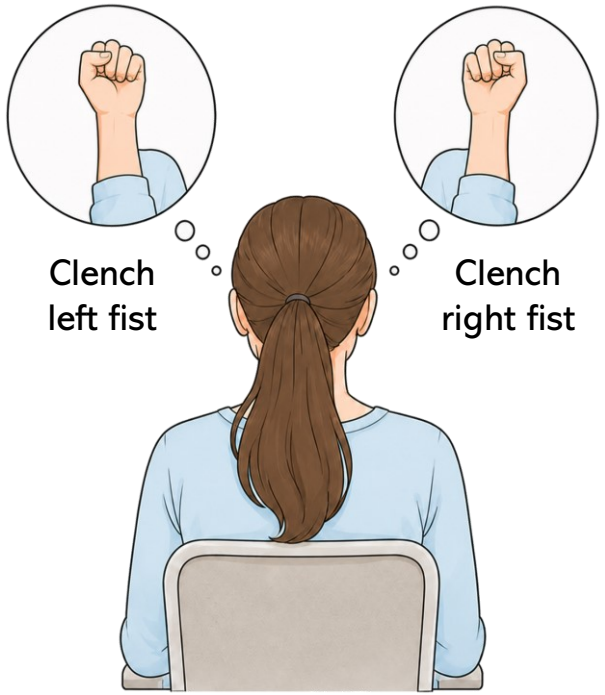
NeuroPath: Practically Adopting Motor Imagery Decoding through EEG Signals

Jiani Cao[1], Kun Wang[1], Yang Liu[2], Zhenjiang Li[1]

City University of Hong Kong[1], Florida State University[2]

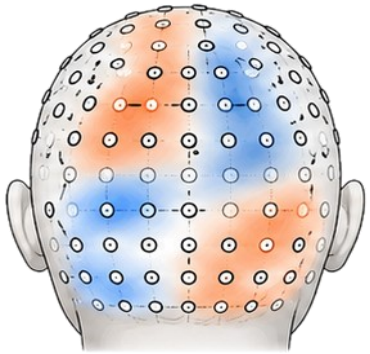
What is Motor Imagery

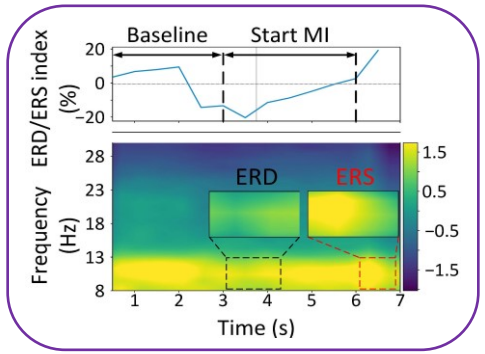
1 Imagined movement



✓ Imagine a specific body-part movement without moving

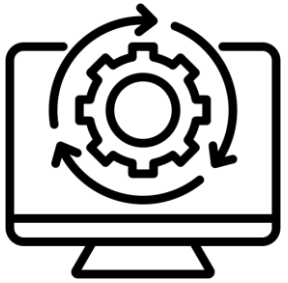
2 Neural response





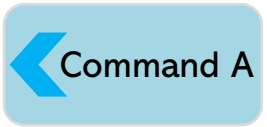
✓ Motor-related patterns

3 Decoding algorithm



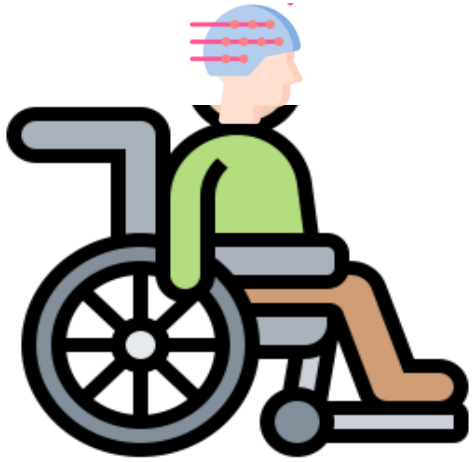
Predicted intent

Mapped command



Why Study Motor Imagery

Assistive control

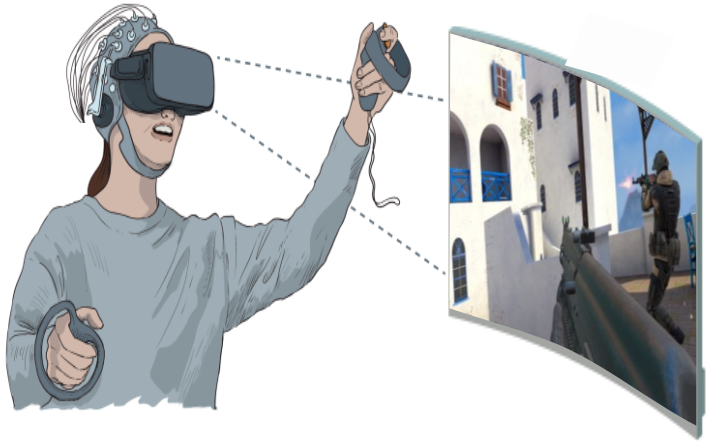


✓ Empower independence and daily living

Rehabilitation

✓ Support motor recovery and neuroplasticity

Human-computer interaction

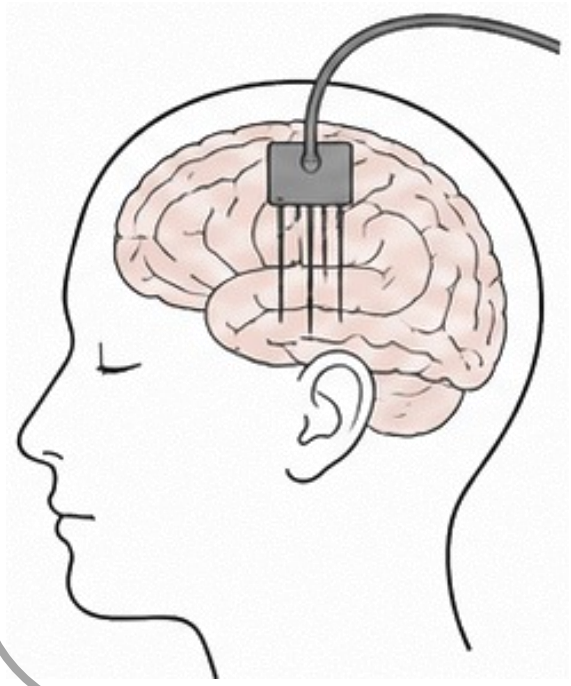


✓ Natural, hands-free digital interaction

MI enables intuitive, hands-free control.
Users can express intent without physical movement.

Existing Solutions

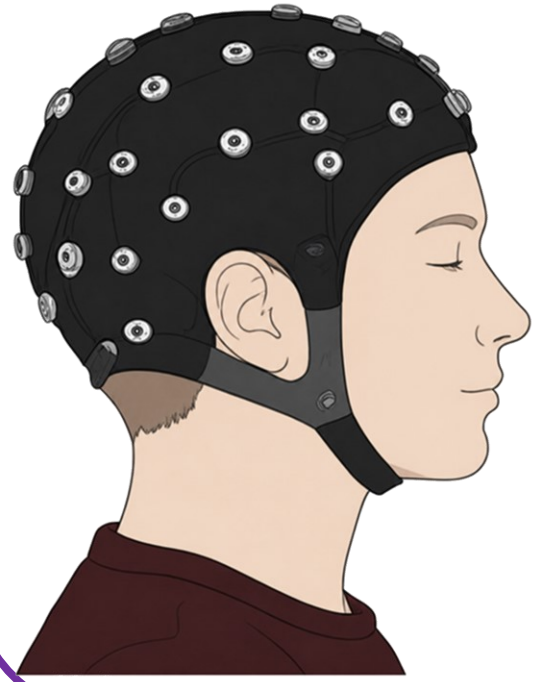
Invasive



- High signal quality
- Requires surgery
- Hard to scale

Our choice

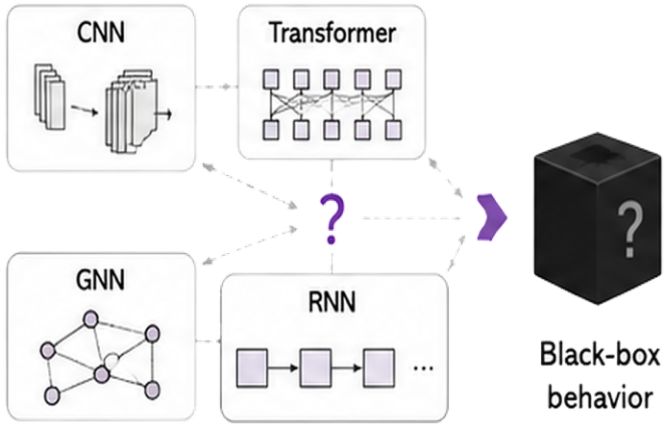
Non-invasive EEG



- Safe and practical
- Low-cost and reusable
- Easy to wear

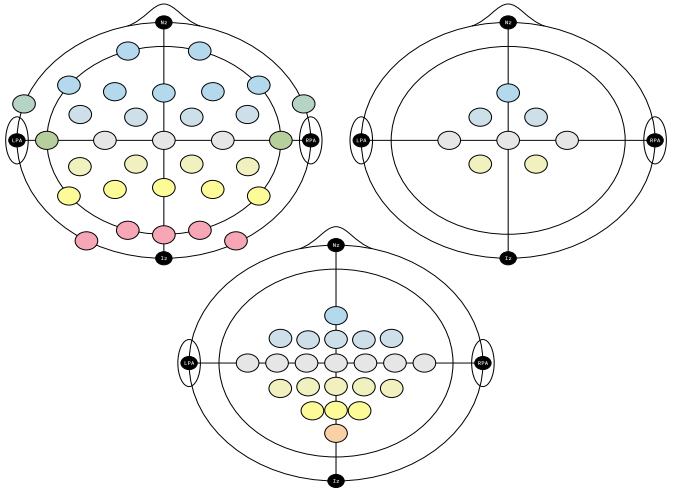
Challenges of Non-invasive EEG

1 Architecture design



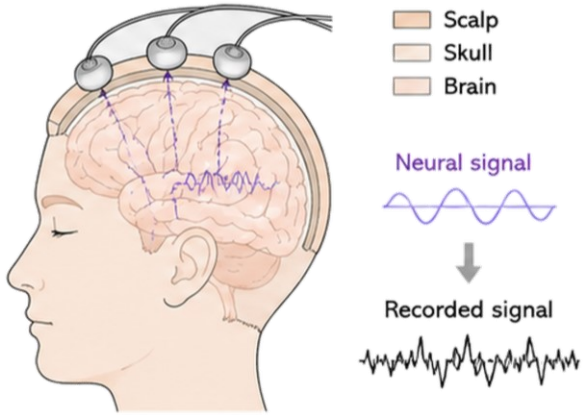
- Many model choices and variants.
- Lack of principled design guidelines.

2 Electrode variability



- Devices differ in electrode number and placement.
- A model trained on one setup may fail on another.

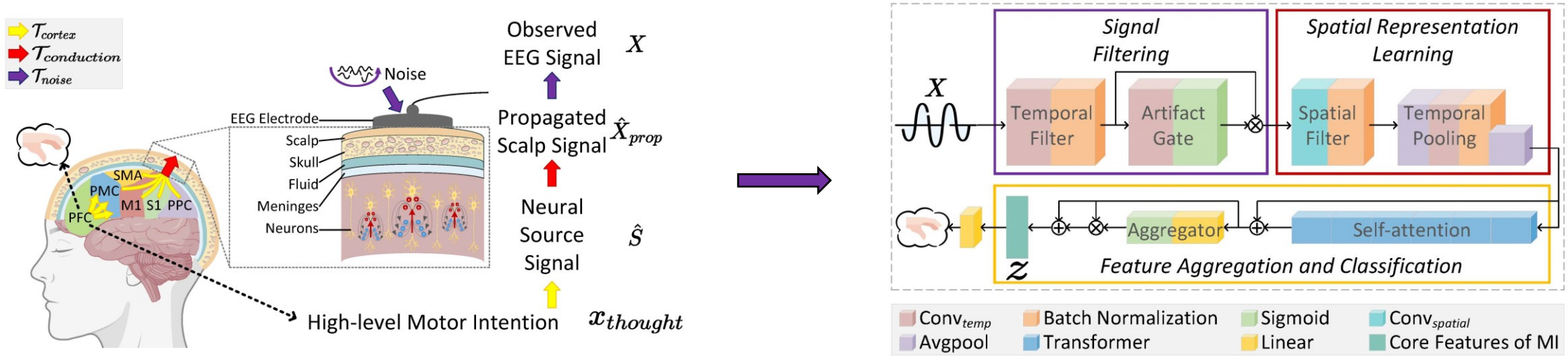
3 Low-SNR signals



- Attenuated and mixed by skull/scalp.
- Easily corrupted by motion and eye blinks.

Design 1: Brain-inspired MI Decoder

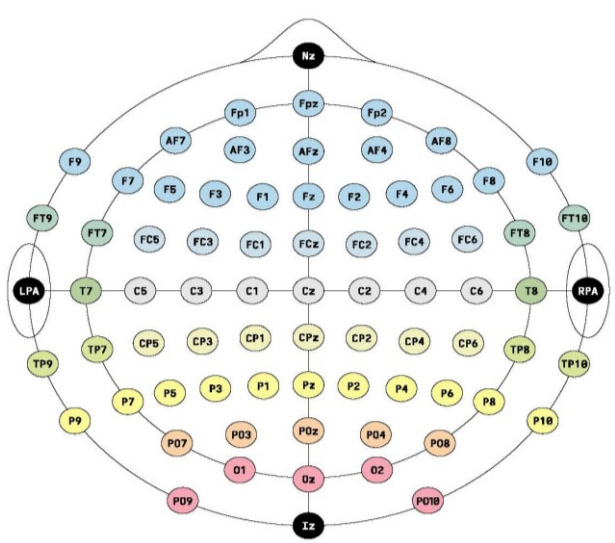
- Abstracted signal generation process
- Brain-inspired MI decoder architecture

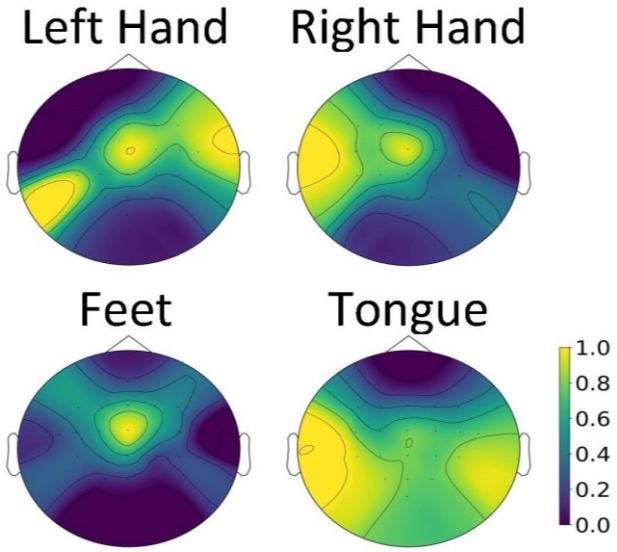


✓ Inspired by key stages, not literal biological inversion.

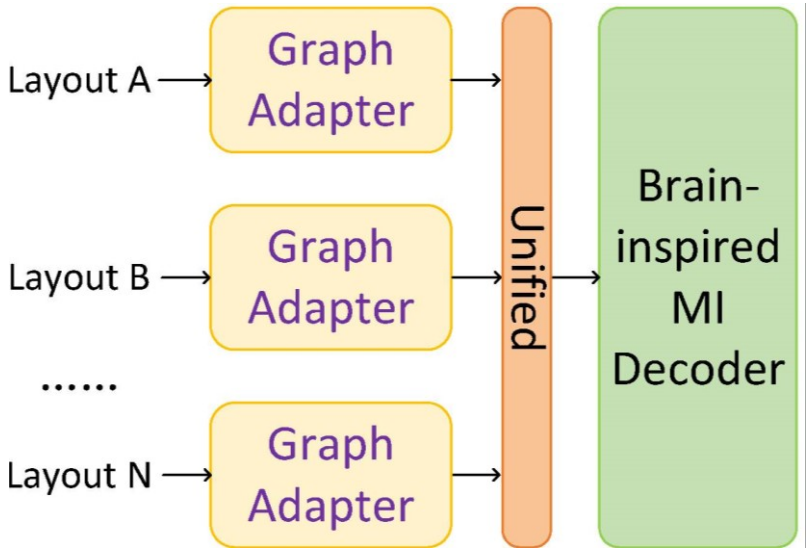
Design 2: Unify Different Electrode Layouts

➢ Two key observations





➢ Design takeaway



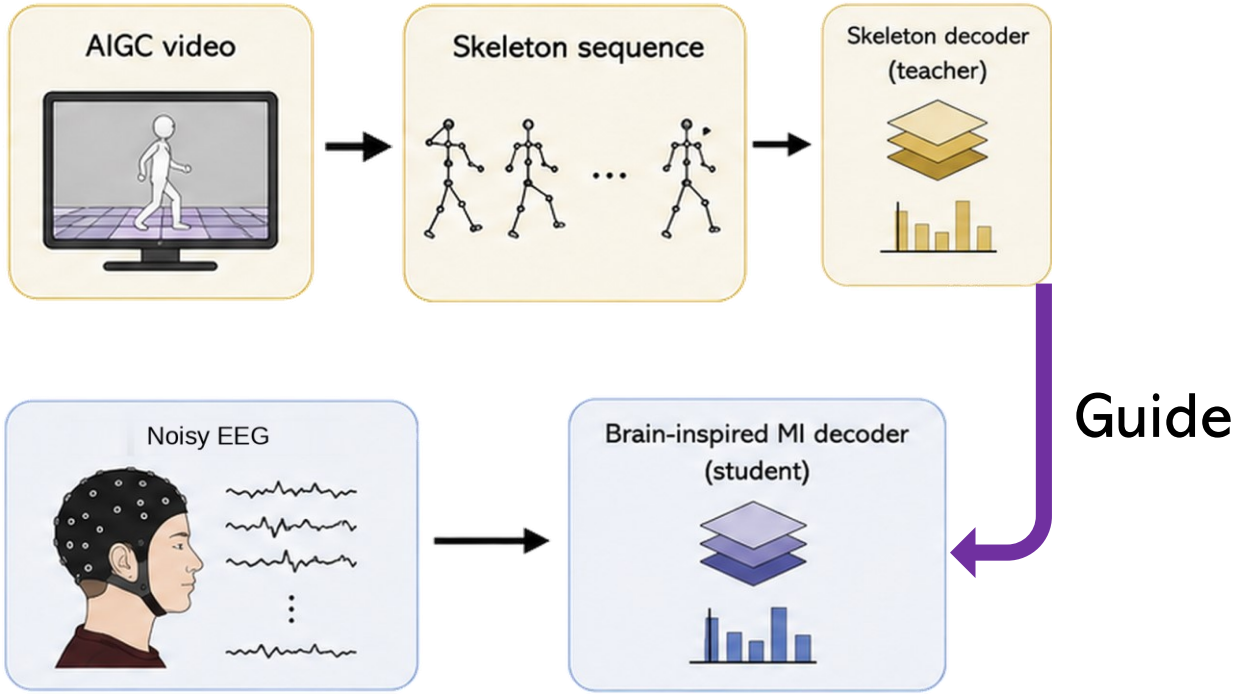
✓ Use the 10-10 spatial prior to align layouts and focus on task-relevant channels.

✓ This enables one decoder to work across different devices.

Design 3: Cross-modality Knowledge Transfer

- Key idea: let a clean, low-cost teacher guide noisy EEG learning

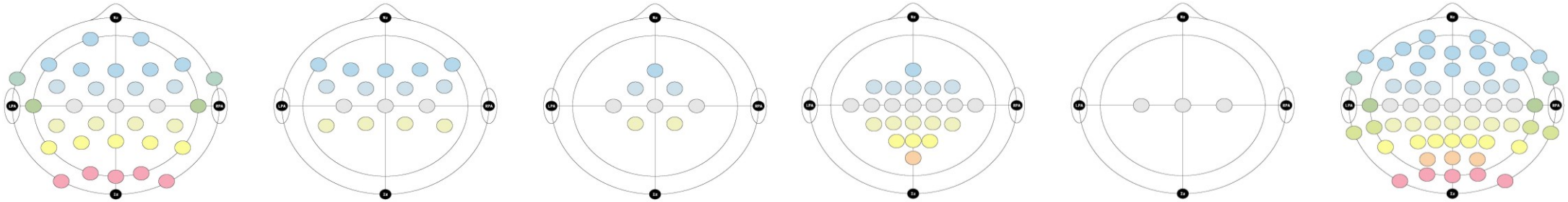
High-quality modality (teacher): automatically generated, no extra sensors

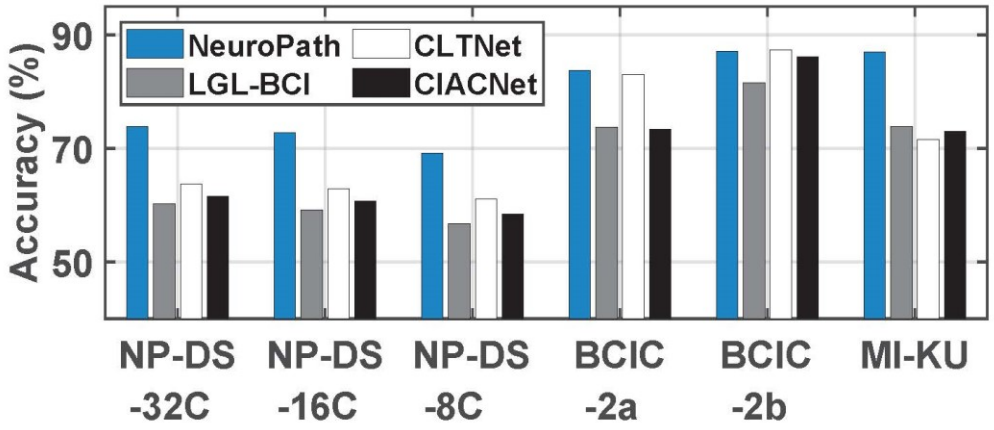


Low-quality modality (student): noisy EEG (inference only needs EEG)

Evaluation

- Three public datasets, three self-collected datasets





✓ NeuroPath achieves good performance.

Conclusion 1, 2, 3

1. One goal:
   - Practical MI decoding using non-invasive EEG

2. Two aspects:
   - Adapt to different electrode layouts
   - Work with low-SNR EEG

3. Three modules:
   - Brain-inspired MI decoder
   - Spatially-aware graph adapter
   - Cross-modality knowledge transfer

Thank you

Q&A

NeuroPath: Practically Adopting Motor Imagery Decoding through EEG Signals

Jiani Cao[1], Kun Wang[1], Yang Liu[2], Zhenjiang Li[1]

City University of Hong Kong[1], Florida State University[2]