

Headset-Integrated Brain-Machine Interface for Mind Imagery and Control in VR/MR Applications

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UNIVERSITY

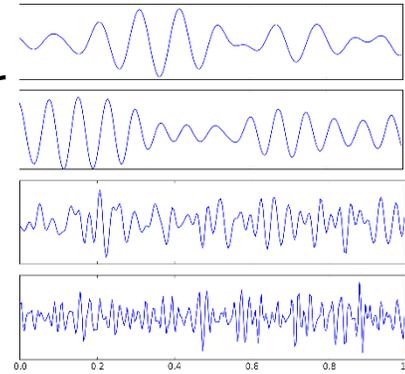
New Opportunities from BMI for VR/MR

VR/MR Headsets

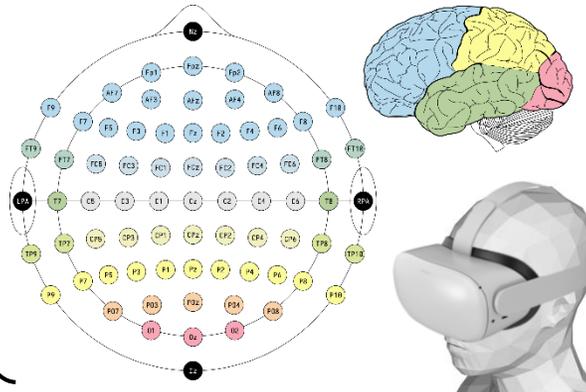


- **Electroencephalogram (EEG)**
 - Brain's electrical activity
- **Brain-Machine Interface (BMI)**
 - Brain activity tracking
 - Active control
 - Reactive control
 - Passive control

Interaction Methods



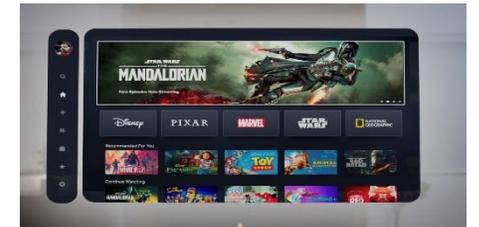
EEG waves



Applications



Gaming



Movie/Shopping



Office

Motivation and Challenges



VR headset



EEG electrode cap



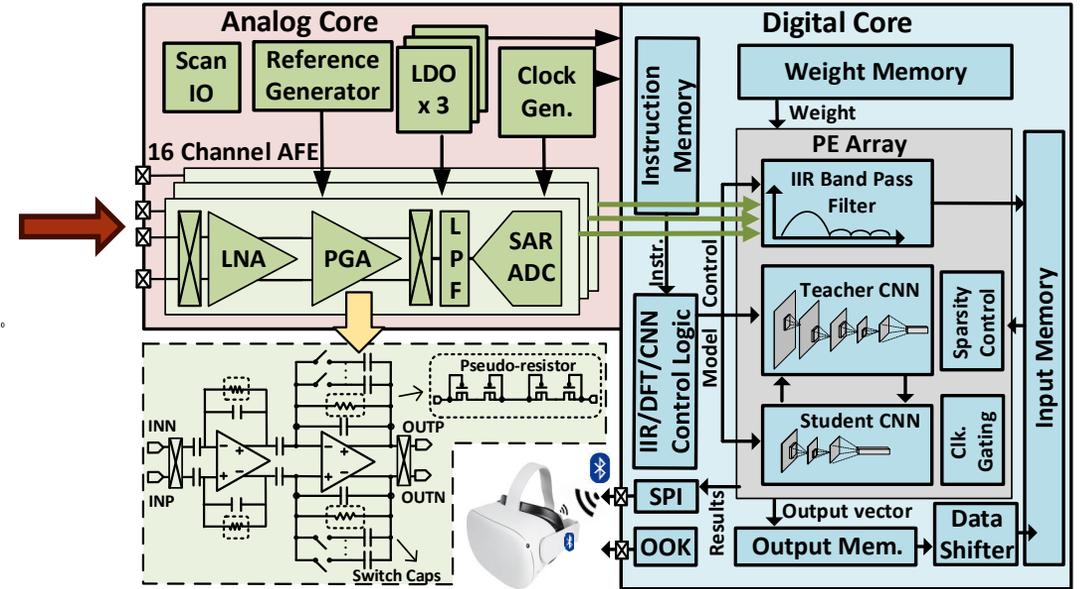
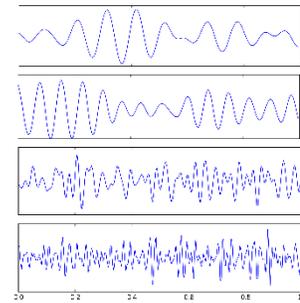
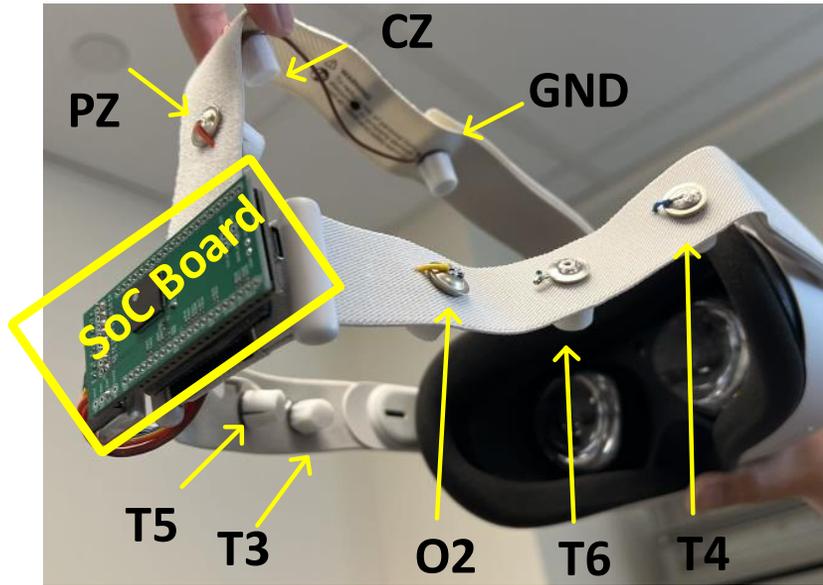
Desktop



Immersive virtual environment
& brain activity combination

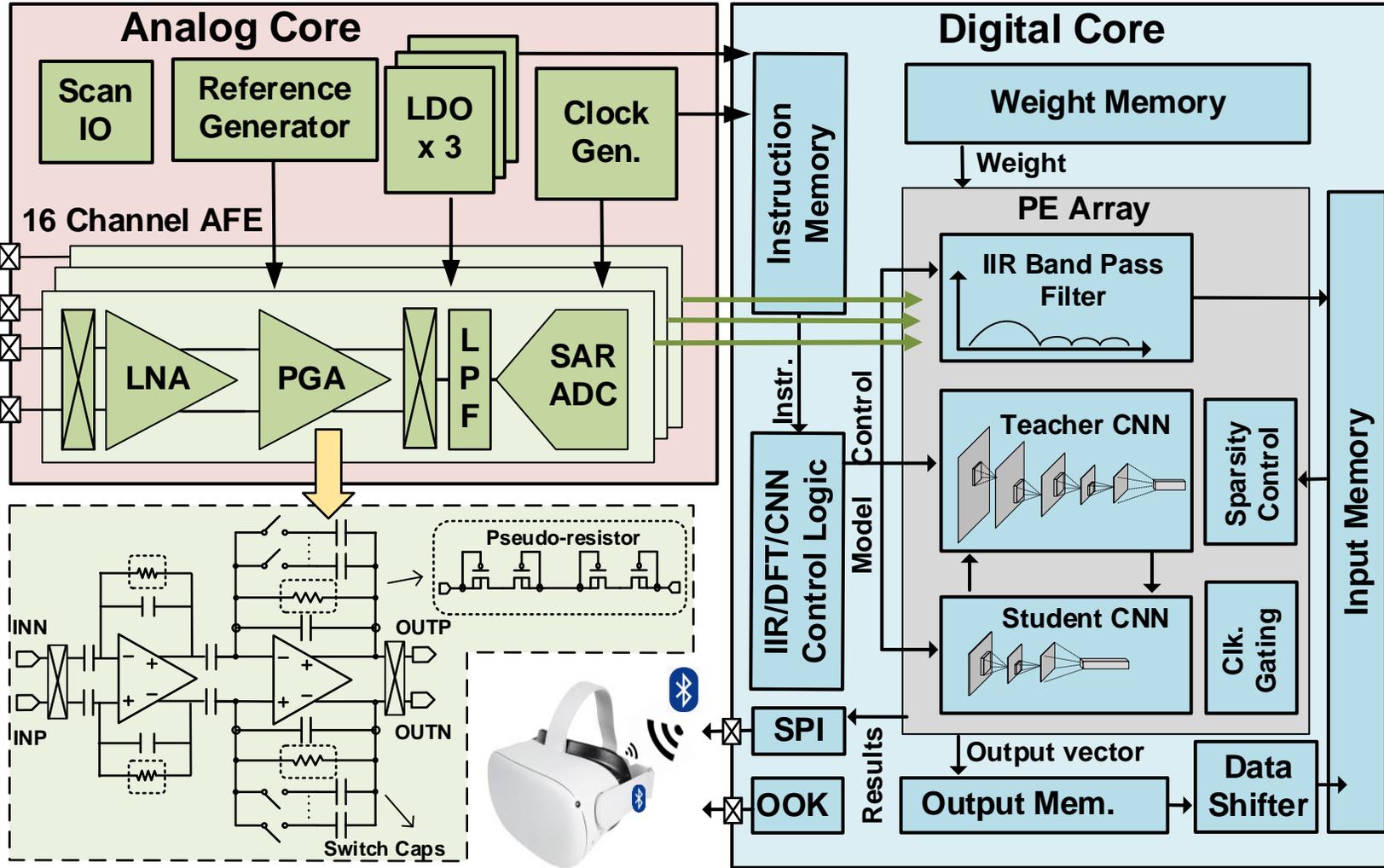
- **Cumbersome wearing**
- **High power for AI models**
- **Lack of low-latency computing support**
- **Lack of real-time feedback control**

This Work



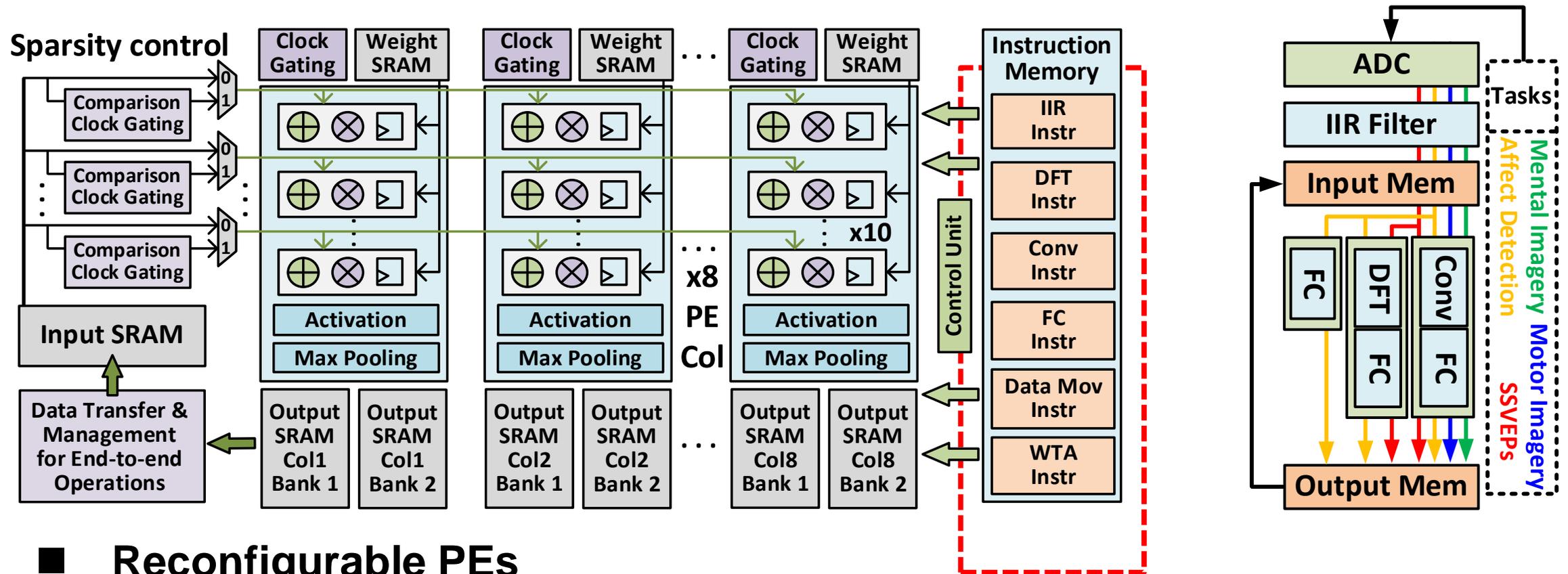
- The First SoC supporting mind imagery control for VR/MR
- Integration with VR headset and optimized channel placement
- ISA and AI architecture for general-purpose mind imagery tasks
- Teacher-Student CNN and sparsity enhancement for power saving

System Overview



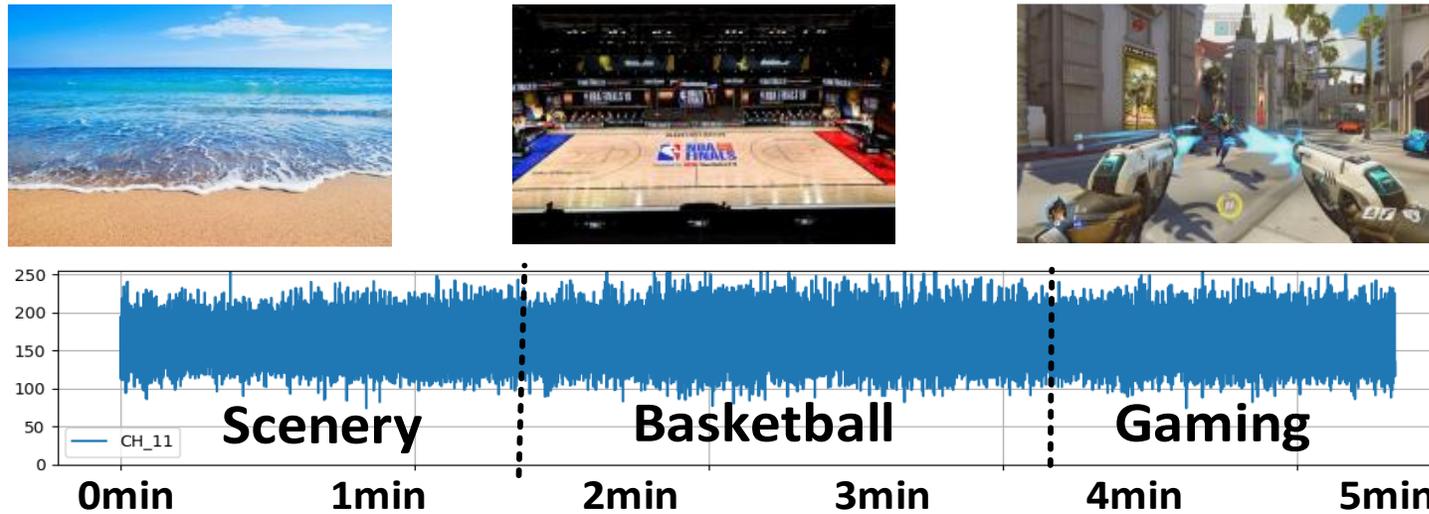
- **16-ch AFE for EEG**
 - Two-stage chopper amp.
 - 45-72dB gain
 - 0.05-400Hz bandwidth
- **8x10 MAC PE array**
- **IIR band pass filter**
- **Discrete Fourier trans.**
- **Convolutional NNs**
- **Instruction Mem.**
- **Customized inst.**
- **Control VR by ext. BLE**

Neural Processor Architecture and Configuration

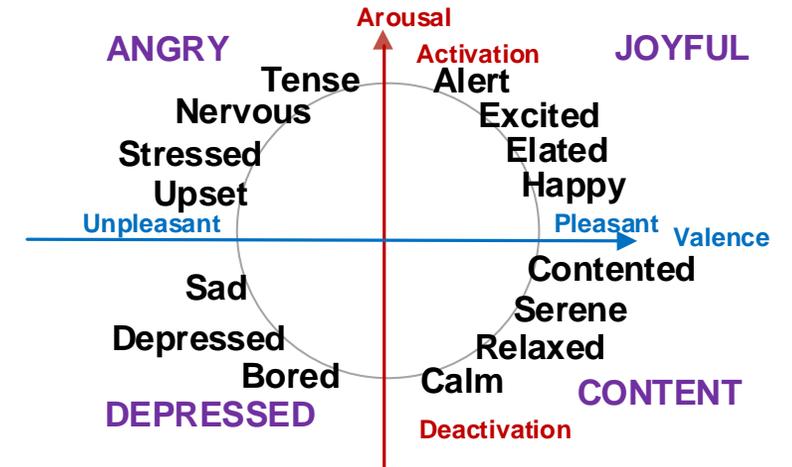


- Reconfigurable PEs
- Flexible solutions for EEG tasks
- End-to-end flow without Off-Chip data reloading

Teacher-Student CNN for Affect Monitoring



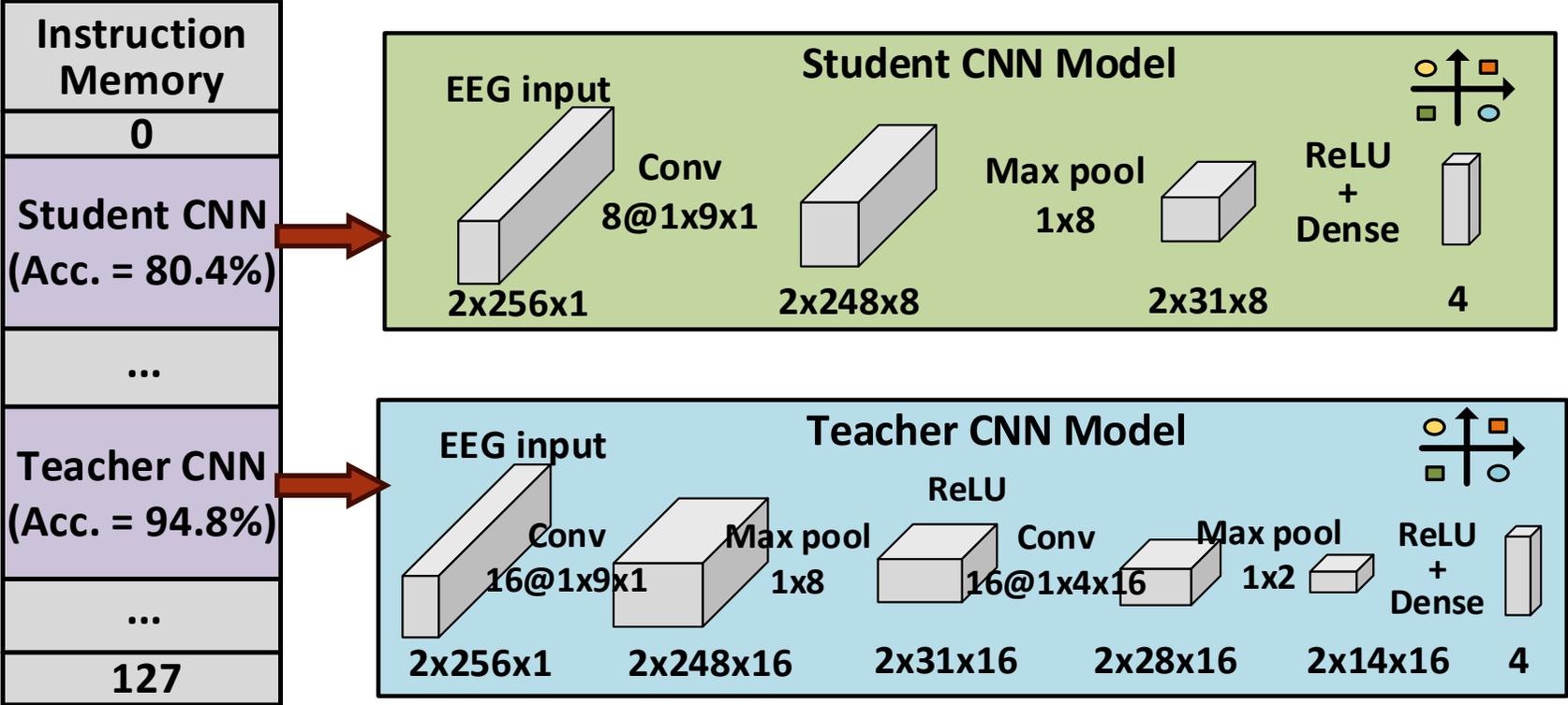
EEG recorded during YouTube watching



Russell circumplex model on emotion

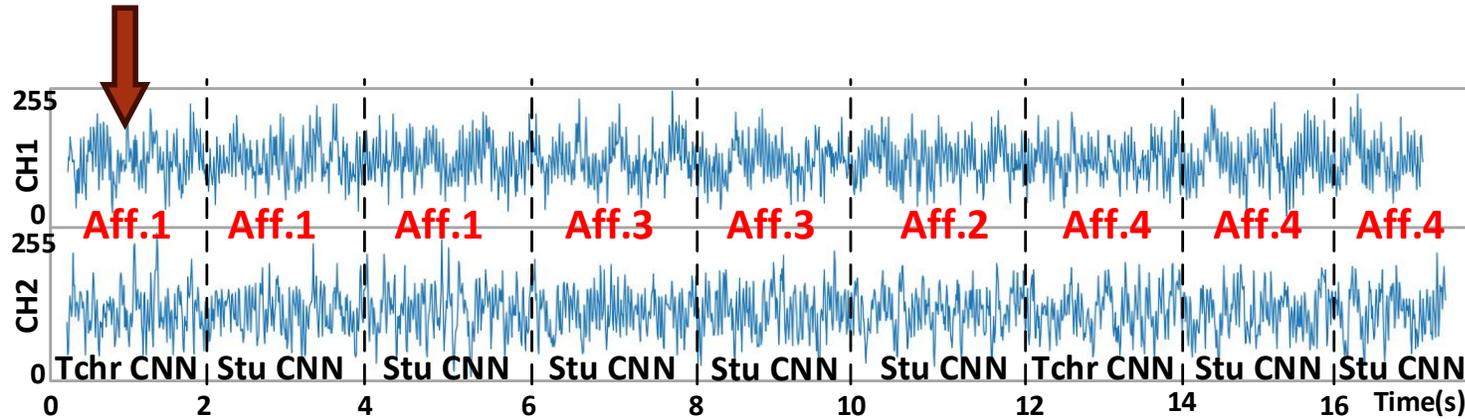
- **Affect changes at a slow pace over a long period**
- **Integrated circuits run at a much faster speed**
- **Teacher-Student CNN scheme based on temporal locality**
 - Two CNN models with different cost and accuracy
 - Balance between computational power and accuracy

Confusion Matrix Guided CNN Scheme



- **Affect classification**
 - Four classes
- **Student CNN model**
 - 3x faster
 - 70% less energy
 - 14% lower accuracy
- **Teacher CNN model**
 - Higher cost
 - Higher accuracy

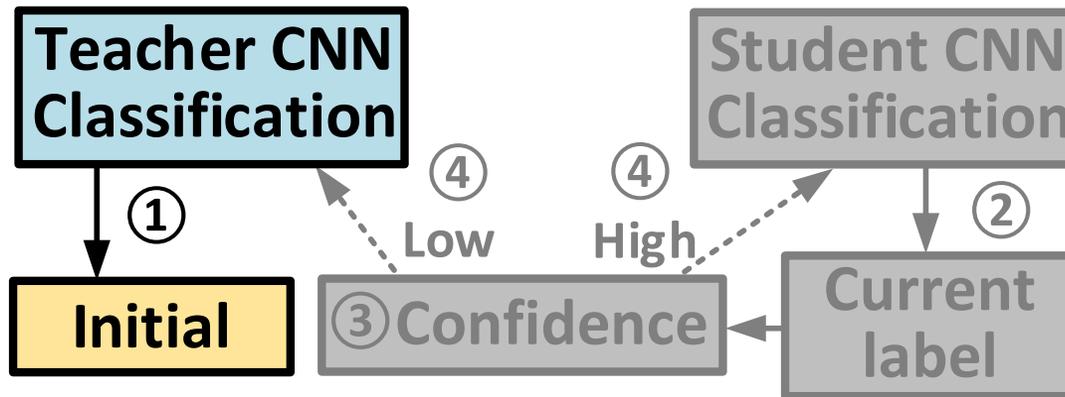
Confusion Matrix Guided CNN Scheme



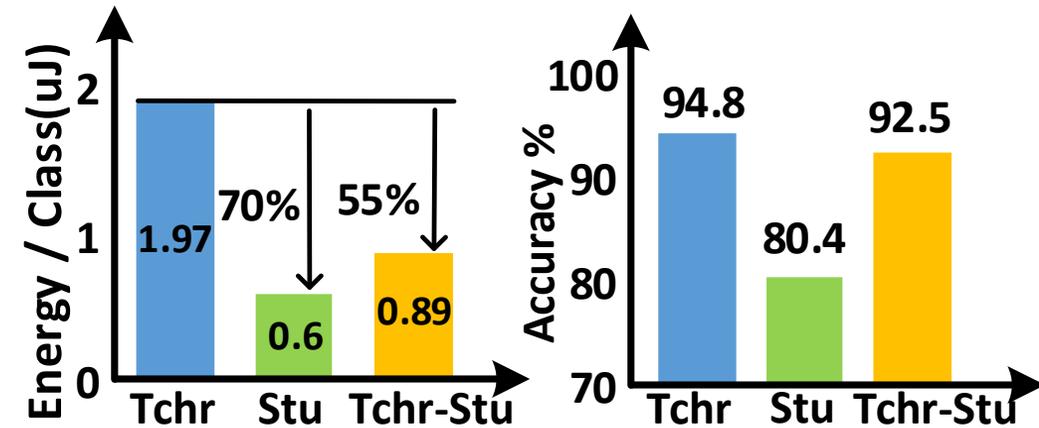
Predicted

	Aff.1	Aff.2	Aff.3	Aff.4
Actual Aff.1	0.986	0.014	0	0
Actual Aff.2	0.014	0.966	0	0.02
Actual Aff.3	0.027	0	0.932	0.041
Actual Aff.4	0	0.667	0	0.333

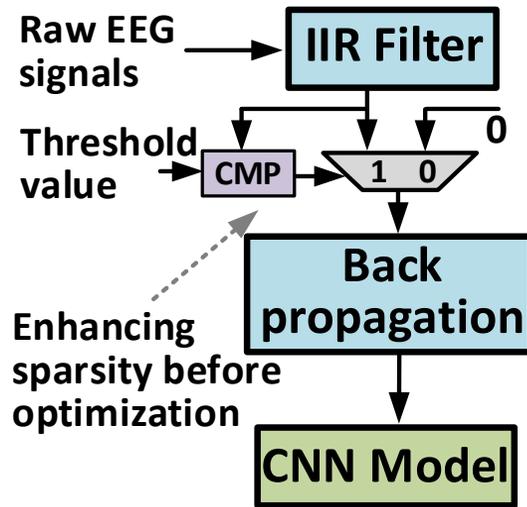
Student confusion matrix



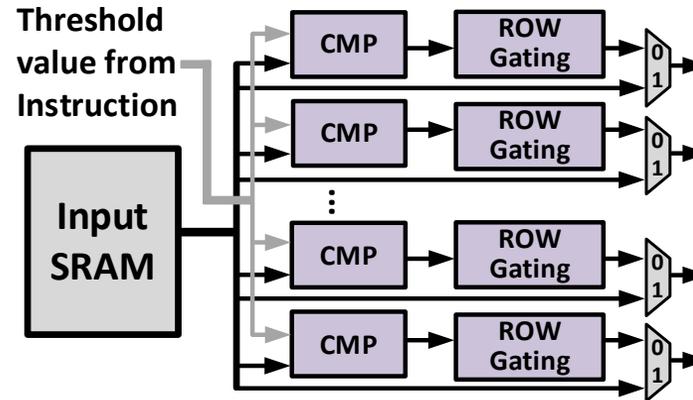
- Teacher CNN for initial prediction
- Student CNN for monitoring



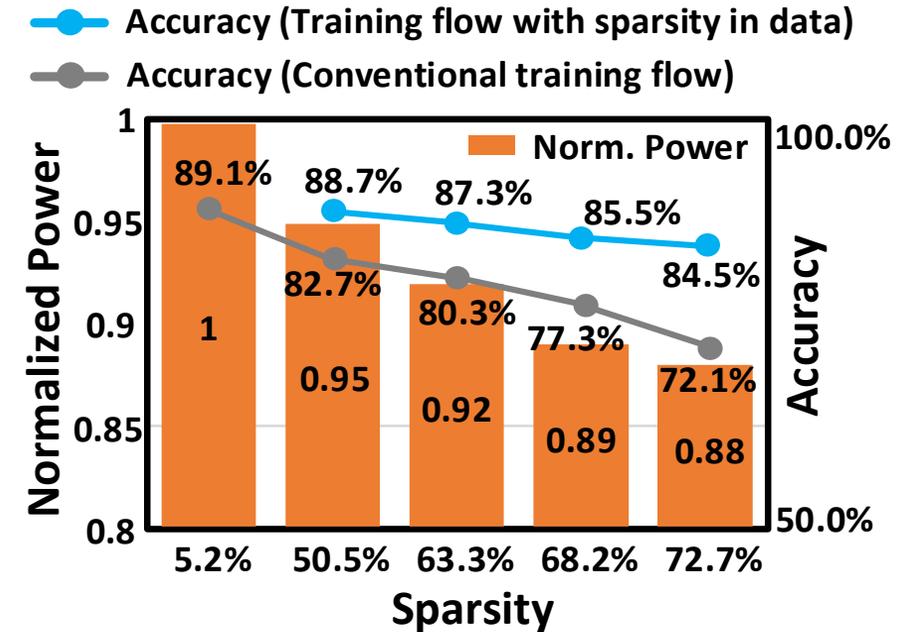
Sparsity Enhancement



Sparsity-Enhanced training flow



On-Chip Inferencing

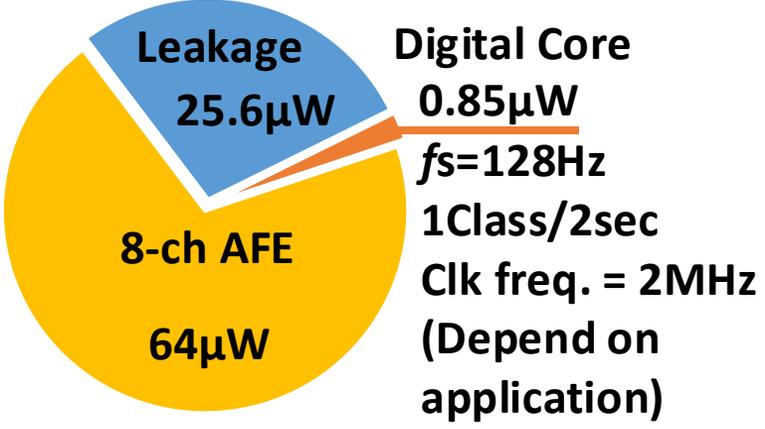
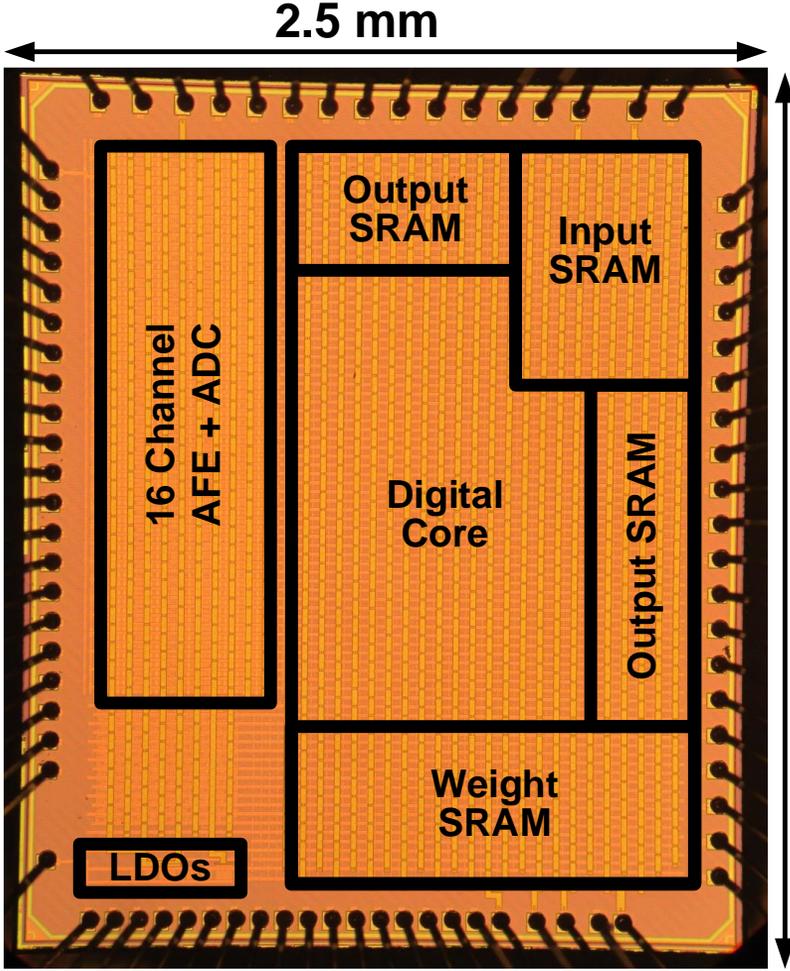


Binary affect classification

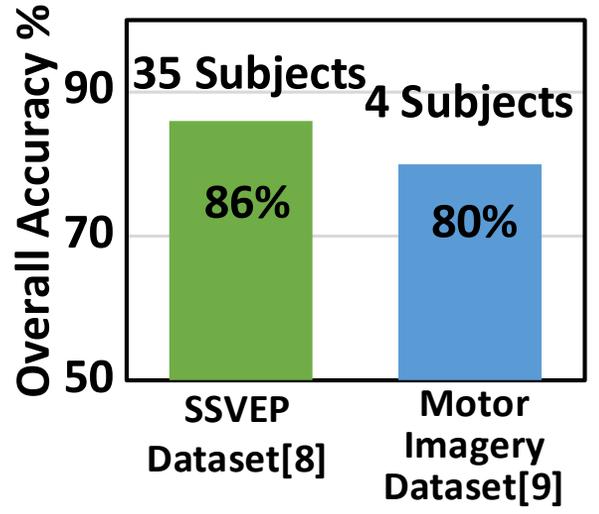
■ Increase data sparsity and accuracy w/ sparsity-aware training

- 12% power saving
- 12.4% accuracy improvement by sparsity-aware training

Chip Implementation & Measurement Results



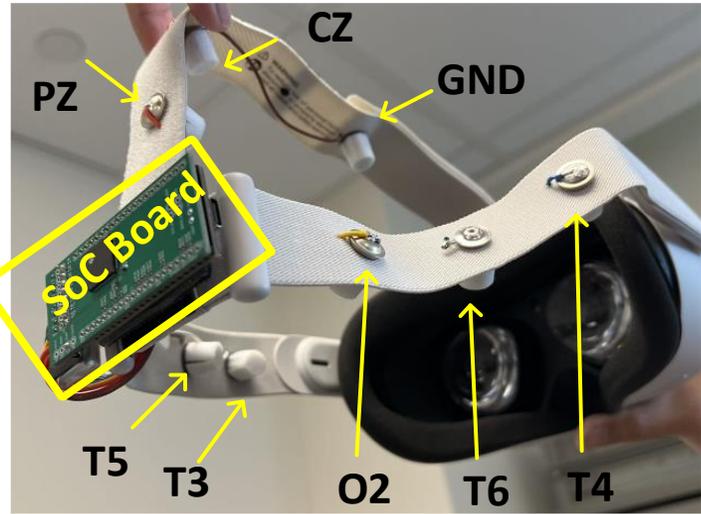
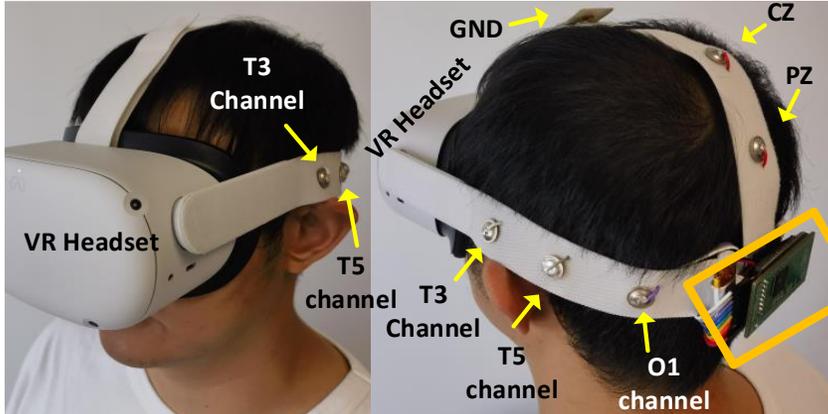
Average power in affect monitoring



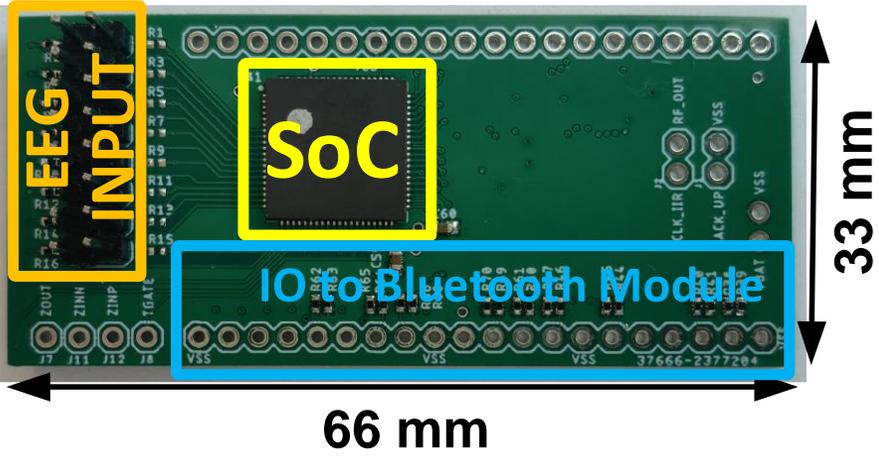
Public dataset results

Chip fabricated In TSMC 65nm

System Setup and Applications



- Meta Quest 2 VR
- Customized VR scene and games
- Chip communicated with VR through BLE

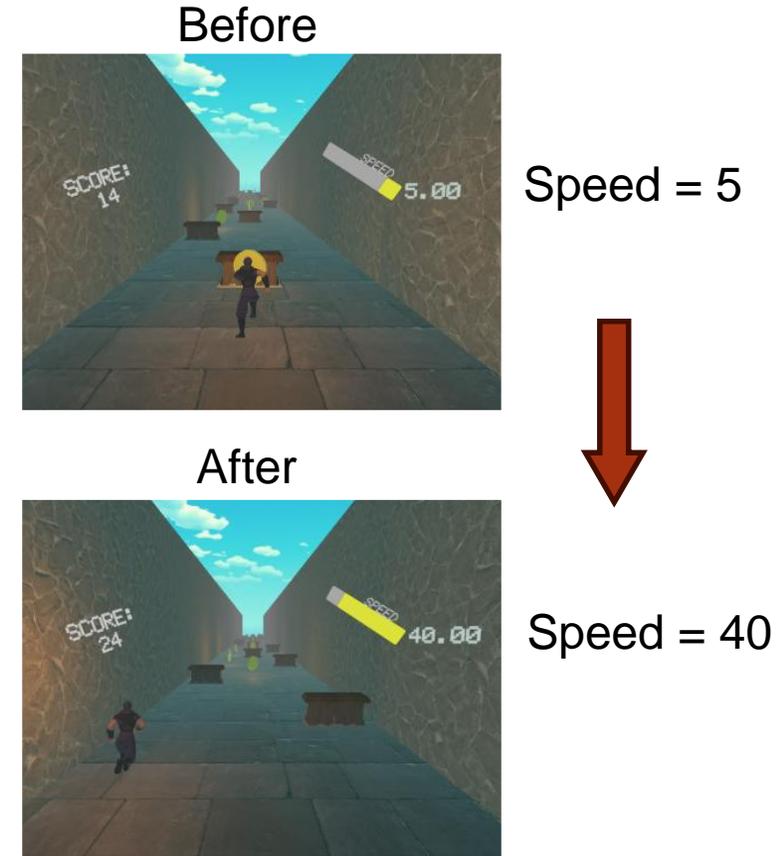
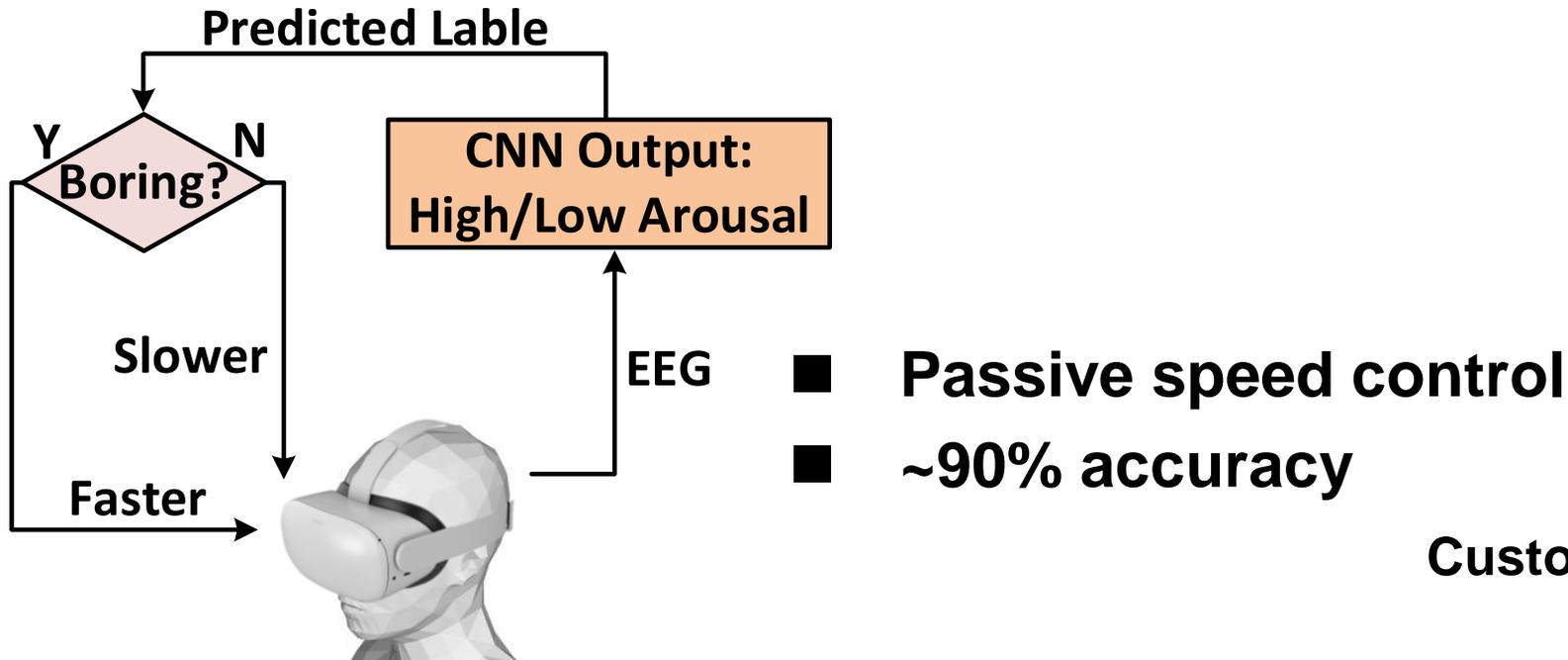


Real-time Affect Tracking and Control for VR Game

① Collect EEG signals as training and validation data



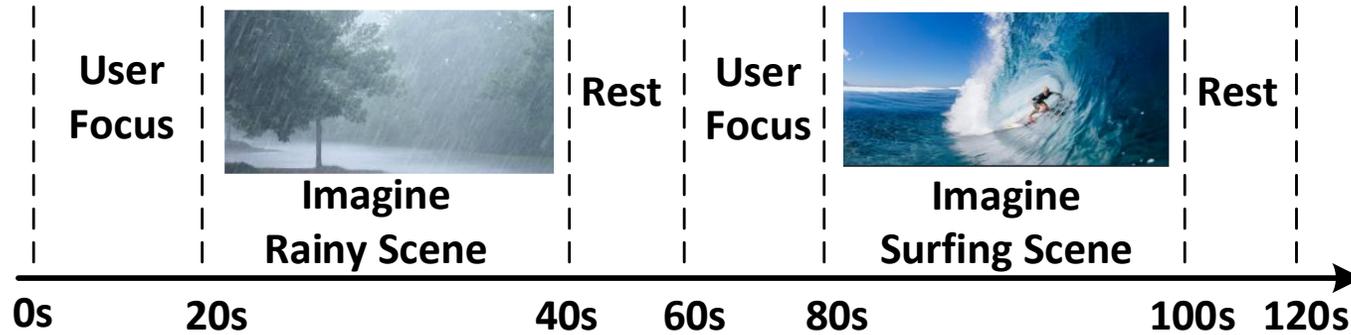
② Change the game speed based on gaming experience



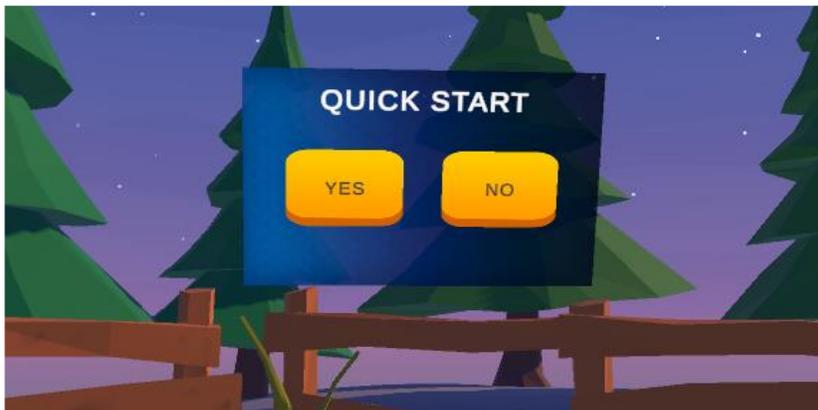
Customized Endless-Runner VR game

Mental Imagery Controlled Menu Selection

① Collect EEG signals as training and validation data



② Issue commands to VR by actively changing mental states



Focus: open menu

Surfing (intense): YES

Rainy (relaxed): NO

- Active control by mind states
- Scenario-aided imagery
- ~80% accuracy

Real-time Affect Tracking and Control for VR Game

The image displays a real-time affect tracking and control system for a VR game. On the left, a terminal window (COM5) shows a sequence of voting messages and final decisions. An orange arrow points from the text "Predicted Results" to the final decision "faster" in the terminal. The main window shows a VR game interface with a character running in a virtual environment. The score is 206 and the speed is 25.00. The interface includes a navigation menu with options like PRODUCTS, EXPERIENCES, APPS & GAMES, and SUPPORT. The bottom of the screen shows the Meta Quest logo and product information for Quest 3, Quest Pro, and Quest 2. The system tray at the bottom indicates the time is 1:28 PM on 2/13/2024.

```
COM5
voting: slower
voting: slower
voting: faster
voting: faster
voting: slower
Final decision: slower
voting: faster
voting: faster
voting: slower
voting: slower
voting: faster
voting: faster
voting: faster
Final decision: faster
voting: faster
voting: faster
voting: faster
voting: slower
voting: faster
voting: faster
voting: faster
Final decision: faster
voting: faster
voting: faster
voting: faster
voting: slower
voting: faster
voting: faster
voting: faster
Final decision: faster
```

Predicted Results

SCORE: 206

SPEED 25.00

Meta Quest

QUEST 3
QUEST PRO
QUEST 2

ALL PRODUCTS
Quest 3
Quest Pro
Quest 2
Quest 2 (Refurbished)

MORE META QUEST
Forums
Blog
Referrals
VR for Good

ABOUT
Careers
Meta Connect
Research

Type here to search

115200 baud

1:28 PM 2/13/2024

Mental Imagery Controlled Menu Selection

The image shows a VR application interface. On the left, a terminal window displays a sequence of commands and responses: 'voting: no', 'voting: yes', 'Final decision: No', 'Pop up menu', 'voting: yes', 'Final decision: YES', 'Pop up menu', 'voting: yes', 'voting: yes', 'voting: no', 'voting: yes', 'voting: no', 'voting: yes', 'voting: no', 'voting: no', 'voting: no', 'voting: no', 'Final decision: YES', 'Pop up menu', 'voting: no', 'voting: yes', 'voting: yes', 'voting: no', 'voting: no', 'voting: no', 'voting: no', 'Final decision: No'. An orange arrow points from the text 'Predicted Results' to the final 'Final decision: No' line. The main VR view shows a 'QUICK START' menu with a yellow 'YES' button and a green 'NO' button. The text 'Intend to choose NO' is displayed above the menu. The background features a stylized forest scene with green trees and a blue sky. The interface includes a navigation bar with 'PRODUCTS', 'EXPERIENCES', 'APPS & GAMES', and 'SUPPORT'. The bottom of the screen shows a Windows taskbar with various application icons and a system tray displaying the time '1:58 PM' and date '2/13/2024'.

Summary

■ **The first SoC for Mind Activity Monitor and Control for VR/MR**

- Integration with VR headset and optimized EEG electrodes placement
- Instruction Set and reconfigurable architecture for various brain activity tasks

■ **Special Low-power Features**

- Teacher-Student CNN guided by confusion matrix with 55% energy saving
- Sparsity-aware training flow with 12% power saving

■ **65nm Test Chip and System Demonstrations**

- Mental imagery and control for VR menu operation
- Affect tracking and control of gaming scenes
- Achieved lowest energy per class for CNN operation among biomedical ICs

Thank you!