequence) model

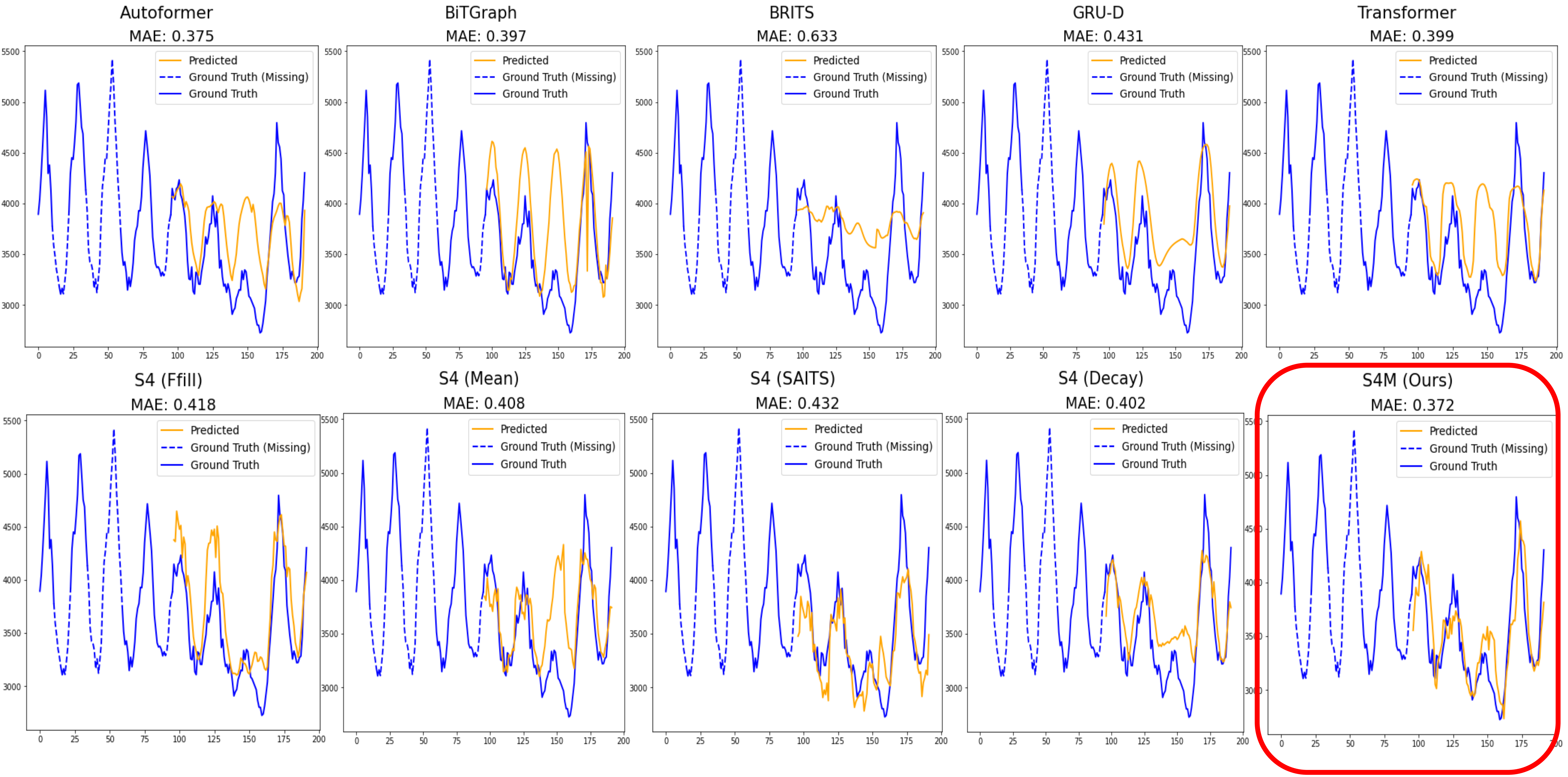
- High accuracy
- High computational efficiency
- Specialized kernel structure extendable to multiple input streams



Method overview



Qualitative result



Conclusion

- The structured state space(S4) model demonstrates superior forecasting performance with high efficiency, outperforming RNN-based and attention-based models.
- Imputing in a lower-dimensional latent space, rather than the original high-dimensional variable space, enhances robustness and accuracy.
- A prototype bank that stores rich historical patterns can be highly beneficial for handling missing observations.