TRAMBA: A Hybrid Transformer and Mamba Architecture for Practical Audio and Bone Conduction Speech Super Resolution and Enhancement for Mobile and Wearable Platforms

October 14, 2025

UbiComp/ISWC 2025

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Northwestern University

COLUMBIA ICSL

INTELLIGENT & CONNECTED SYSTEMS LAB

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Bone and Vibration-based Microphones

- Other sounds

- Speech is attenuated

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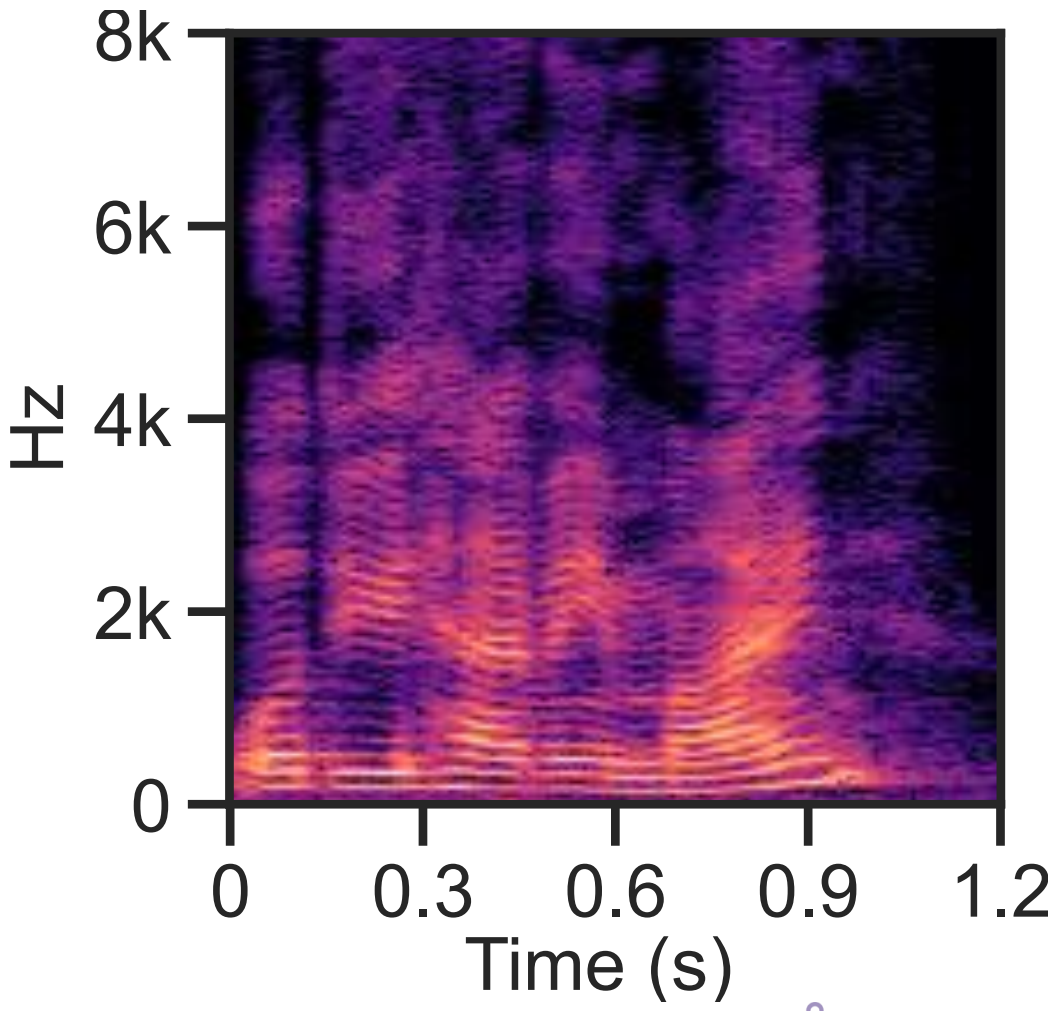
Bone and Vibration-based Microphones

- Other sounds
  - Mitigated with vibration-based sensing (BCM or IMU)

- **Speech is attenuated**

Standard Speech



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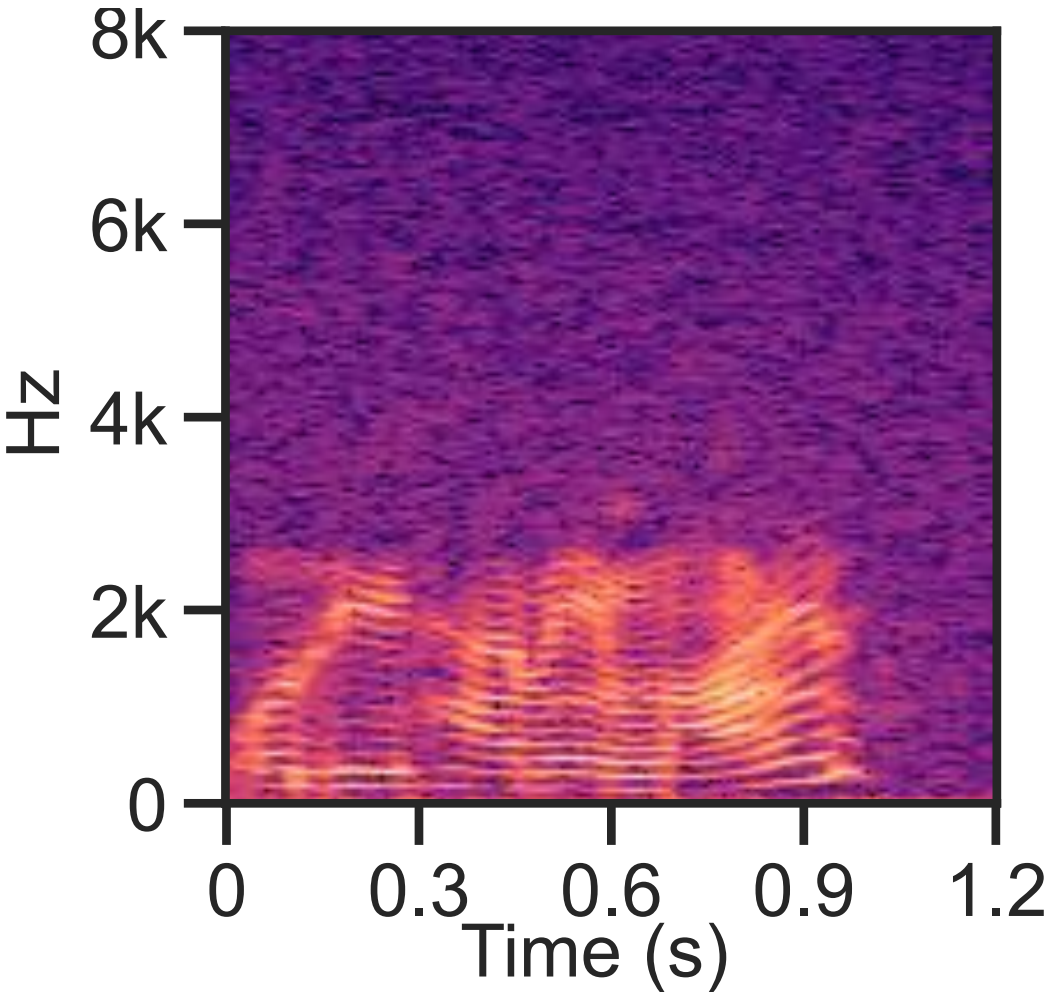
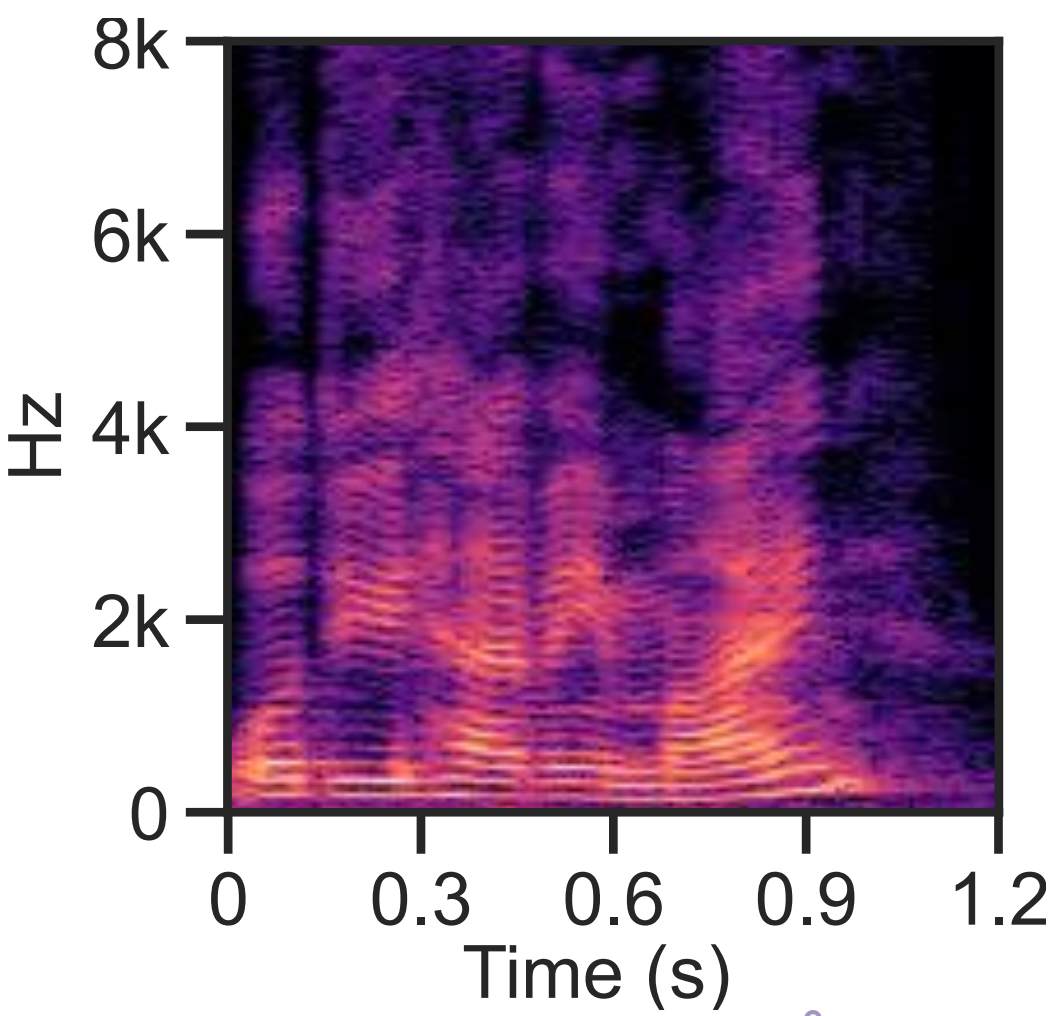
Corrupted Speech





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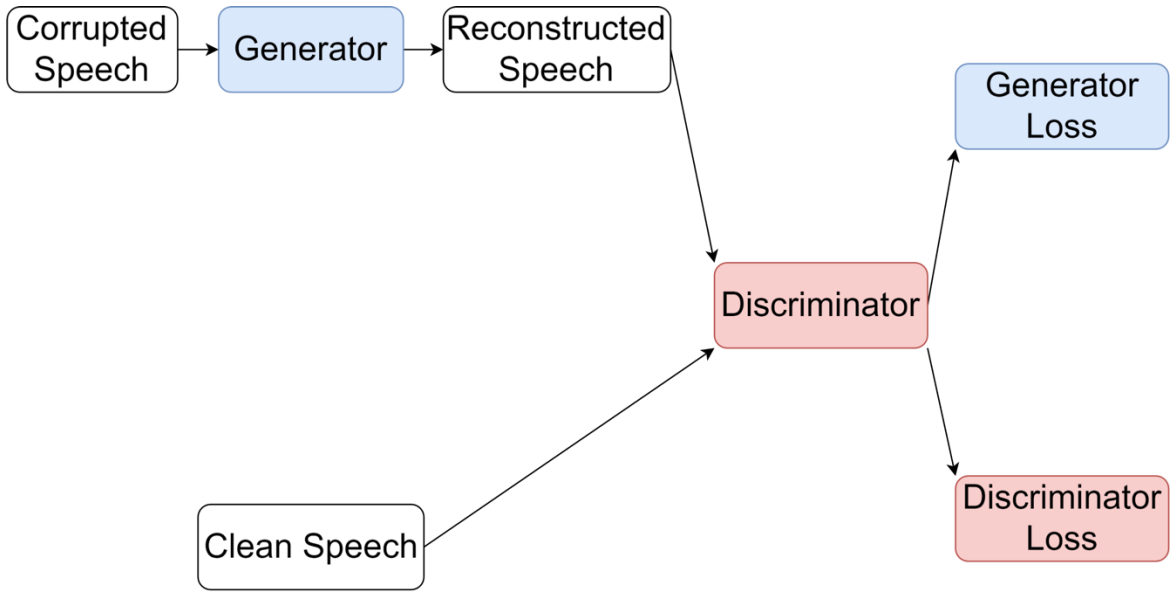
Current Solutions:

Generative Adversarial Networks



Performance: good, Compute: heavy

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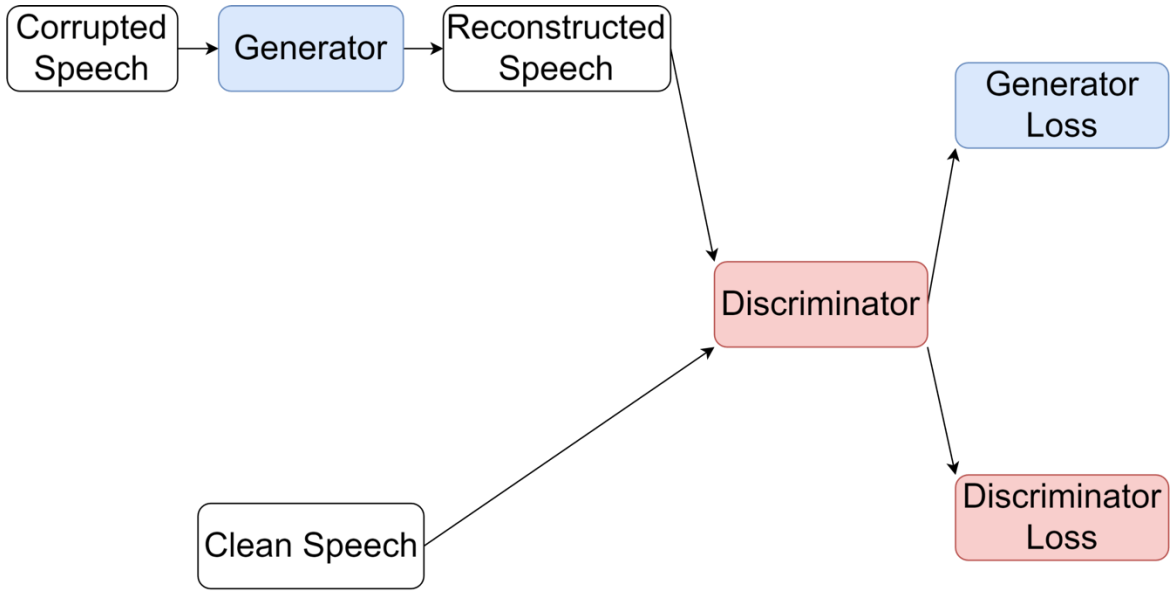
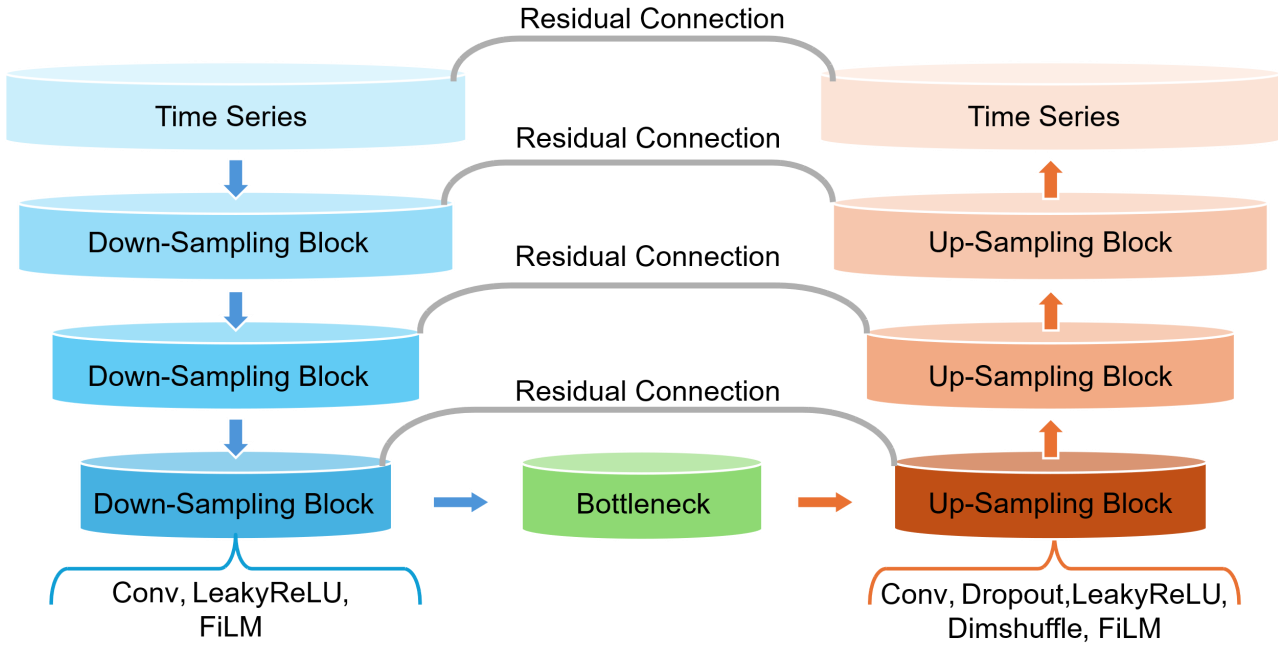
Current Solutions:

Generative Adversarial Networks



Performance: good, Compute: heavy

U-Net



Performance: less good, Compute: light

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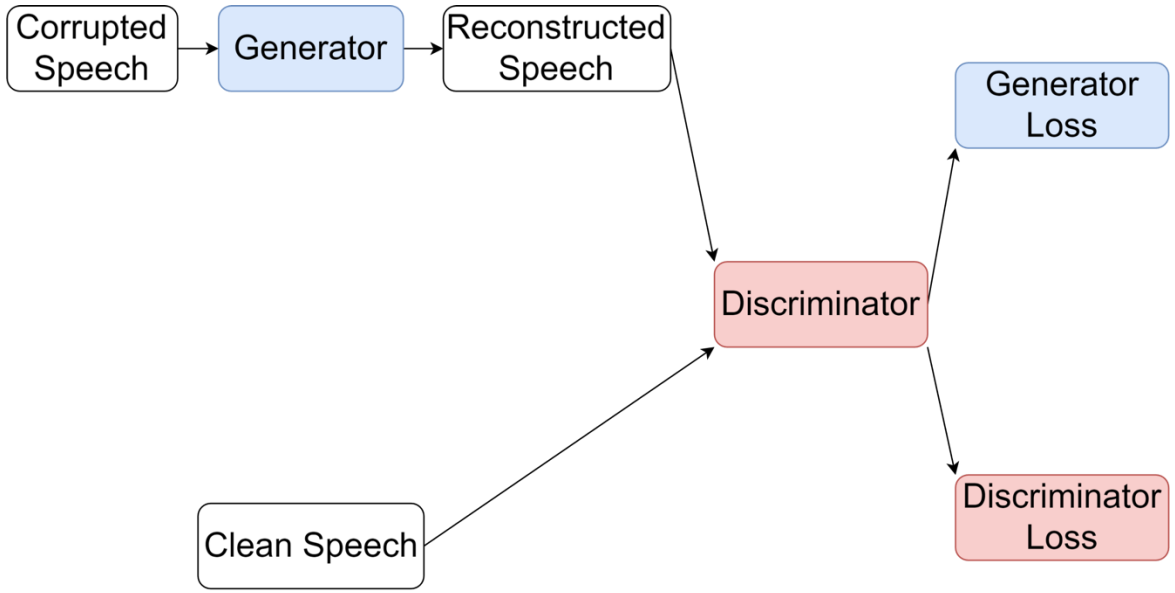
Current Solutions:

Generative Adversarial Networks



Performance: good, Compute: heavy

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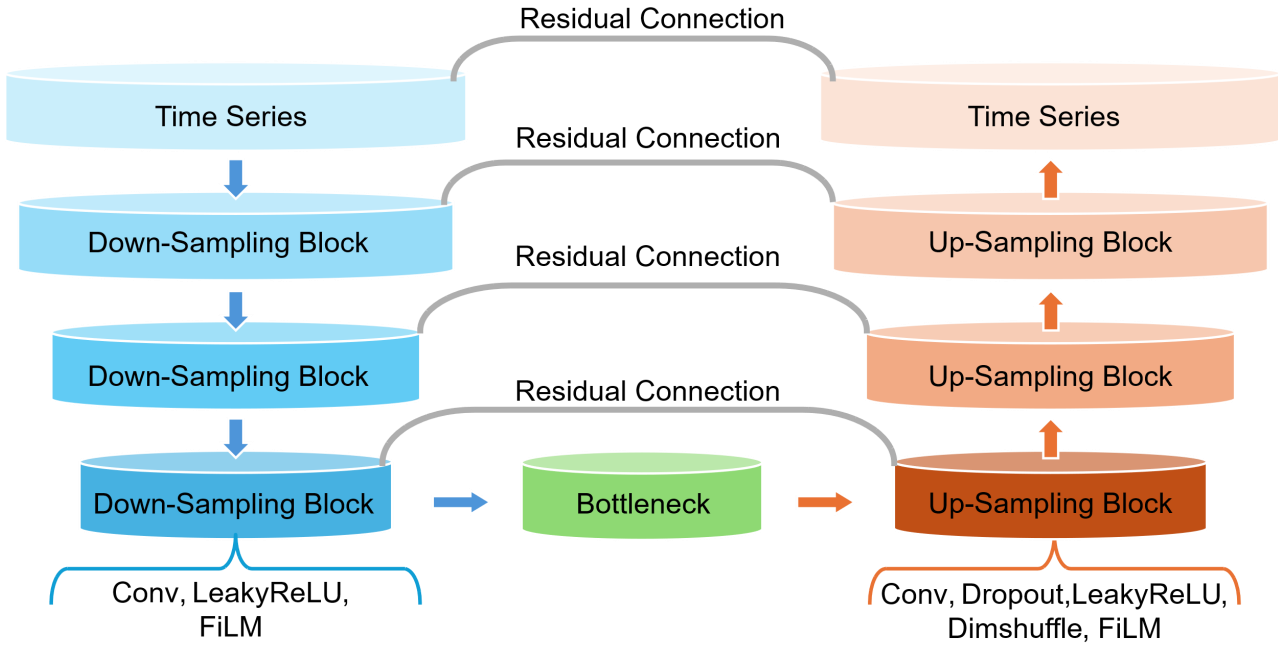

Performance: less good, Compute: light

Goal: bridge performance, speed, and efficiency

TRAMBA: good, compute: light

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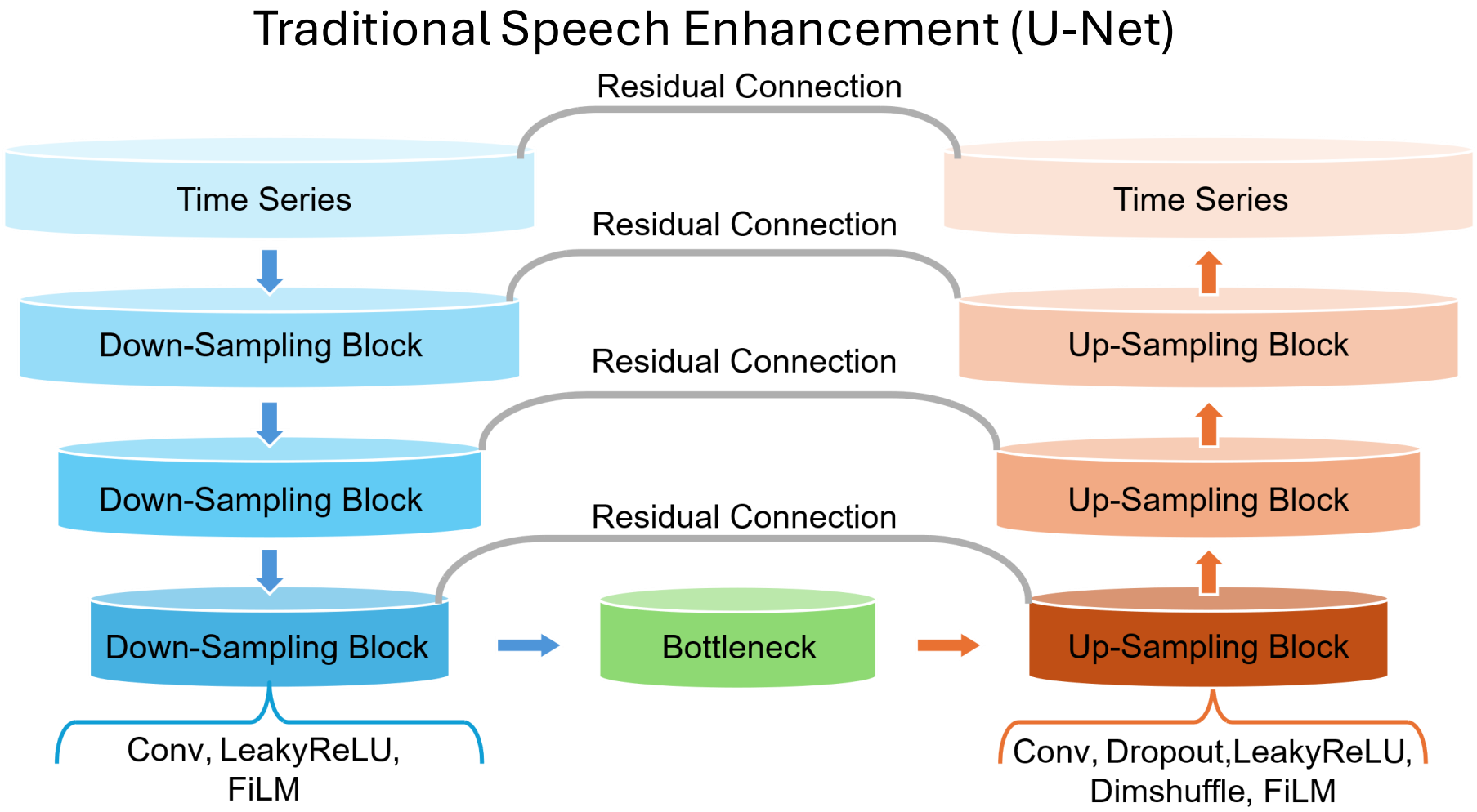
Design



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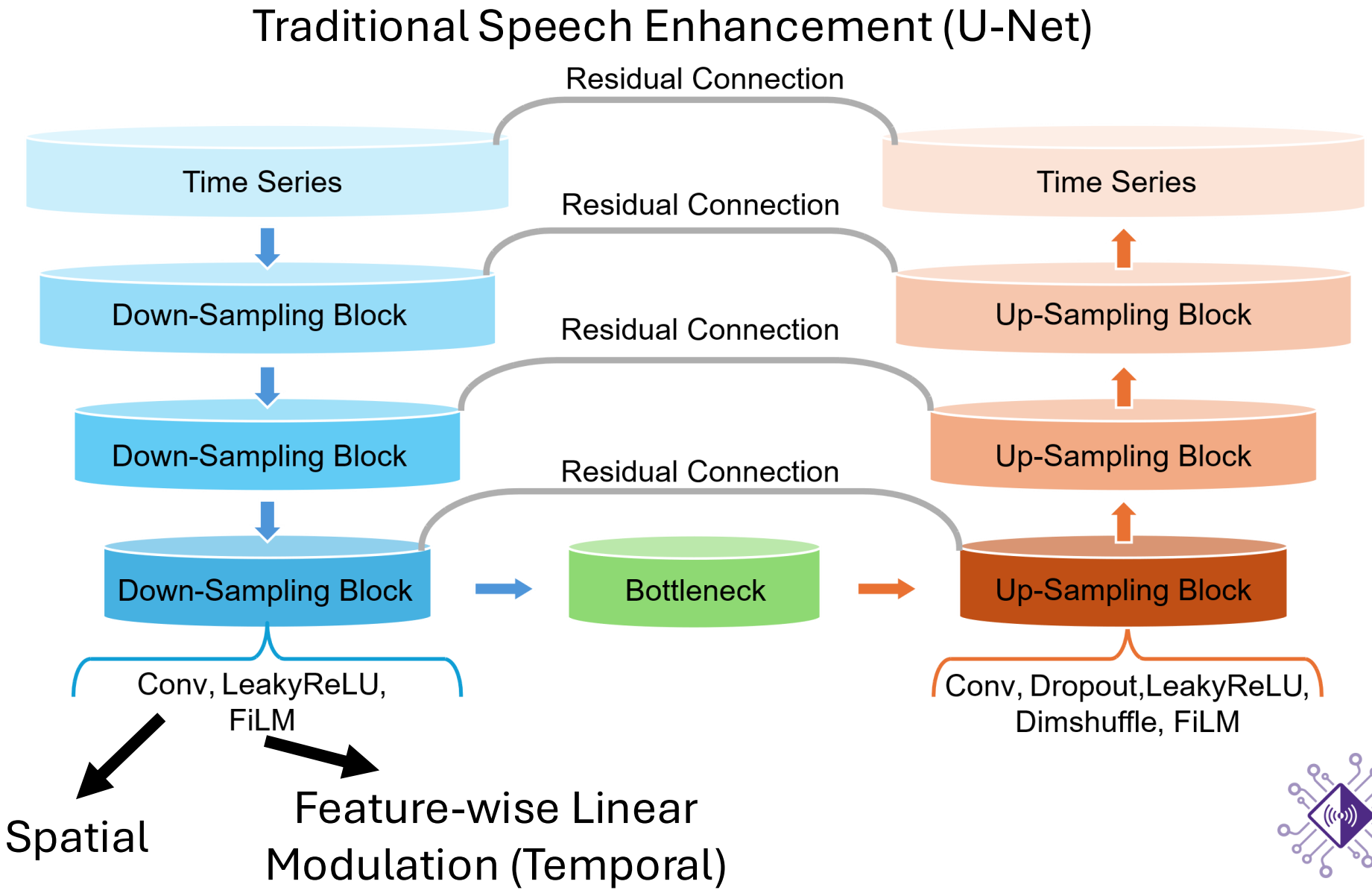
Design



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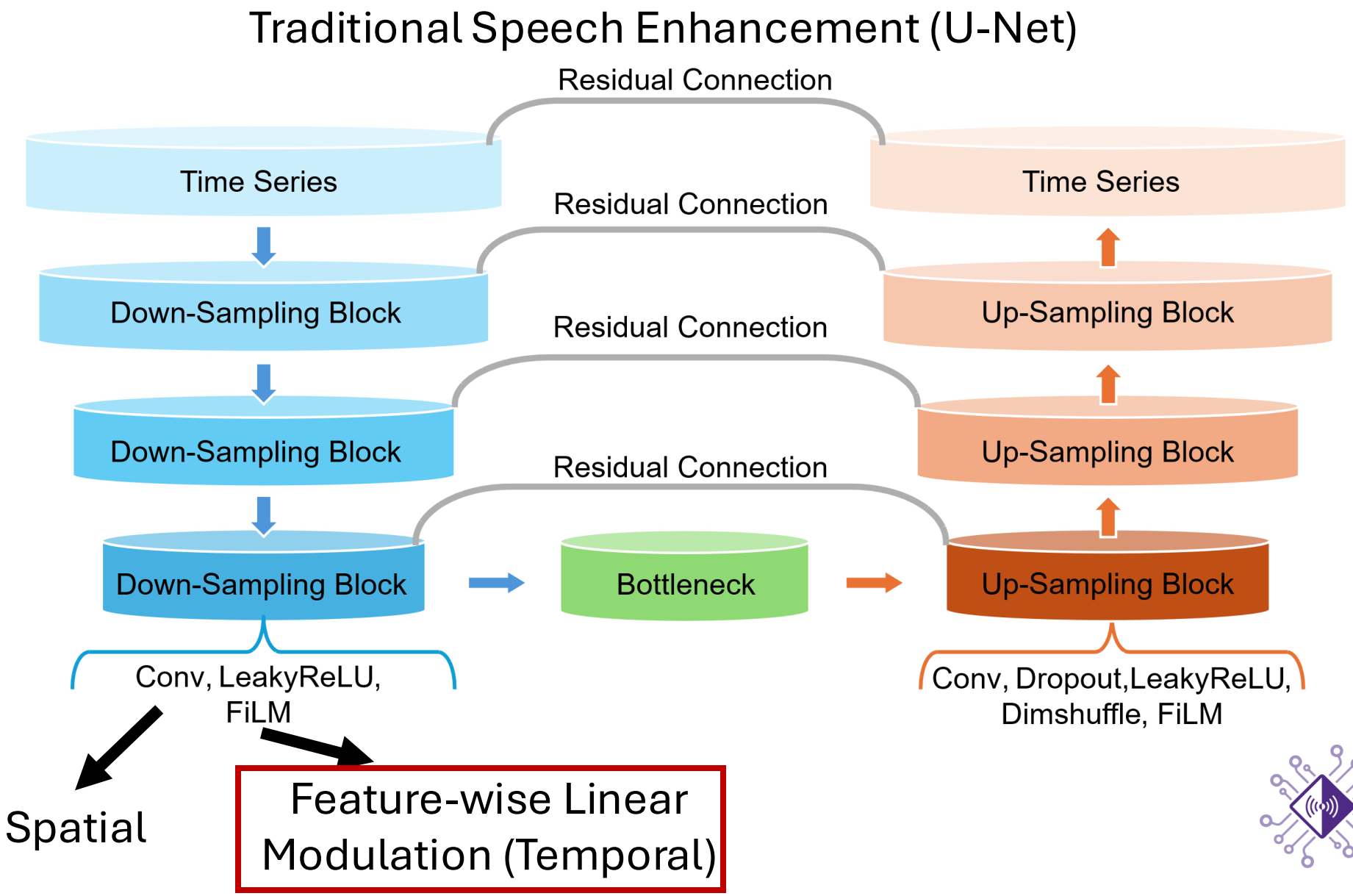
Design



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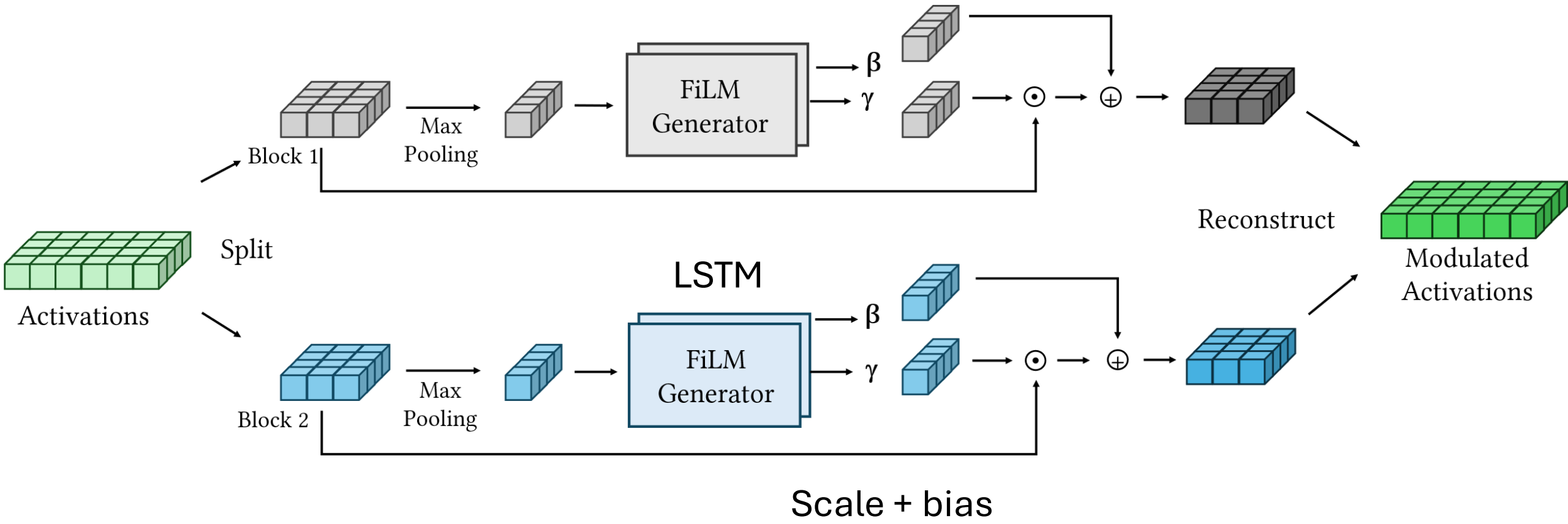
Temporal Feature-wise Linear Modulation (TFiLM)



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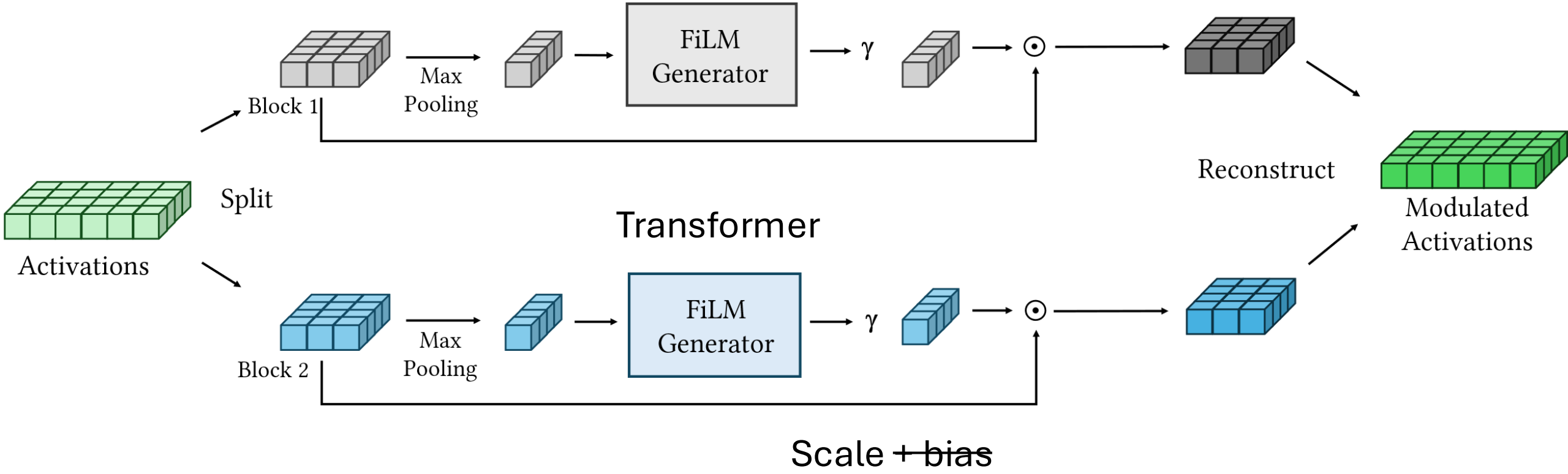
Scale-Only Attention-based Feature-wise Linear Modulation (SAFiLM)



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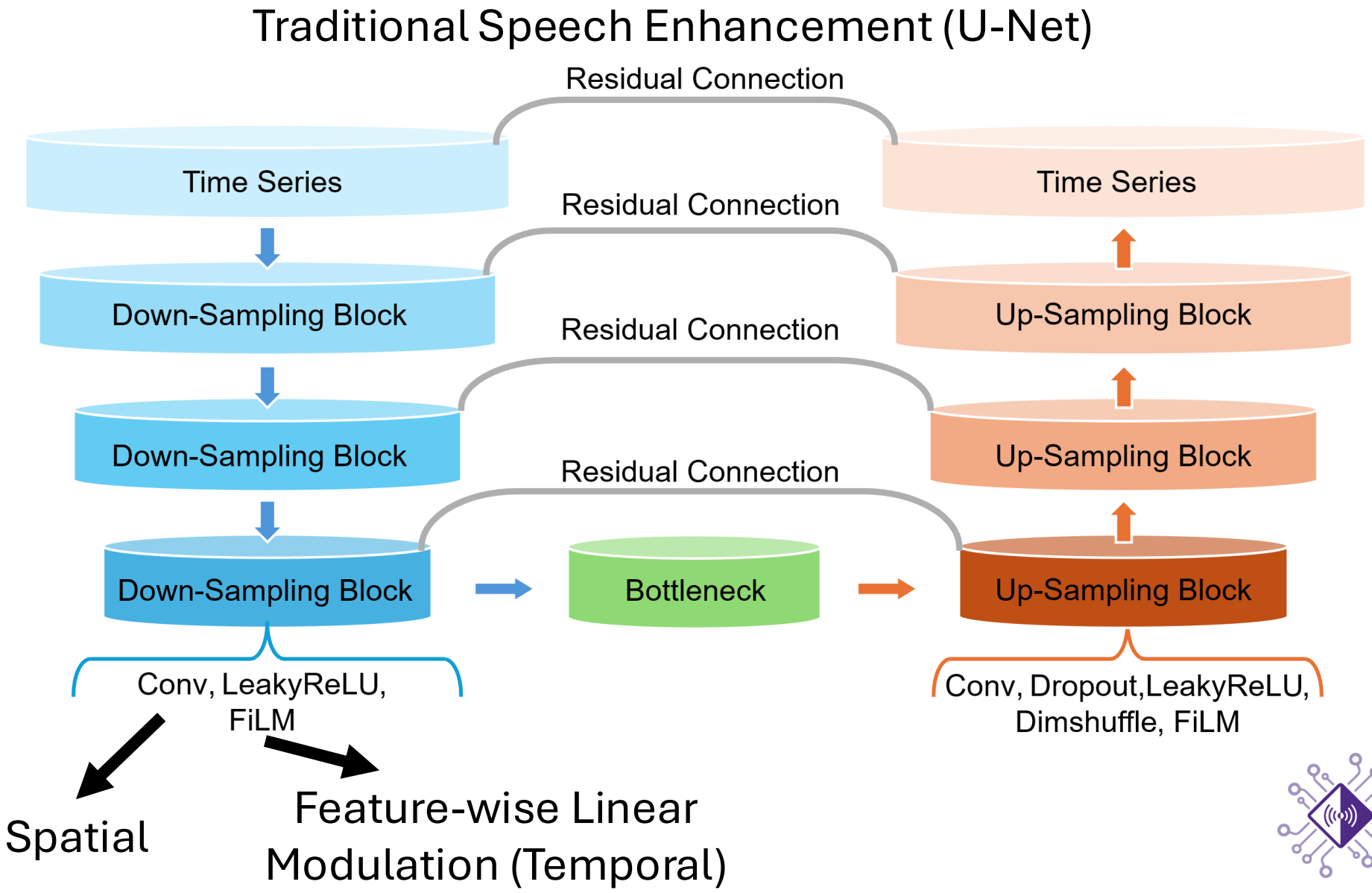
Design



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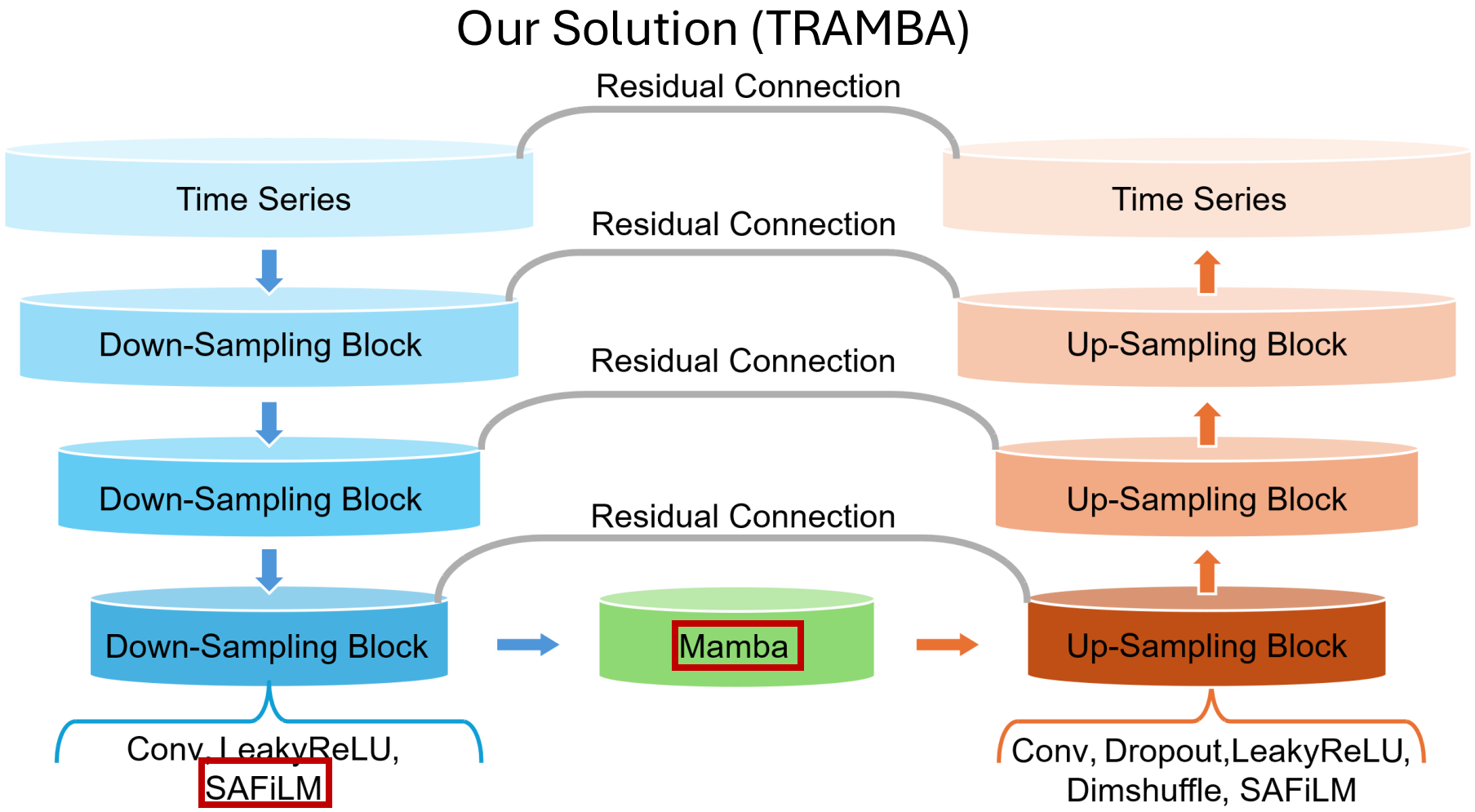
Design



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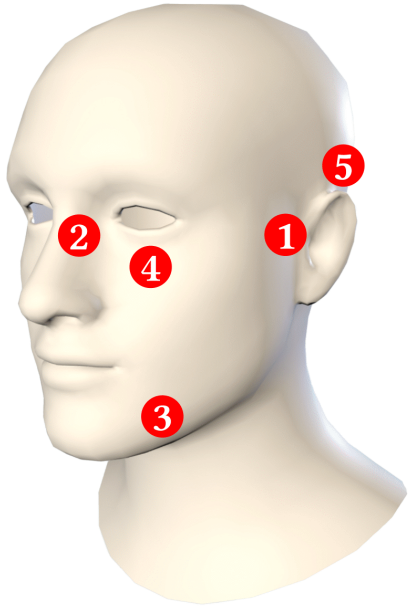
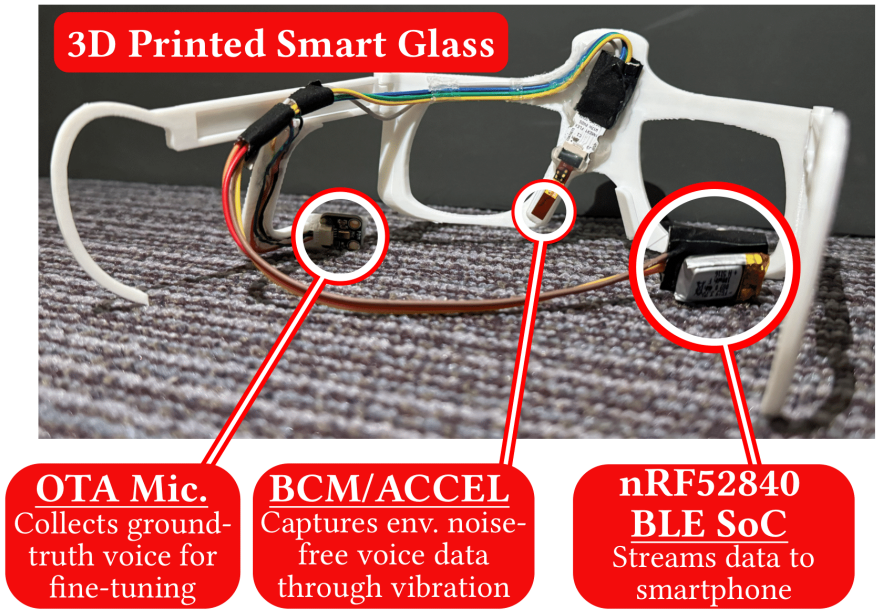
Deployment and Evaluaton



1. **Temporal Bone** (Bone-conduction Headsets)
2. **Nasal Bone** (Smart Glasses)
3. **Mandible** (Face Masks)
4. **Zygomatic Bone** (VR Headsets)
5. **Parietal Bone** (Hats and Bone-conduction Headsets)

(a) Attachment positions tested

(b) Environments tested



(c) Mobile-TRAMBA prototype

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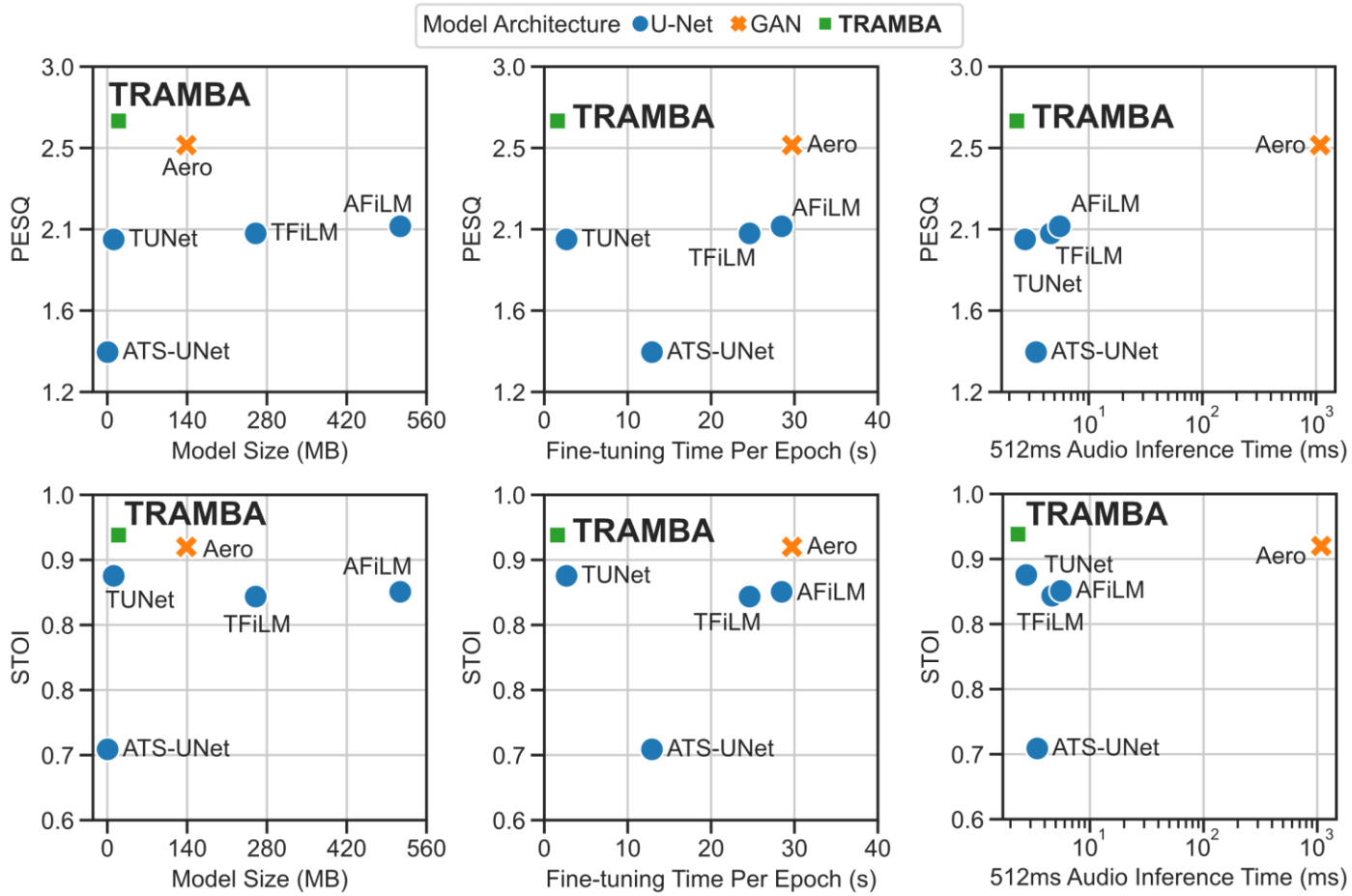
Overall Performance

- Highest Perceptual Quality and Intelligibility
- Only ~20 MB
- Real-time
- Reduced power



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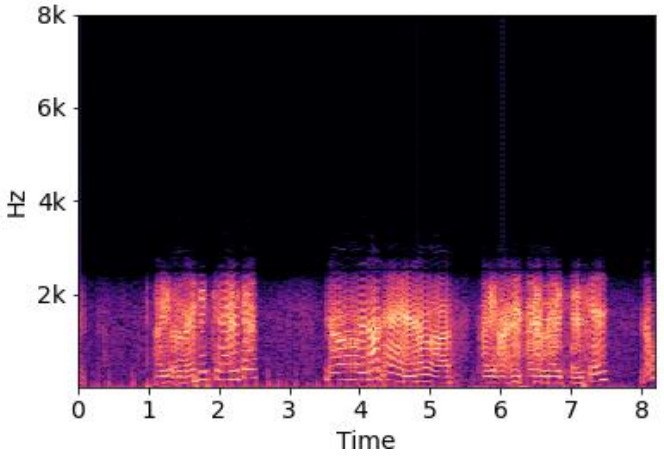
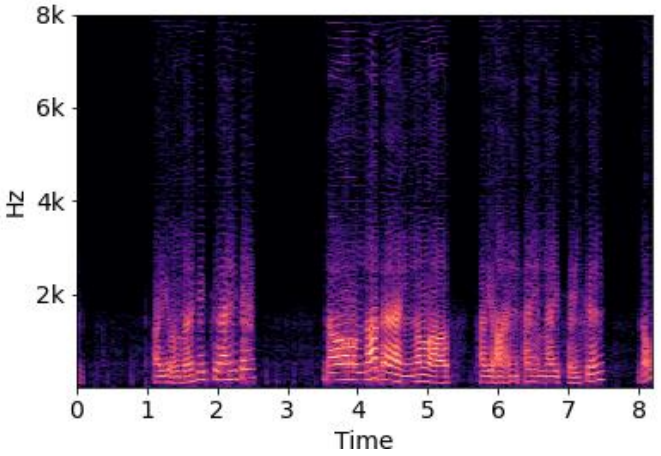
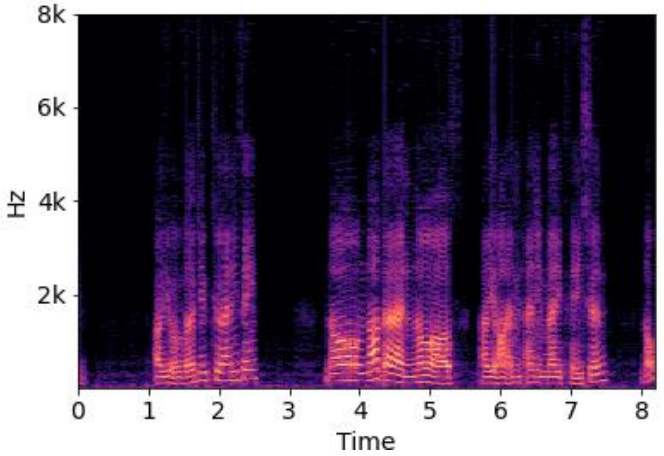
Demo



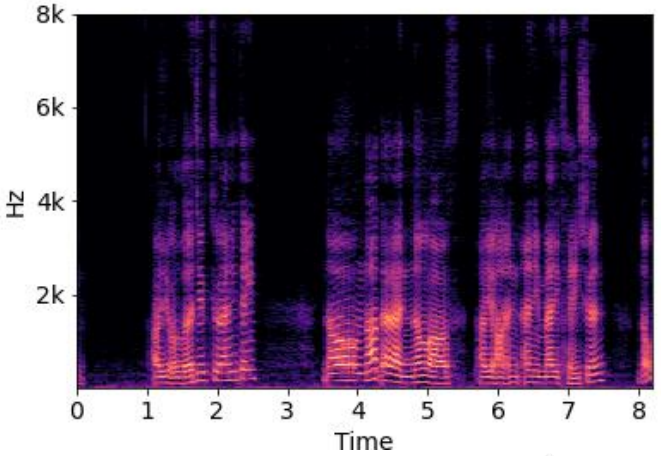
Raw BCM:



TFiLM:



TRAMBA (Ours):



Ground Truth:

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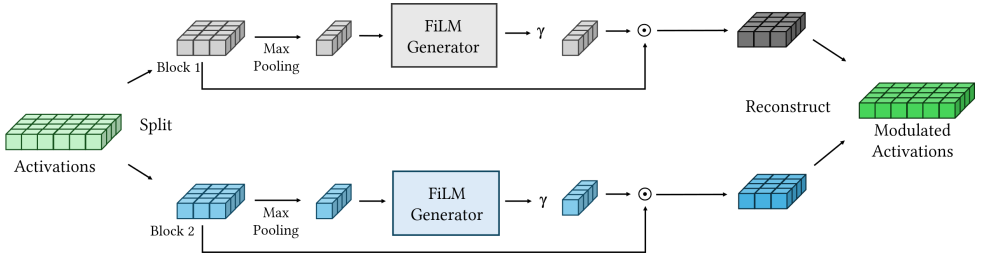
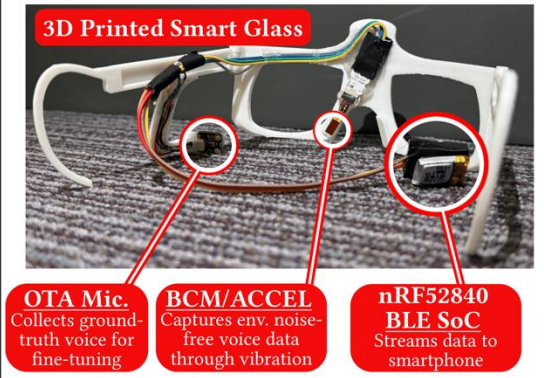
TRAMBA: Practical Speech Enhancement for Mobile and Wearable Systems

- Efficient Temporal Modeling: Scale-only Attention-based Feature-wise Linear Modulation (SAFiLM)
- Efficient Bottleneck: Mamba
- Bridges performance + efficiency





Feel free to reach out!

- Yueyuan Sui: yueyuansui2024@u.northwestern.edu
- Stephen Xia: stephen.xia@northwestern.edu

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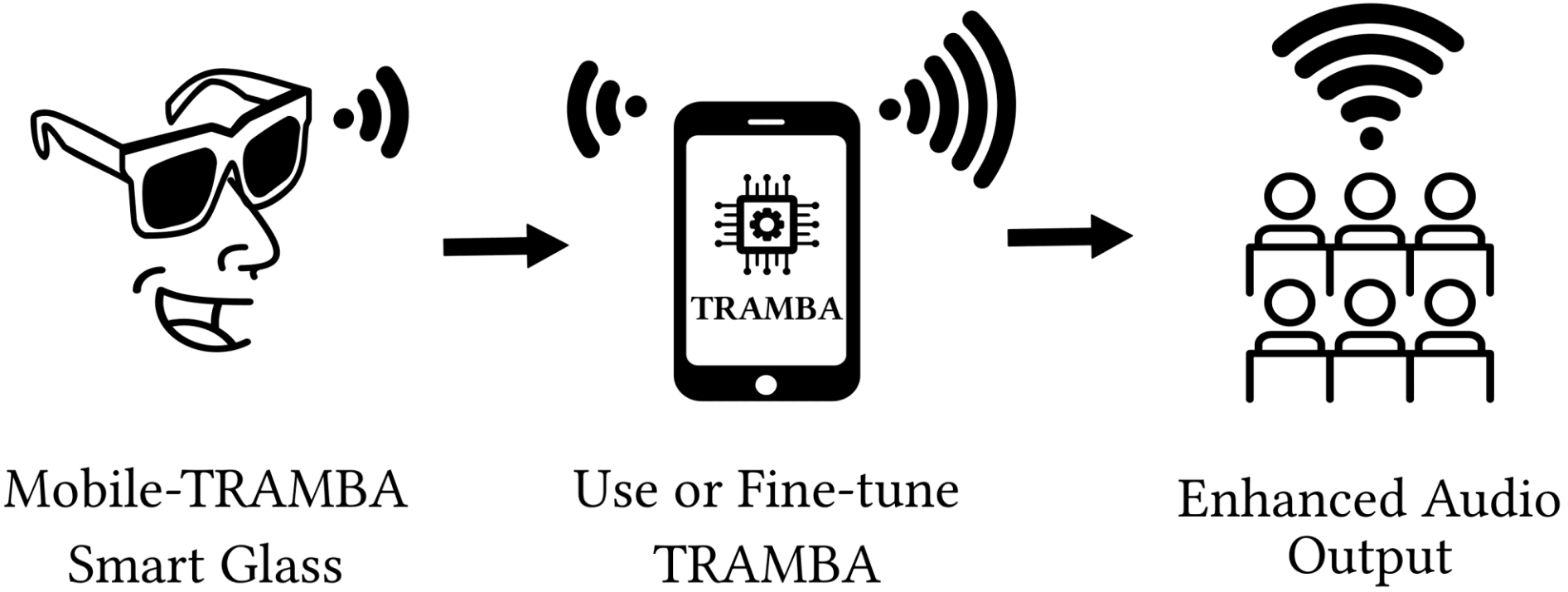
Training and Fine-tuning: Dealing with Lack of Data



- Pretrain with Over-the-Air Audio
  - Subsample and Decimate

- Fine-tune with small amount of user speech

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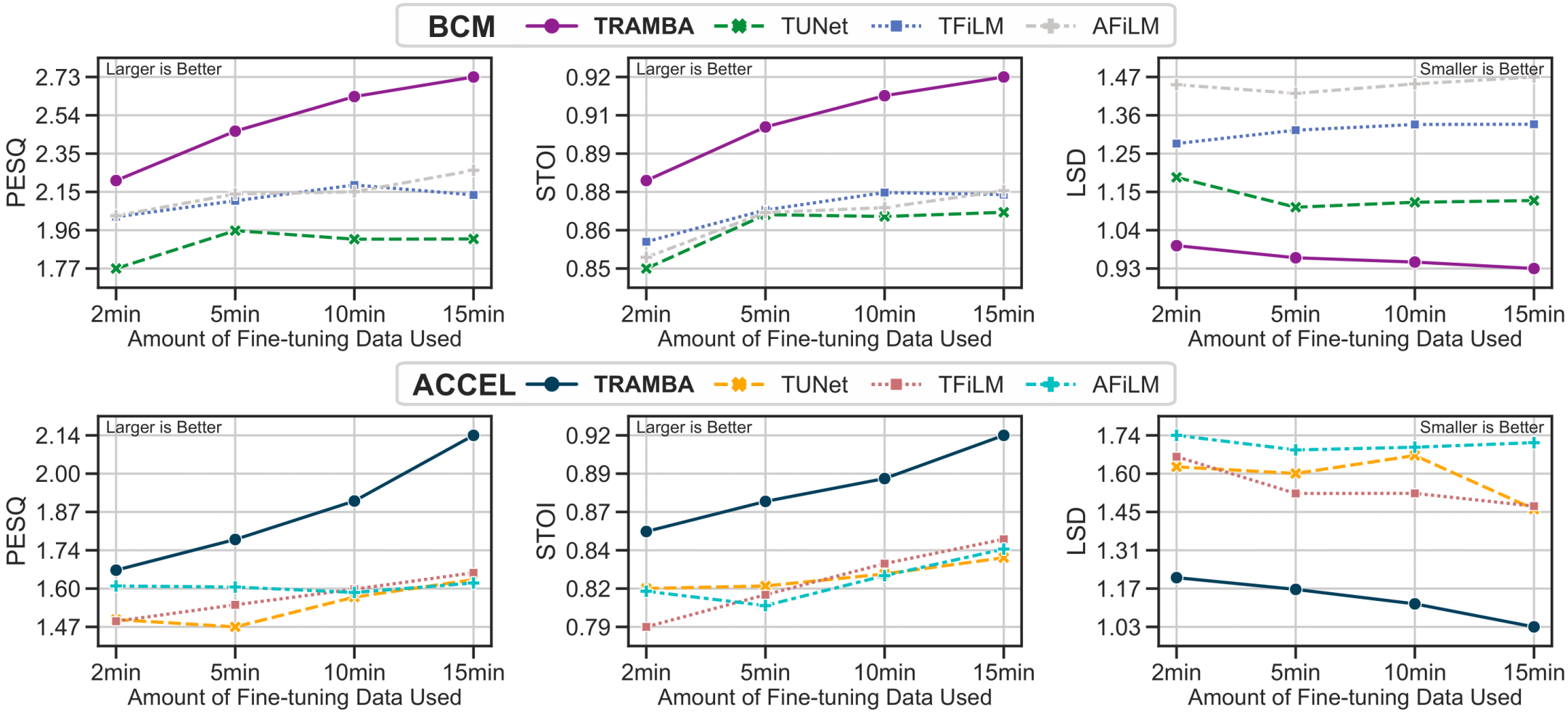
Fine-tuning Performance



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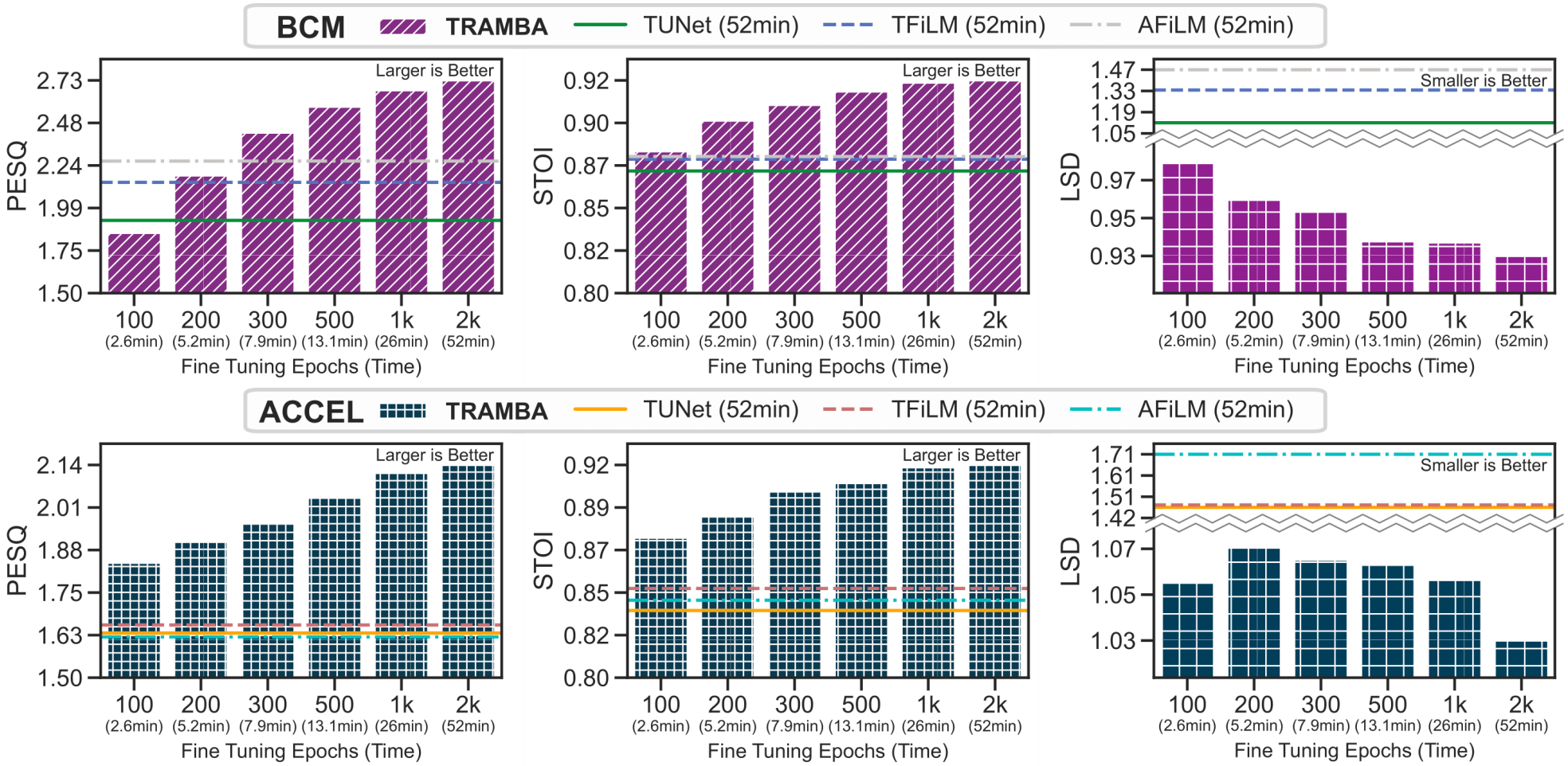
Fine-tuning Performance



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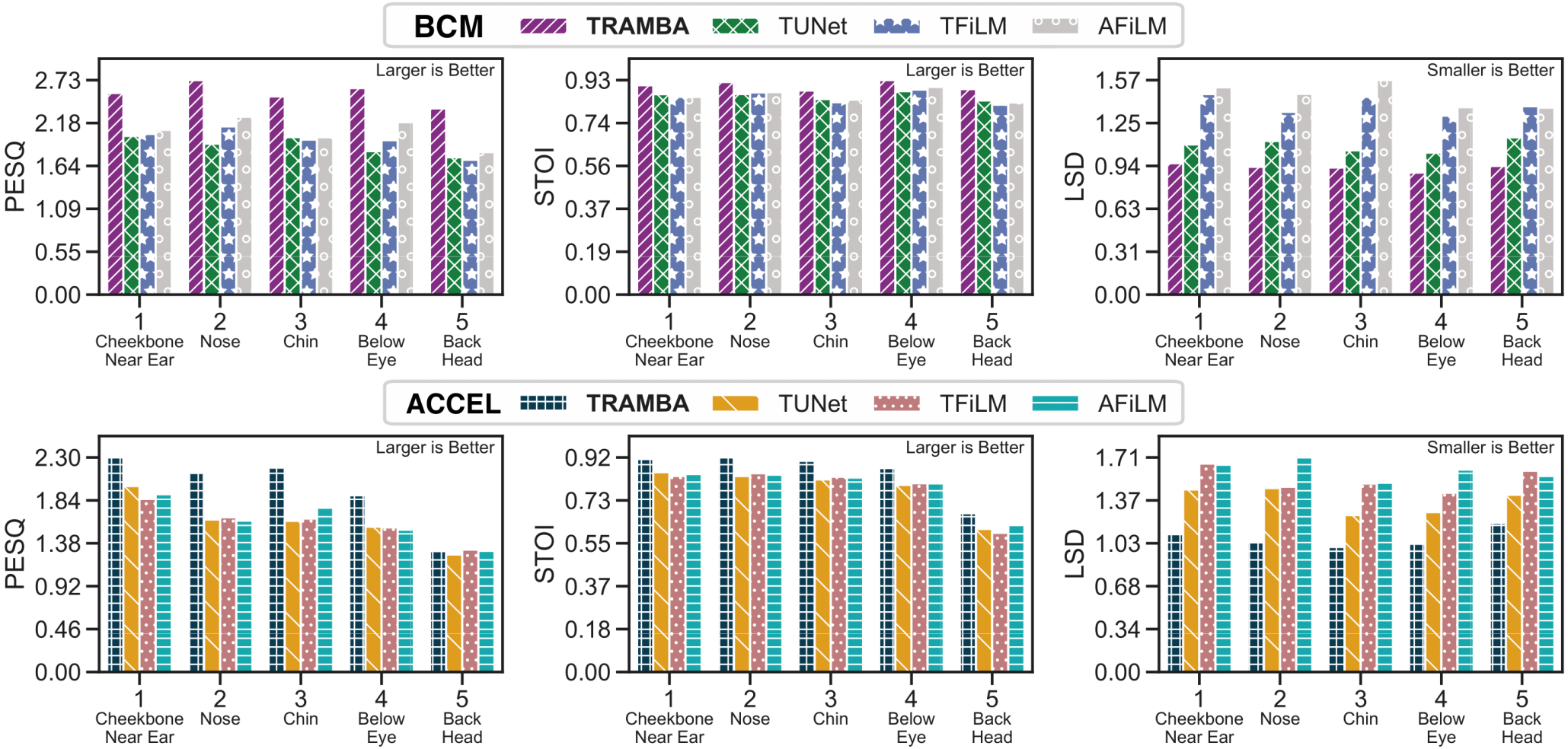
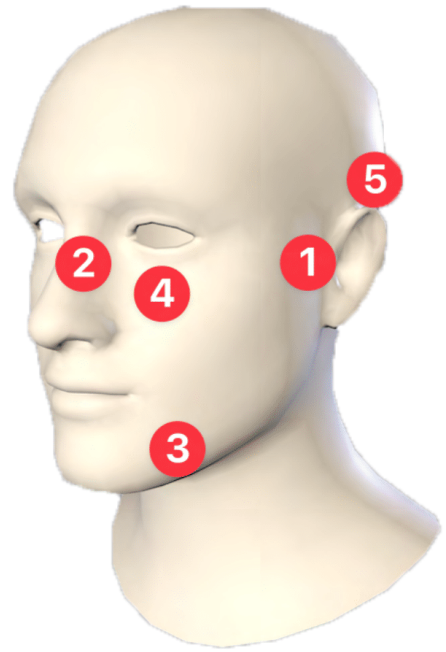
Microphone Placement





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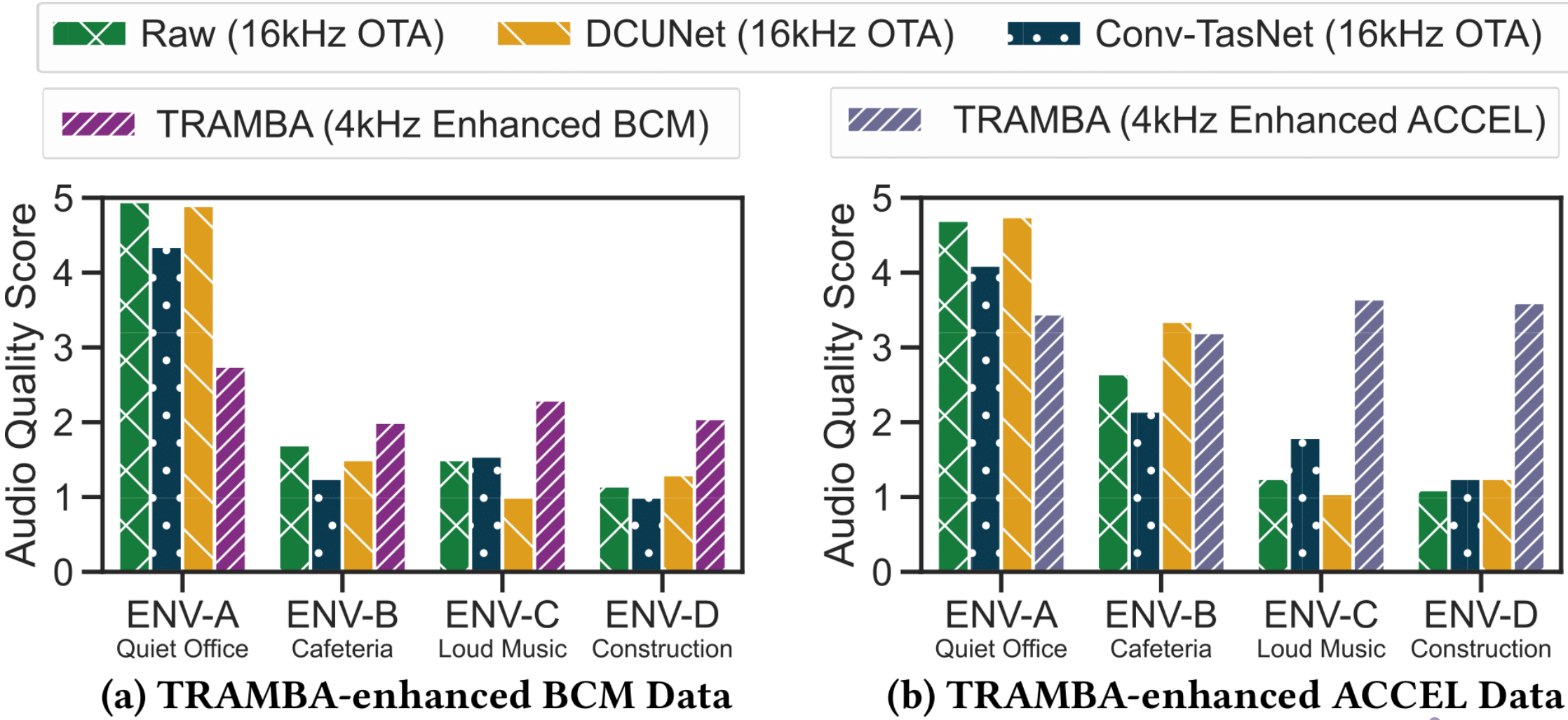
Different Environments



(a) TRAMBA-enhanced BCM Data

(b) TRAMBA-enhanced ACCEL Data

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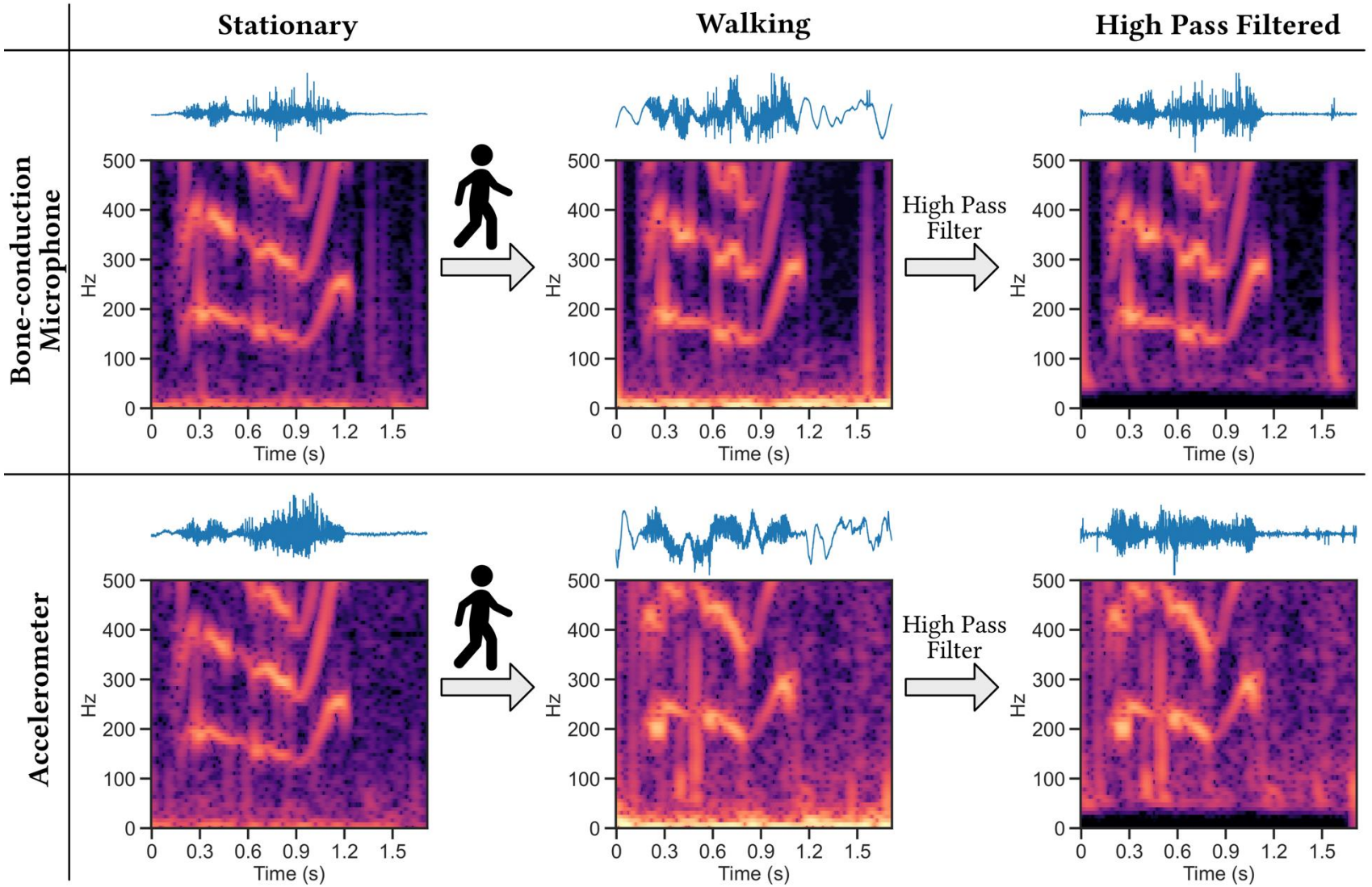
Under Motion



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