THD-BAR: Topology Hierarchical Derived Brain Autoregressive Modeling for EEG Generic Representations

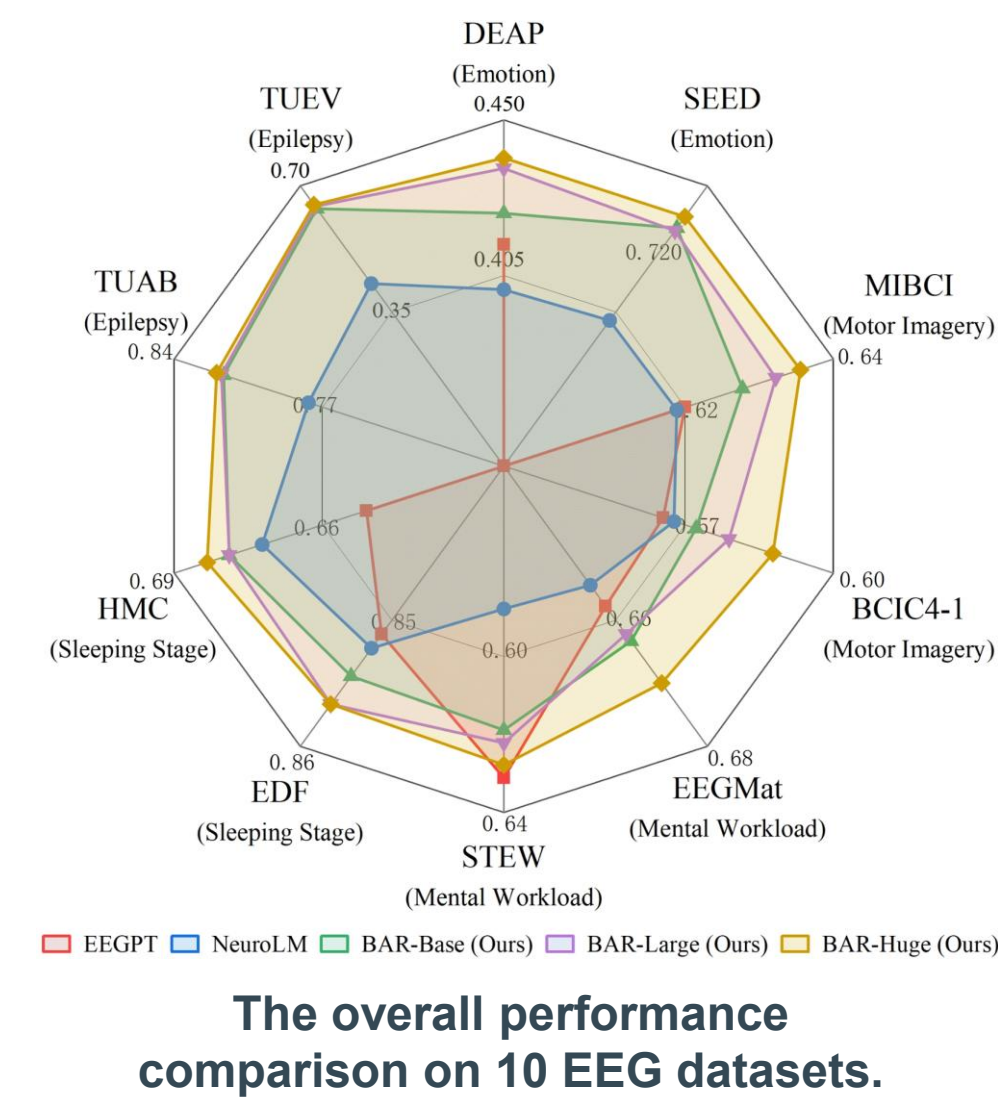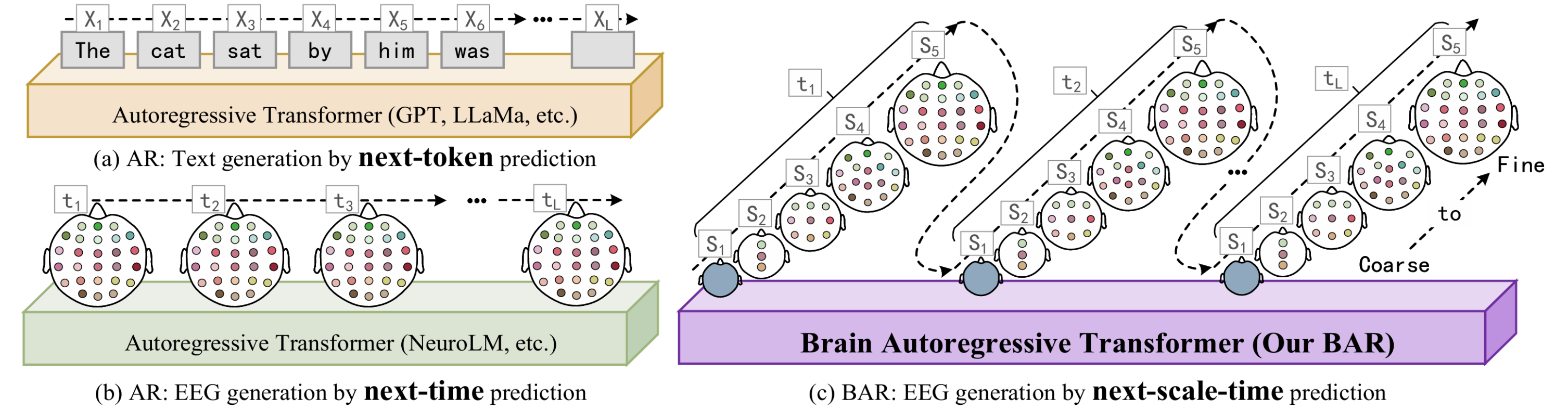Wenchao Yang*, Weidong Yan*, Wenkang Liu*, Yulan Ma, Yang Li†

Contributions

- We propose **THD-BAR** framework, a generic foundation model for EEG generic representation learning. Pre-trained on 17 diverse datasets, it captures complex spatio-temporal dynamics, yielding significant performance on various downstream tasks over existing methods.

- We introduce the **BTH**, which establishes a "whole brain - brain region - channel" relationship grounded in physiological structure. Building on this hierarchy, we develop the **THVQ-VAE** to generate discrete, multi-scale quantized tokens.

- A nested **"next-scale-time prediction"** strategy is employed for pre-training. This strategy compels the BAR module to learn complex spatio-temporal dependencies by predicting tokens hierarchically across scales within each time step before progressing to the next time step, thus modeling both intra-time hierarchical relationships and inter-time dynamics.
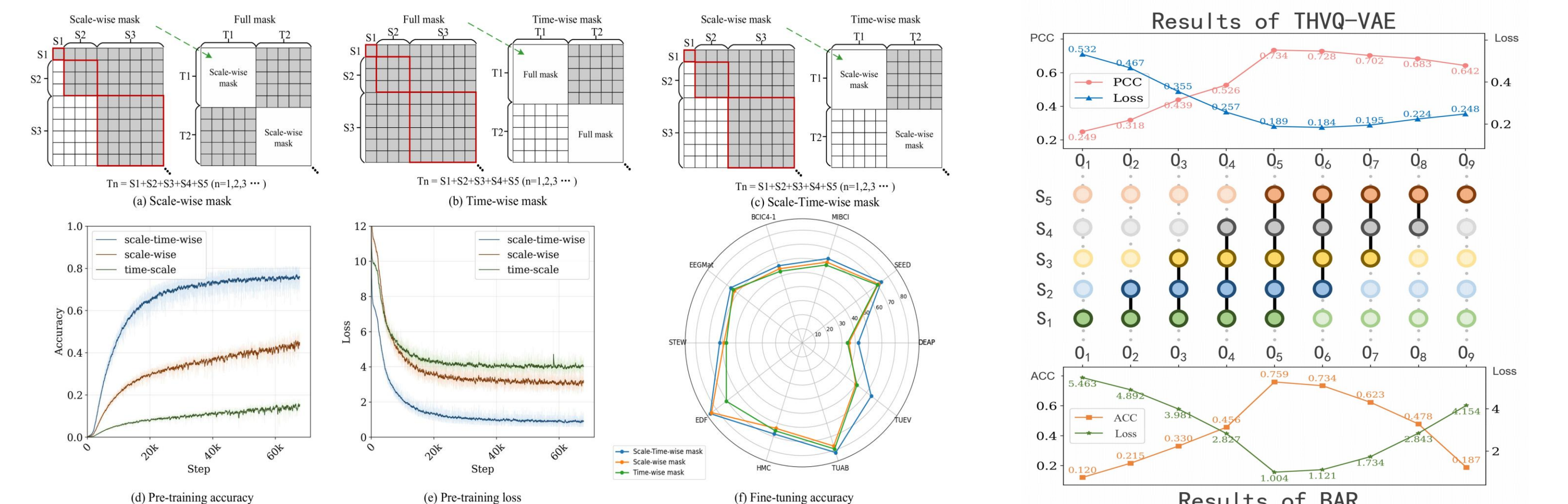

The overall performance comparison on 10 EEG datasets.

Motivation

(a) AR: Text generation by **next-token** prediction

(b) AR: EEG generation by **next-time** prediction

(c) BAR: EEG generation by **next-scale-time** prediction

Conceptual comparison of autoregressive prediction strategies.
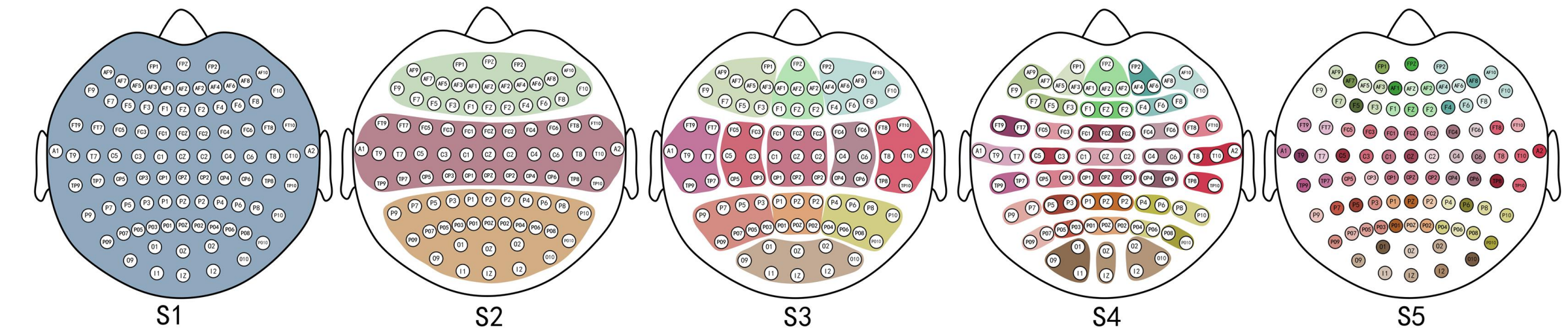
Brain Topology Hierarchy (BTH).
S1: Whole Brain; S2: Major Brain Regions; S3: Sub-regions; S4: Channel Clusters; S5: Individual Channels.

Framework

Stage.1 Neural Tokenizer Training

Stage.2 BAR Pretraining

Stage.3 Fine-tuning

The pipeline of the THD-BAR framework

Topology-Hierarchical Vector Quantized-Variational Autoencoder (THVQ-VAE)

A BAR causal transformer is trained via "next-scale-time prediction".

$T_m = S_1+S_2+S_3+...+S_n$

Experiments

Methods	Year	General Model?	Multi-Task?	Model Parameter	Emotion		Motor Imagery		Mental Workload		Sleeping Stage		Epilepsy	
					DEAP	SEED	MIBCI	BCIC4-1	EEGMat	STEW	EDF	HMC	TUAB	TUEV
EEGNet	2018	✗	✗	-	35.2±9.4	69.3±2.1	63.3±7.2	51.9±1.5	60.0±8.7	52.3±17.6	84.0±4.4	54.5±8.7	76.3±1.5	53.5±0.2
TSception	2020	✗	✗	-	34.3±8.1	68.6±1.3	61.4±6.5	52.2±1.6	50.3±1.2	**63.8**±1.6	68.6±4.5	36.4±9.8	74.3±4.2	51.3±0.4
LGGNet	2024	✗	✗	-	33.5±8.5	69.5±1.4	56.7±3.7	50.0±0.4	50.2±1.1	46.7±12.5	68.6±4.5	17.0±5.9	75.5±3.1	52.8±0.3
BIOT	2023	✓	✗	3.2M	35.2±8.9	71.0±0.2	53.2±2.0	51.1±0.5	50.2±1.1	51.3±11.9	69.4±4.6	63.0±1.1	79.6±0.6	52.8±0.3
LaBraM	2024	✓	✗	5.8M	34.3±9.9	73.2±0.2	50.5±1.1	50.3±0.4	50.4±1.3	52.5±12.4	69.3±3.8	68.1±0.7	81.4±0.2	64.1±0.7
EEGPT	2024	✓	✓	1.46M	41.4±2.7	-	62.2±2.8	56.9±1.6	66.0±8.6	63.2±10.6	85.2±3.4	65.5±4.0	-	-
NeuroLM	2024	✓	✓	254M	40.1±1.4	70.2±0.3	62.1±2.6	57.1±1.8	65.7±7.5	59.3±5.8	85.3±3.7	67.4±5.6	78.3±0.5	45.6±0.6
THD-BAR-Base	2025	✓	✓	124M	42.3±1.2	73.5±0.3	62.9±1.4	57.5±0.9	66.5±6.2	62.1±6.7	85.5±4.6	68.0±3.5	81.9±0.4	64.3±0.2
THD-BAR-Large	2025	✓	✓	354M	43.6±1.6	73.4±0.4	63.3±1.7	58.1±1.2	66.4±7.1	62.4±7.5	**85.7**±4.7	68.0±3.2	82.0±0.3	64.9±0.3
THD-BAR-Huge	2025	✓	✓	1555M	**43.9**±1.7	**73.9**±0.3	**63.6**±1.8	**58.9**±1.5	**67.1**±5.8	62.9±7.9	**85.7**±4.4	**68.4**±4.3	**82.2**±0.4	**65.3**±0.5

Mask design ablation study.

Results of THVQ-VAE

Results of BAR

Multi-scale ablation study.