Memformer

A Memory Guided Transformer for Time Series Forecasting

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1. Introduction

1.1 Motivation

Forecasting

- Predicting the future
  - Allows preparation
- Many applications
  - Electricity prices
  - Finance
- Long term forecasting?
  - Obviously more difficult than short term
  - Time constrained tasks

1.1 Motivation

Long Term Forecasting

- What defines long term?
  - Historical horizon
  - Forecasting horizon
  - Both exceed 96 time steps
    - Hourly time step $\longrightarrow$ 4 days
  - Time series

Variable Correlation

- Complex systems have many variables
- A increases and B increases $\longrightarrow$ Positive
- A increases and B decreases $\longrightarrow$ Negative
- A increases and B is stagnant $\longrightarrow$ None
- These impact forecasting accuracy
  - Patterns in the data

Dynamic Correlations

- Are variable correlations stable over time?
  - No
- Correlations are dynamic over time
  - Seasons
  - Sensor drift
- We often consider average
  - Especially hurtful in time series
  - Predictions are bad in periods

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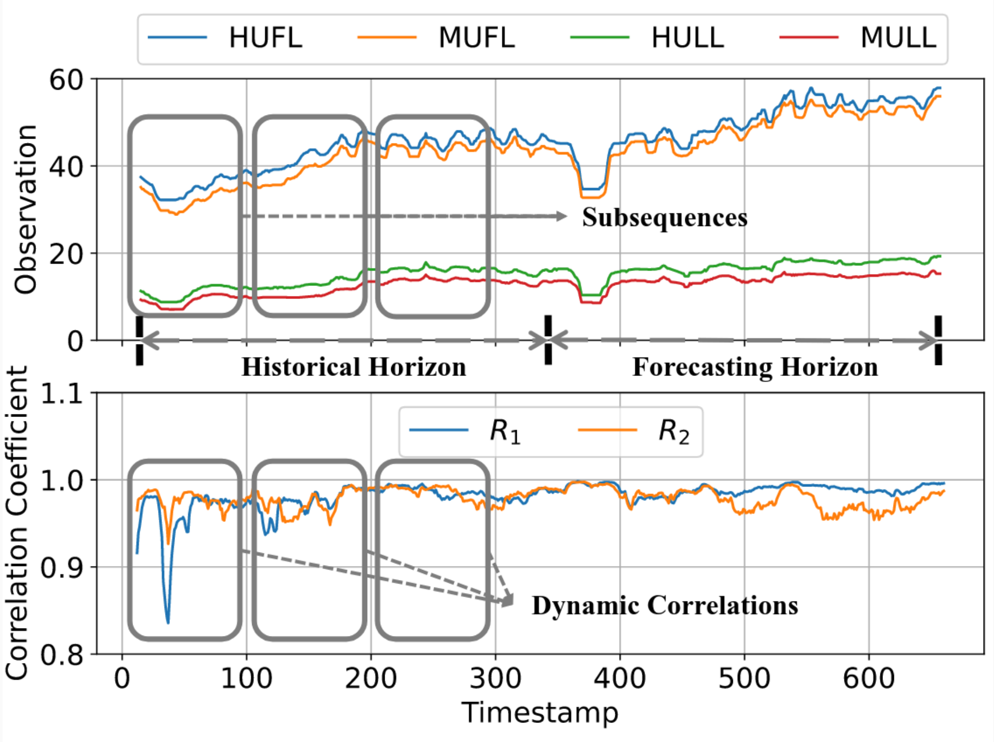

(a) Dynamic correlations. The Average $R_1 = 0.995$ and $R_2 = 0.990$.

Disrupted Correlations

- System errors
- External influence
- What happens with outliers?
  - Affect correlation $\longrightarrow$ accuracy
- Many models are sensitive to outliers
  - Numeric difference dominates training
  - Reason for a lot of preprocessing
    - Normalization
    - Clipping
    - Pruning

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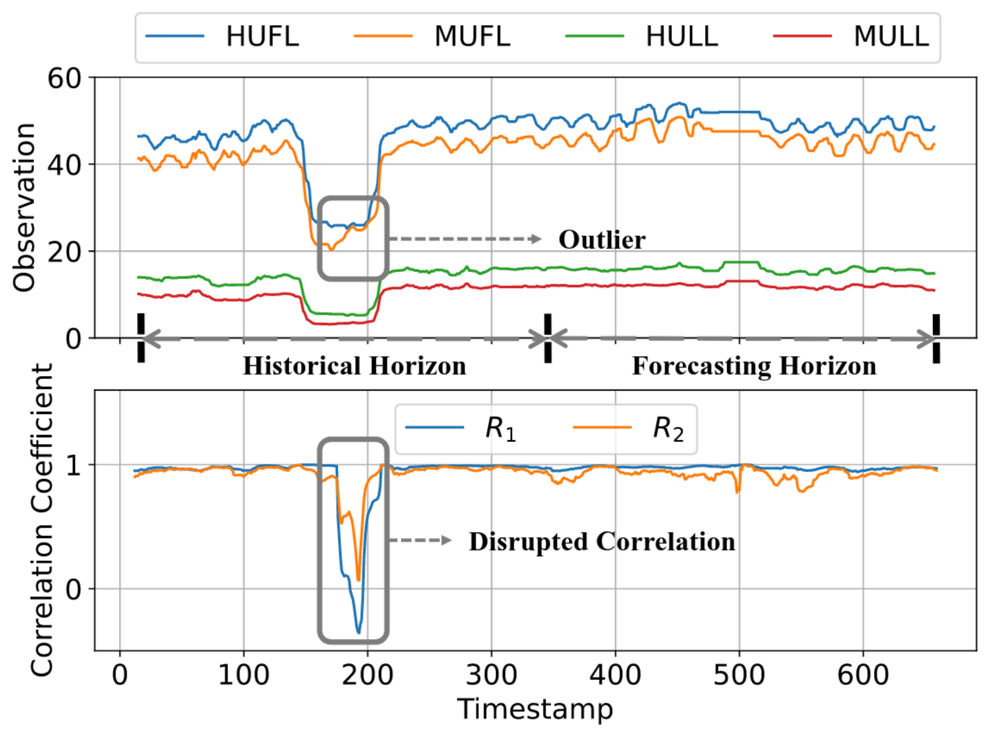

(b) Disrupted correlation. The Average $R_1 = 0.908$ and $R_2 = 0.963$.

1.2 Problem

Challenge 1

- Capture dynamic correlations
- Mitigate disrupted correlations
- Existing solutions struggle with the latter
  - Capture dynamic and disrupted
  - Reduces model robustness

Challenge 2

- Local information 🤝 global information
- Global information is *all* local information
- Local information *affects* global information
- Existing solutions struggle with combining
  - Only local
  - Only global

1.3 Contributions

Memformer

- Transformer
- Patch-wise recurrent graph learning
  - Captures dynamic correlations
- Global attention
  - Mitigates disrupted correlations
- Adresses challenge 1

Alternating Memory Enhancer

- Memory network
- Associates local and global information
- Adresses challenge 2

Experiments

- Proof

2. Methodology

2.2 Preprocessing

Instance normalization

- Normalize within historical horizon only
- Mitigates the issue of internal covariate shift
- Allows model to effectively grasp the intricate temporal dynamics inherent in time series

$$H' = (H - \mu)/\sqrt{(\sigma^2 + c)}, \text{ where}$$

H is the historical horizon

μ is the mean

σ is the variance

c ensures numerical stability

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poral dynamics inherent in time series. Instance normalization is defined as $\mathbf{H}' = (\mathbf{H} - \mu)/\sqrt{(\sigma^2 + \text{constant})}$, where $\mathbf{H}'$ denotes the preprocessed feature, μ and σ denote the mean and variance of the sample, respectively, and "constant" is a small positive real number included to ensure numerical stability.

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- Mistake in variance?
  - σ is conventional notation for standard deviation
  - σ^2 is conventional notation for variance

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- Explored code to find answer
- `data_provider/data_loader.py`
  - Only place anything related to loading data happens
  - `Dataset_ETT_hour`, `Dataset_ETT_minute`, `Dataset_Custom`, `Dataset_Pred`

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from sklearn.preprocessing import StandardScaler
class ...:
    def __read_data__(self):
        self.scalar = StandardScaler()
        self.scaler.fit(train_data.values)
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- They fit on training data
- Normalize entire dataset with μ and σ from training data

What are they actually doing?

Preprocessing

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StandardScaler

$z = (x - \mu)/\sigma$, where

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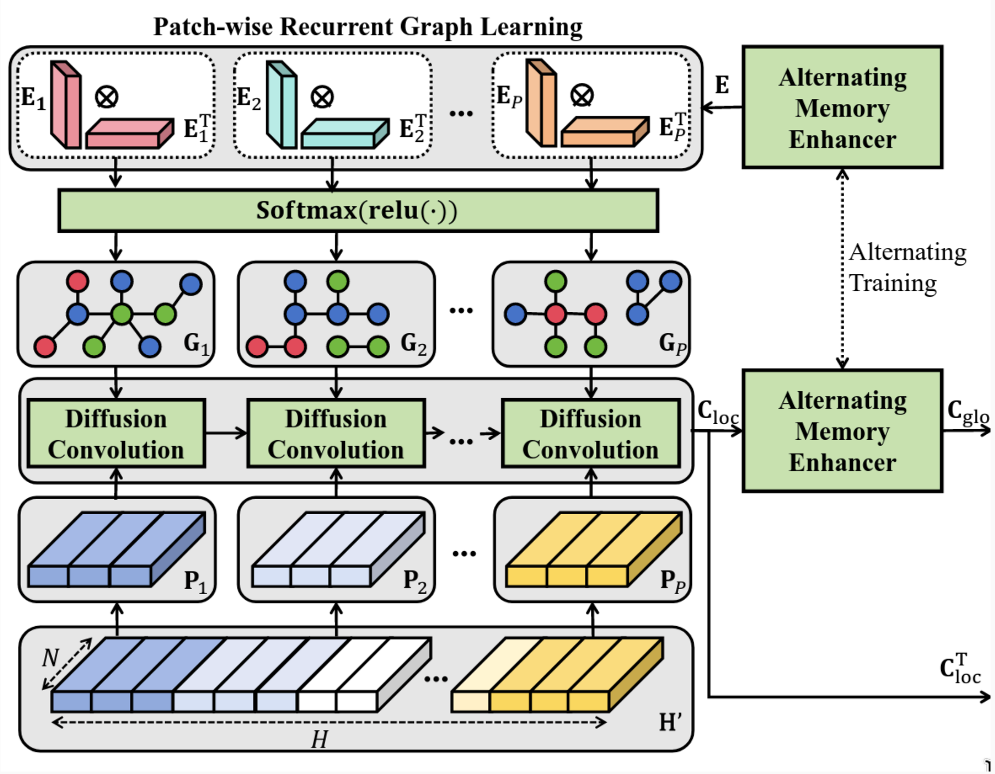
- We know that $\sqrt{\sigma^2} = \sigma$
- Essentially same formula, except constant
- Fit on training data, normalize entire dataset $\longrightarrow$ global normalization
- None of the stated benefits of instance normalization
  - Mitigate internal covariate shift
  - Grasp intricate temporal dynamics in TS

Architecture

Upper part → dynamic correlation

Lower part → normalized data

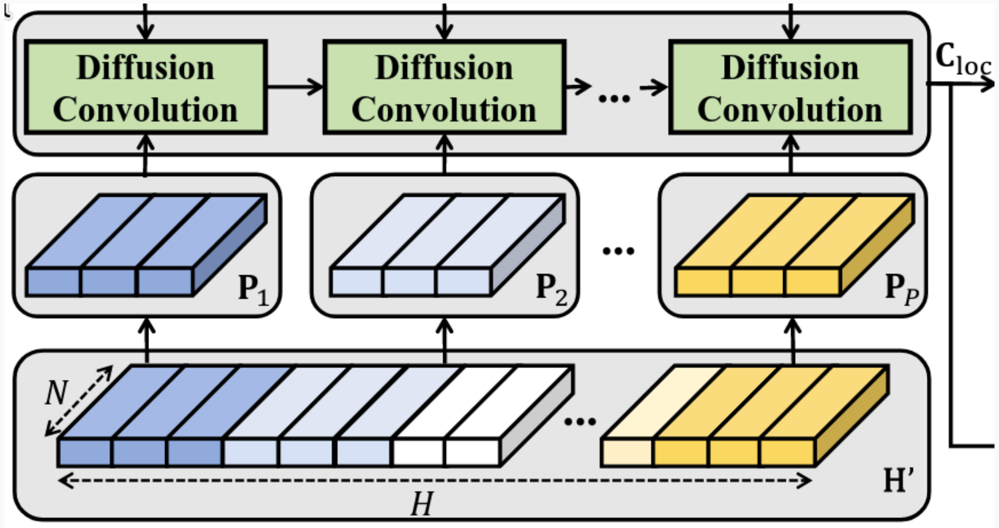
Output → enriched input features



2.3 Patch-wise Recurrent Graph Learning

Normalized Data

- Normalized as described earlier
  - Not what the paper actually states



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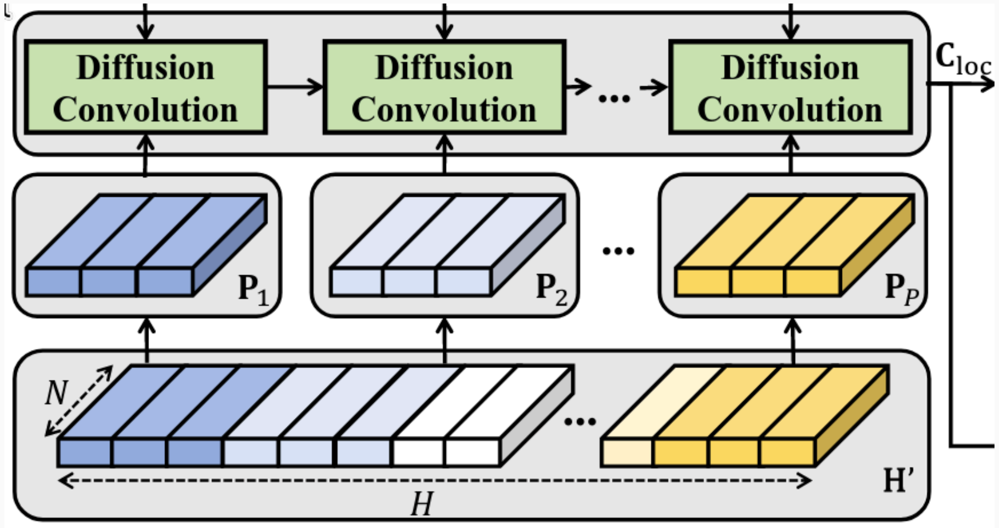
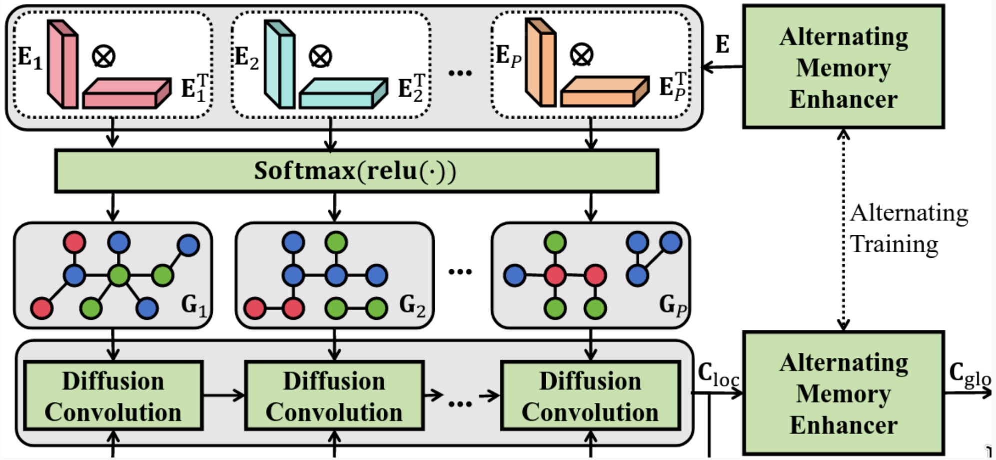
Patches

- H' is split into p patches
- Stride S
- Size T
- If $S \geq T$ patches are disjoint
- If $S < T$ patches overlap
  - Common elements for adjacent patches



AME

- Provides local memory embedding
  - These are learnable parameters
- Consistant local memory for patch P_i
- Matrix product of $E_i \otimes E_i^T$
  - Similarity matrix for variables in P_i



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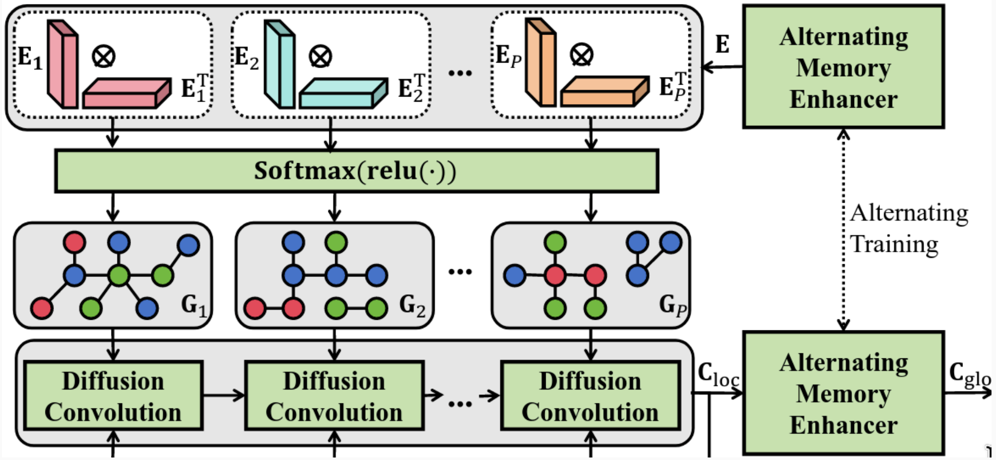
ReLU + Softmax

- ReLU eliminates negative values
  - Removes negative correlations
- Softmax scales into influence scores



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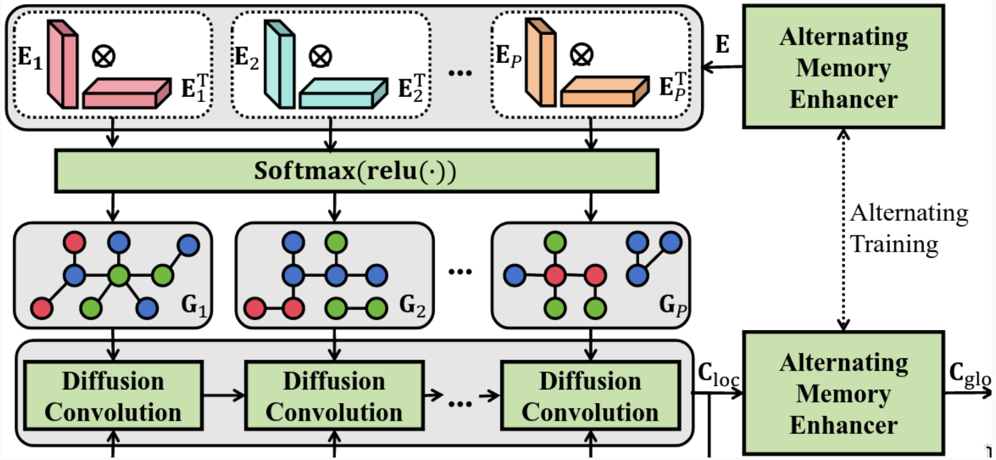
Graph

- Translates influence scores into graph
- Captures connection between variables
  - Dynamic correlations



Diffusion Convolution

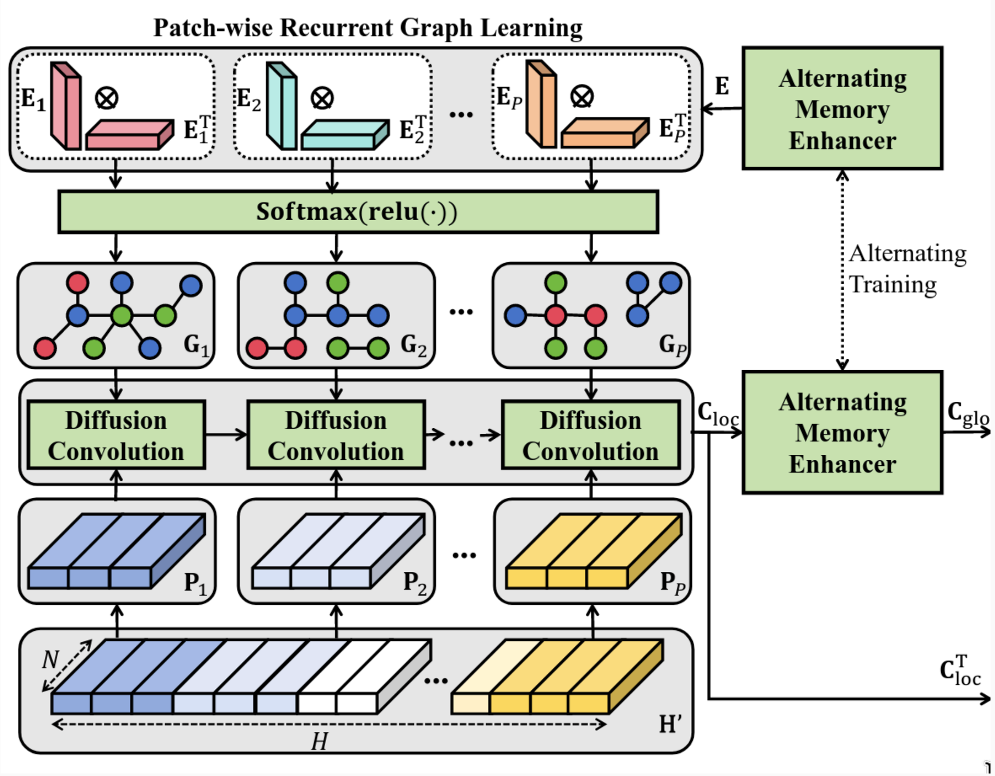
- Normalized data is adjusted based on connections in graph
- Numeric values "diffuse" into neighbours
  - Not only immediate neighbours
- Spatially relates data based on connections

Gated Recurrent Unit

- Forwards information from P_i to P_{i+1}
- Temporally relates data in a sequence

Output

- Input features enriched with local information
- Spatial $\longrightarrow$ dynamic correlations
- Temporal $\longrightarrow$ GRU

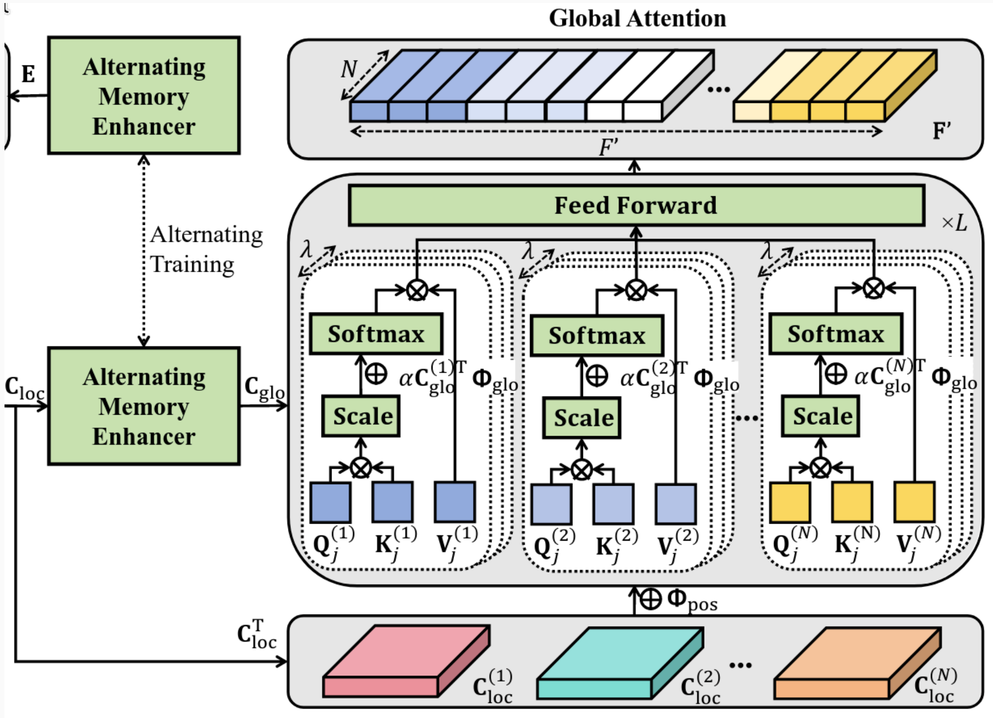


Motivation

- Patch-wise correlations are sensitive
  - Outliers dominate
- Constrain locally enriched features
  - Mitigate disrupted correlations

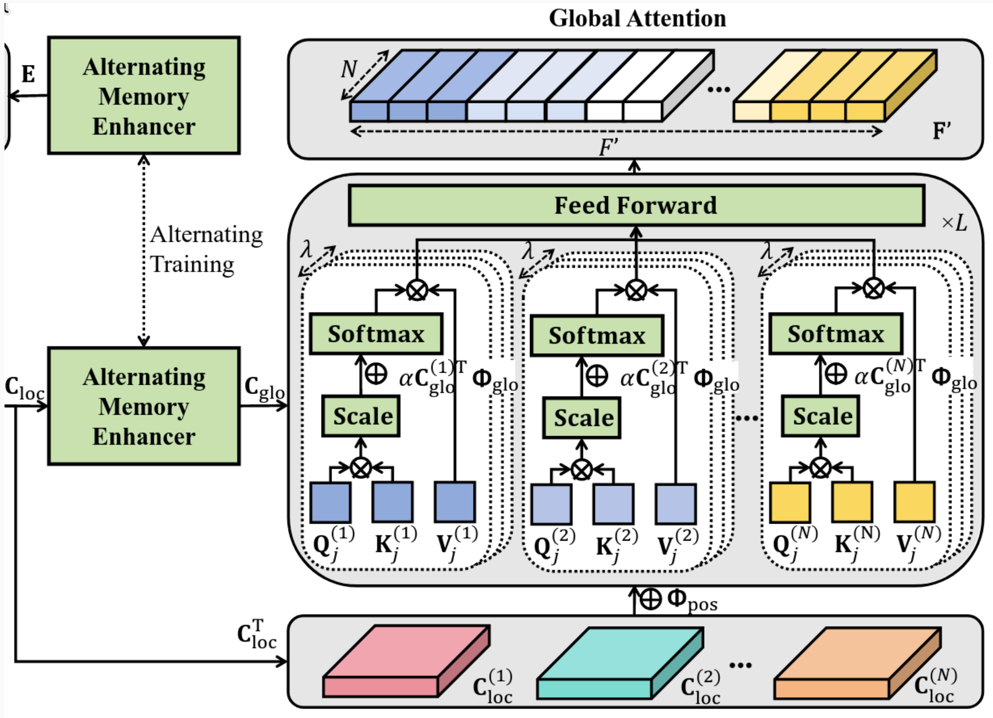
Input

- Transpose locally enriched features
  - Isolate variables
  - Diffusion earlier
- Linear transformation
  - Positional encoding
- Converted to Q, K, V matrices
  - Learnable parameters



Attention

- Relatively conventional implementation
  - Query and Key to find importance
  - Weight Value by importance
- Global information is new
- Adding global information after softmax
  - Bias probabilities
  - Global information affects parameters



Output

- The final “representation” of data
- **F'** is not a forecast
  - Final feature representation
- Linear layer maps to forecasting horizon

3. Results

4. Critique

4.1 Notation

Preprocessing

- As mentioned earlier
- Unconventional notation
- Obscures details

Inconsistencies

- C_{glo} is global memory
- C_{loc} is locally correlated features
- E is local memory

4.1 Notation

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Symbol Reuse

- $\mathbf{F}$ is the ground truth
- F is the dimensionality of $\mathbf{F}$
- $\mathbf{F'}$ is the encoding output
- F' is the dimensionality of $\mathbf{F'}$
- Confusing statements and diagrams

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