BNP PARIBAS
CORPORATE & INSTITUTIONAL BANKING

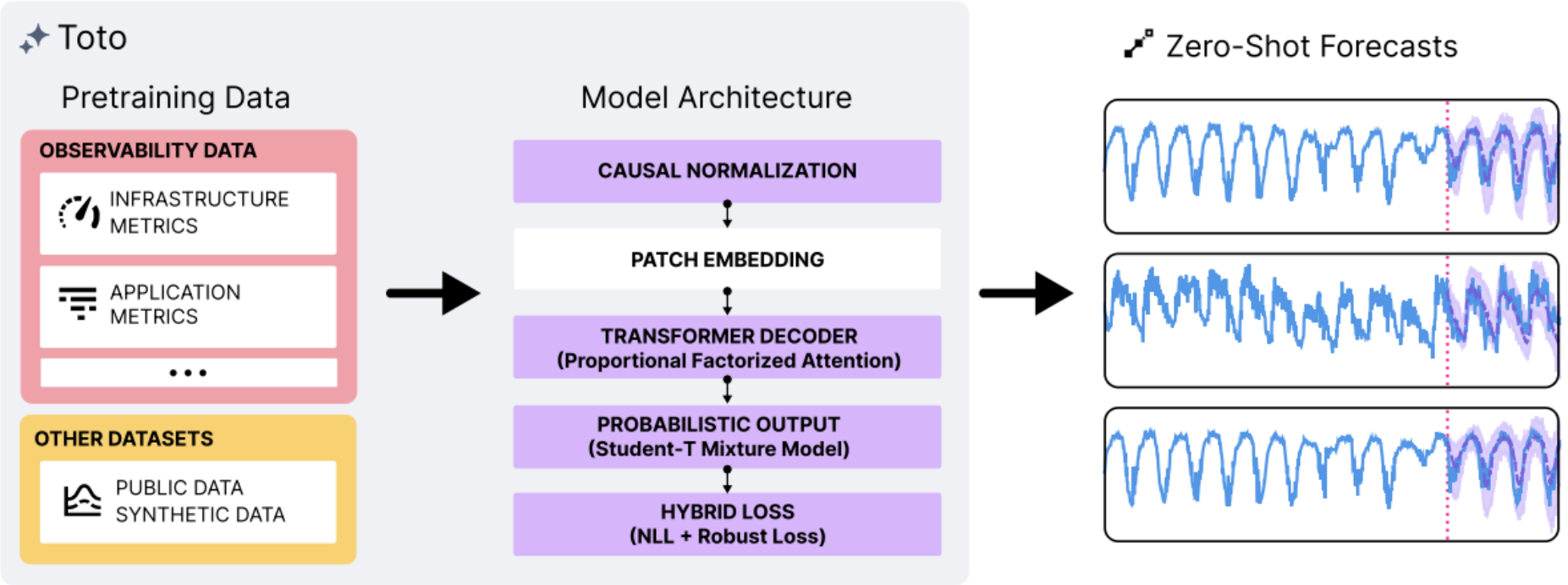
This Time is Different: An Observability Perspective on Time Series Foundation Models

Paper Review

MARZOUG AYOUB

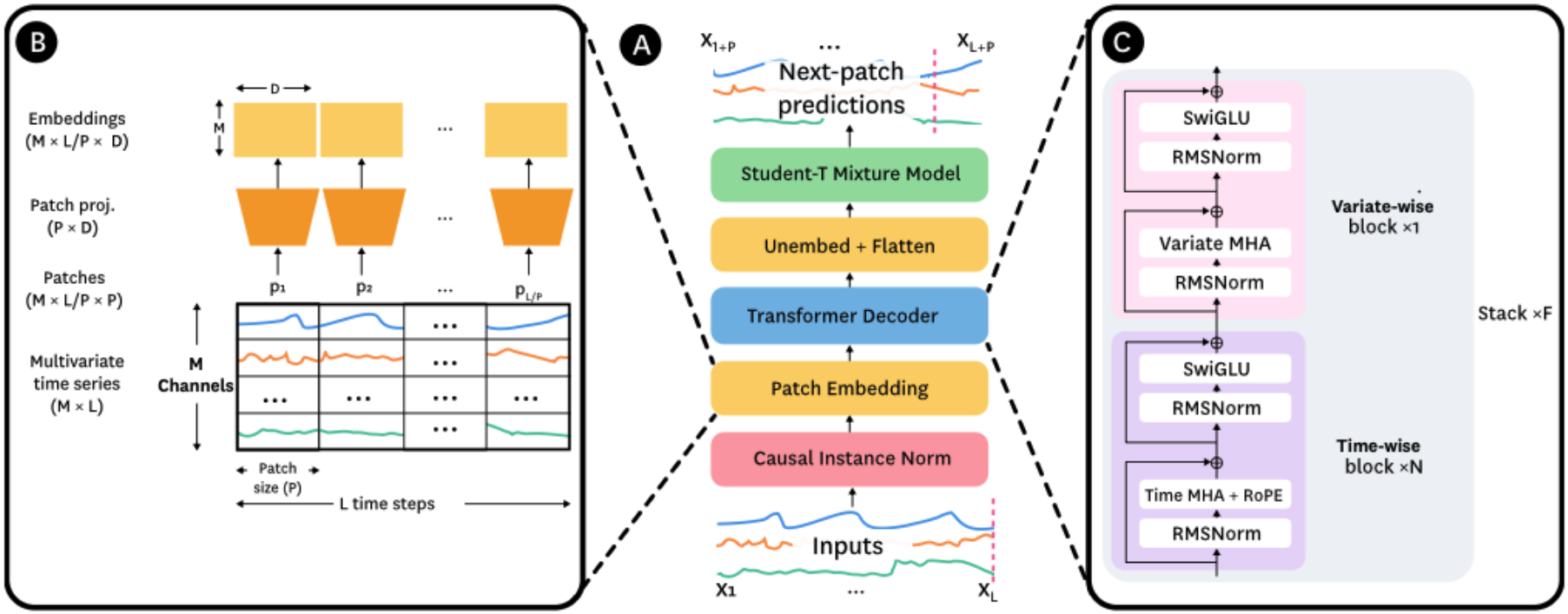
June 26th, 2025

What is TOTO ?



TOTO *(***T***ime* **S***eries* **O***ptimized* **T***ransformer for* **O***bservability) : FM specifically designed for forecasting observability data, with 151M parameters.*

Backbone Architecture



Patch-based Causal Scaling

Problem

Standard LayerNorm is **non-causal** $\Rightarrow$ information leakage in autoregressive settings.

Solution

Scaling factors for each patch are computed exclusively from the current patch and past data :

$$\hat{\mu}_t = \frac{\sum_{i=1}^{t} w_i x_i}{\sum_{i=1}^{t} w_i}, \quad \hat{s}_t = \sqrt{\frac{\sum_{i=1}^{t} w_i \left(x_i - \hat{\mu}_t\right)^2}{\sum_{i=1}^{t} w_i - 1} + 0.1}$$

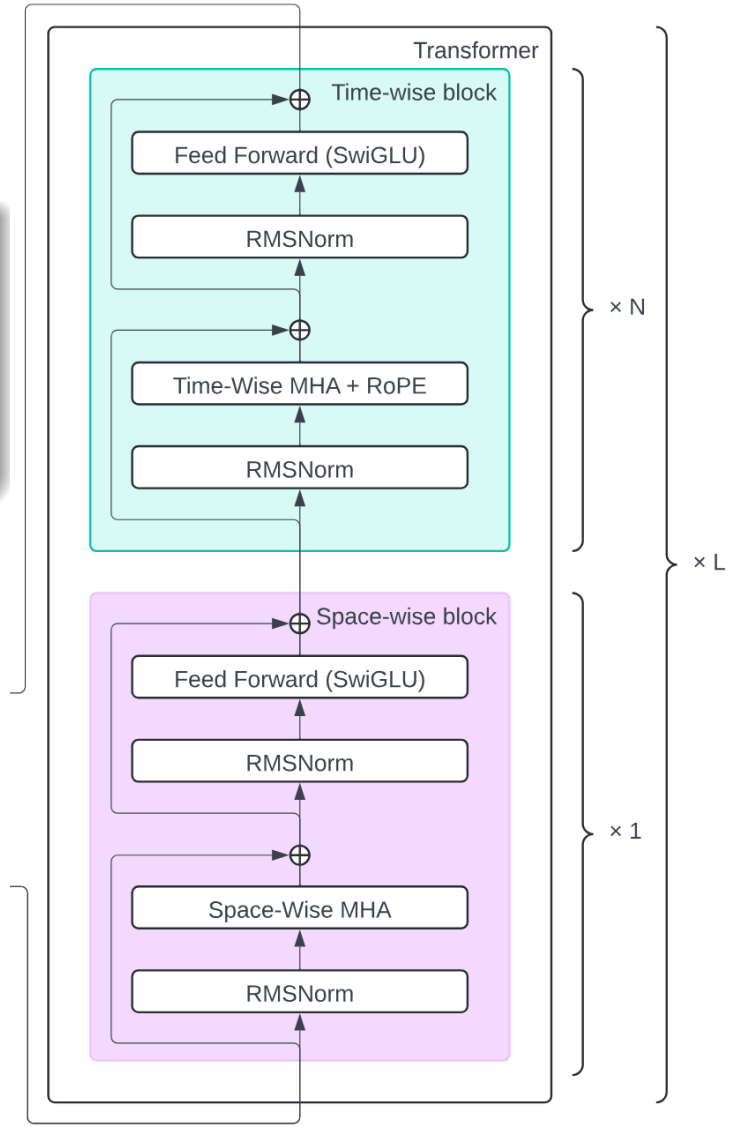
Proportional Factorized Space-Time Attention

Motivation

Standard attention over flattened $[T, D]$ sequences is inefficient for high-dimensional multivariate time series

Factorized Attention alternates :

- **Time-wise attention** over patches across time.
- **Variate-wise attention** over variables across channels.



Probabilistic SMM Head

Forecasting Mechanism

Generating **probabilistic forecasts** via a **Student-T Mixture Model (SMM)** head :

$$p(x) = \sum_{k=1}^{K} \pi_k \mathcal{T}\left(x \mid \mu_k, \tau_k, \nu_k\right)$$

More robust than Gaussian or quantized token prediction — captures heavy tails and outliers in observability data.

Pre-training Loss

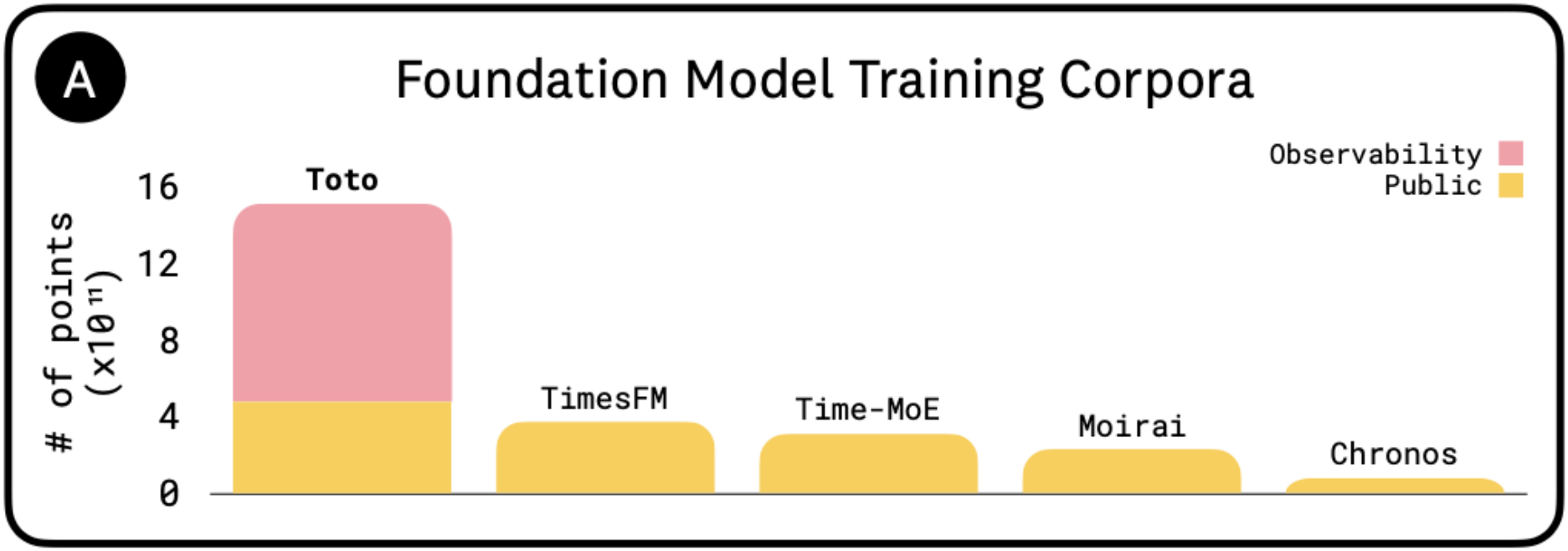
Composite Robust loss

Combining SMM NLL and robust Cauchy loss :

$$\mathcal{L} = \lambda \cdot \mathcal{L}_{\text{NLL}} + (1 - \lambda) \cdot \log\left(1 + \frac{(x_t - \hat{x}_t)^2}{2\delta^2}\right)$$

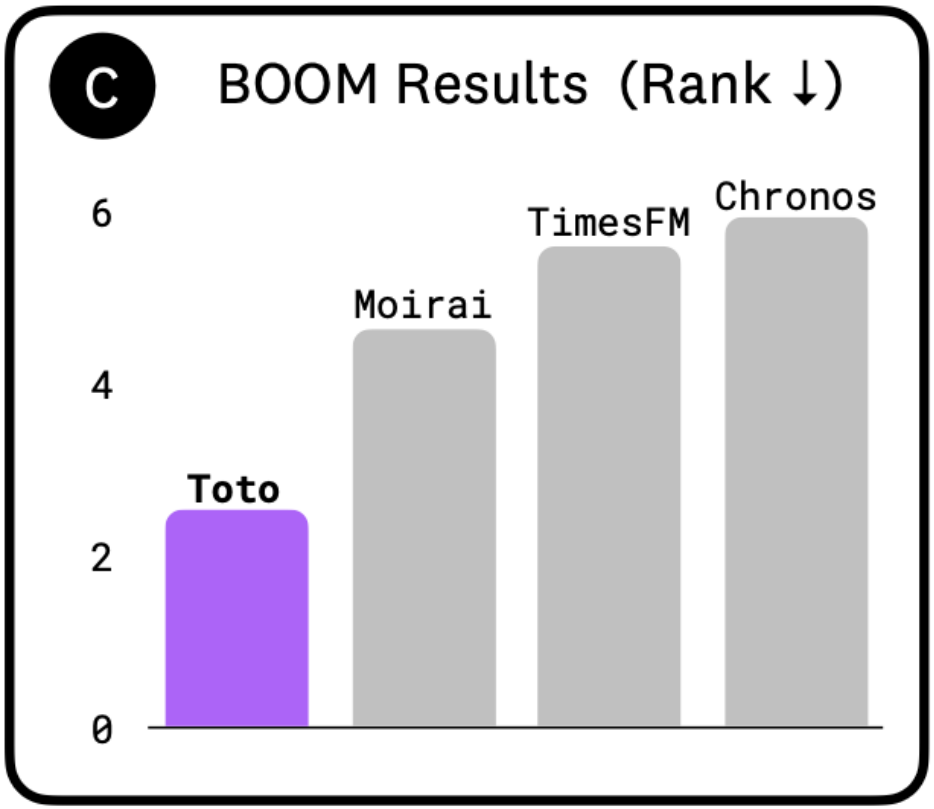
where $\lambda \in [0, 1]$ is a ratio tuned purely for autoregressive forecasting, with optimal value $\lambda = 0.57$.

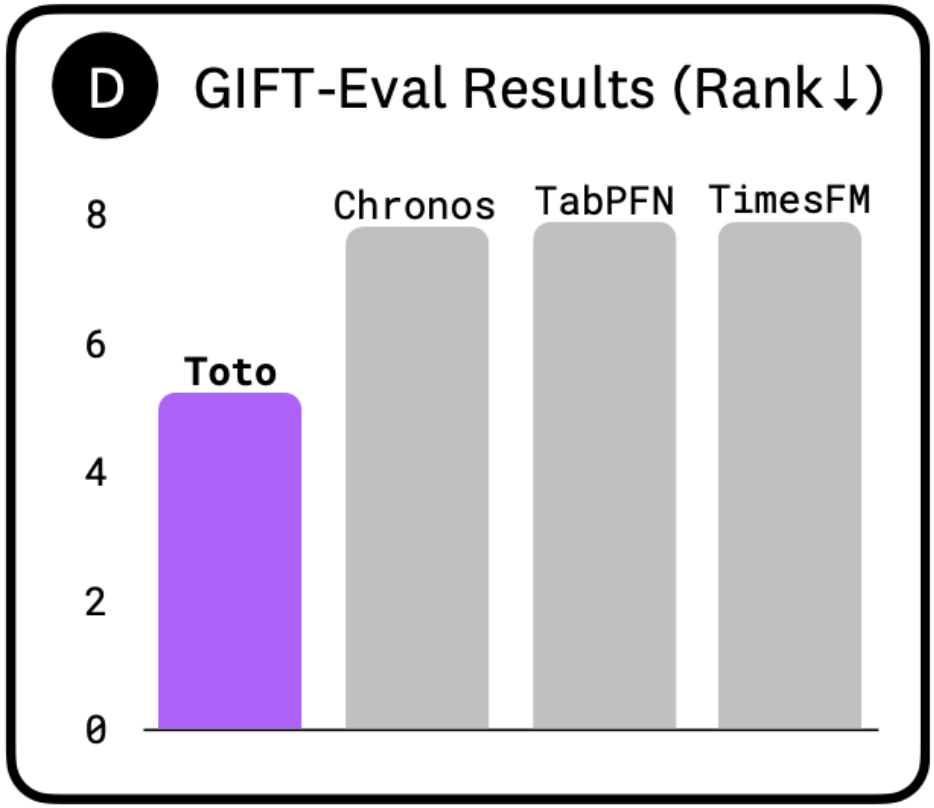
Pretraining Corpora



Largest and most diverse training corpus (2.36 trillion points).

Boom Benchmark & Experiments





TOTO outperforms state-of-the-art models by $\sim 12\%$ *CRPS.*

Potential for Financial-Series

- **Covariates Handling** : Natively supports multivariate input — ideal for integrating multiple financial indicators and correlated instruments.
- **Adaptable flexible loss** : can easily encode finance-specific priors (*e.g.* OU mean-reversion or GARCH volatility) :

$$\mathcal{L} = \lambda_1 \underbrace{\mathcal{L}_{\text{NLL}}}_{\text{Student-T mixture}} + \lambda_2 \underbrace{\mathcal{L}_{\text{Cauchy}}}_{\text{robust point error}} + \lambda_3 \underbrace{\mathcal{L}_{\text{prior}}}_{\text{OU / GARCH /...}}$$

- **Frequency Agnostic** : Patch-based encoder handles high-frequency streams naturally.
  - *Low-freq* : larger patch size and/or add seasonal event covariates.
  - *High-freq* : down-sample slightly.

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Questions ?

Thank you for your attention !