Explore limitless possibilities!
無限の可能性を探求しよう！

https://bsenzio.github.io/bmitutorialALIFE26/

BRAIN–COMPUTER INTERFACE (BCI)

Principles • Discovery • How It Works • How It's Used

A BCI is a direct communication pathway enabling the brain to interact with external devices, bypassing the body's muscles.

1 FUNDAMENTAL PRINCIPLES

Neural Signal Acquisition
Detect electrical or hemodynamic activity from the brain.

Signal Processing
Filter noise, extract relevant features, and transform the signals.

Pattern Recognition
Identify patterns and map them to user intentions.

Translation & Output
Convert intentions into commands for external devices or feedback.

Closed-Loop Adaptation
The system learns and adapts with continuous use.

2 HOW IT WAS DISCOVERED

1924 Hans Berger
First recorded the human electroencephalogram (EEG).

1960s–70s
Neuroscience & engineering advanced how we measure and interpret brain signals.

1990s First BCIs
Early systems demonstrated brain signals controlling a cursor or device.

2000s–Now
Improved sensors, machine learning, and real-time systems enable practical, non-invasive BCIs.

3 HOW IT WORKS

1 Acquisition
Sensors rapture brain activity (EEG, ECoG, fNIRS, etc.).

2 Preprocessing
Remove noise, segment, normalize, and filter.

3 Feature Extraction
Extract meaningful representations.

4 Classification / Decoding
Map patterns to intentions (or mental states).

5 Command / Output
Execute actions, provide feedback, or control devices.

4 HOW IT IS USED

Neurorehabilitation
Restore movement and communication after injury or disease.

Assistive Communication
Enable communication for people with paralysis (e.g., ALS, locked-in syndrome).

Device Control
Control computers, prosthetics, drones, wheelchairs, and more.

Cognitive Enhancement
Improve attention, learning, and mental training.

Neurotechnology & Research
Study the brain and develop new human–computer interactions.

BCIs bridge the gap between mind and machine, opening new possibilities to enhance human potential and improve quality of life.

Brain Signals »» Processing »» Decoding »» Action »» Impact

BCI HARDWARE ARCHITECTURE

How a Brain–Computer Interface is Built

1. SIGNAL ACQUISITION
Capture brain activity

Electrodes placed on the scalp detect tiny electrical signals produced by neuronal activity.

2. SIGNAL CONDITIONING
Amplify and prepare raw signals

AMPLIFIER & FRONT-END

Low Noise Amplifier → Band-pass Filter (e.g., 0.1–100 Hz) → Notch Filter (e.g., 50/60 Hz) → Analog-to-Digital Converter (ADC)

Amplifies microvolt-level signals (UV) and removes noise and interference.

3. PROCESSING
Extract information and detect intent

PROCESSING UNIT
Embedded Processor or Computer

PROCESSING PIPELINE
- **Preprocessing** – Filtering, artifact removal (e.g., eye blinks, muscle noise)
- **Feature Extraction** – Time, frequency, spatial or time–frequency features
- **Classification / Decoding** – Machine Learning algorithms (e.g., LDA, SVM, CNN, RNN)
- **Intent Recognition** – Translate patterns into commands or actions

4. OUTPUT / APPLICATIONS
Translate intent into action

OUTPUT INTERFACE
Bluetooth | Wi-Fi | USB | Custom Protocol

APPLICATIONS
- Communication
- Device / Robot Control
- Assistive Technology
- Neurofeedback
- Gaming & VR
- Monitoring & Analytics

Feedback to User (Visual / Audio / Haptic)

KEY HARDWARE COMPONENTS

EEG CAP / ELECTRODES – Ag/AgCl electrodes capture brain signals.

AMPLIFIER – Boosts weak signals while minimizing noise.

ADC – Converts analog signals to digital data.

PROCESSING UNIT – Runs algorithms and decodes brain activity.

COMMUNICATION MODULE – Transmits data wirelessly or via cable.

POWER SUPPLY – Provides stable and portable power.

TYPES OF EEG ACQUISITION

WIRED SYSTEMS – High-quality signal, less interference

WIRELESS SYSTEMS – More mobility and comfort

DRY ELECTRODES – Easy to use, no gel required

OVERALL BCI HARDWARE FLOW

Brain Activity → EEG Electrodes → Amplifier & Signal Conditioning → ADC → Processing Unit → Decoded Intent → Output / Application

WHAT MAKES IT POSSIBLE?

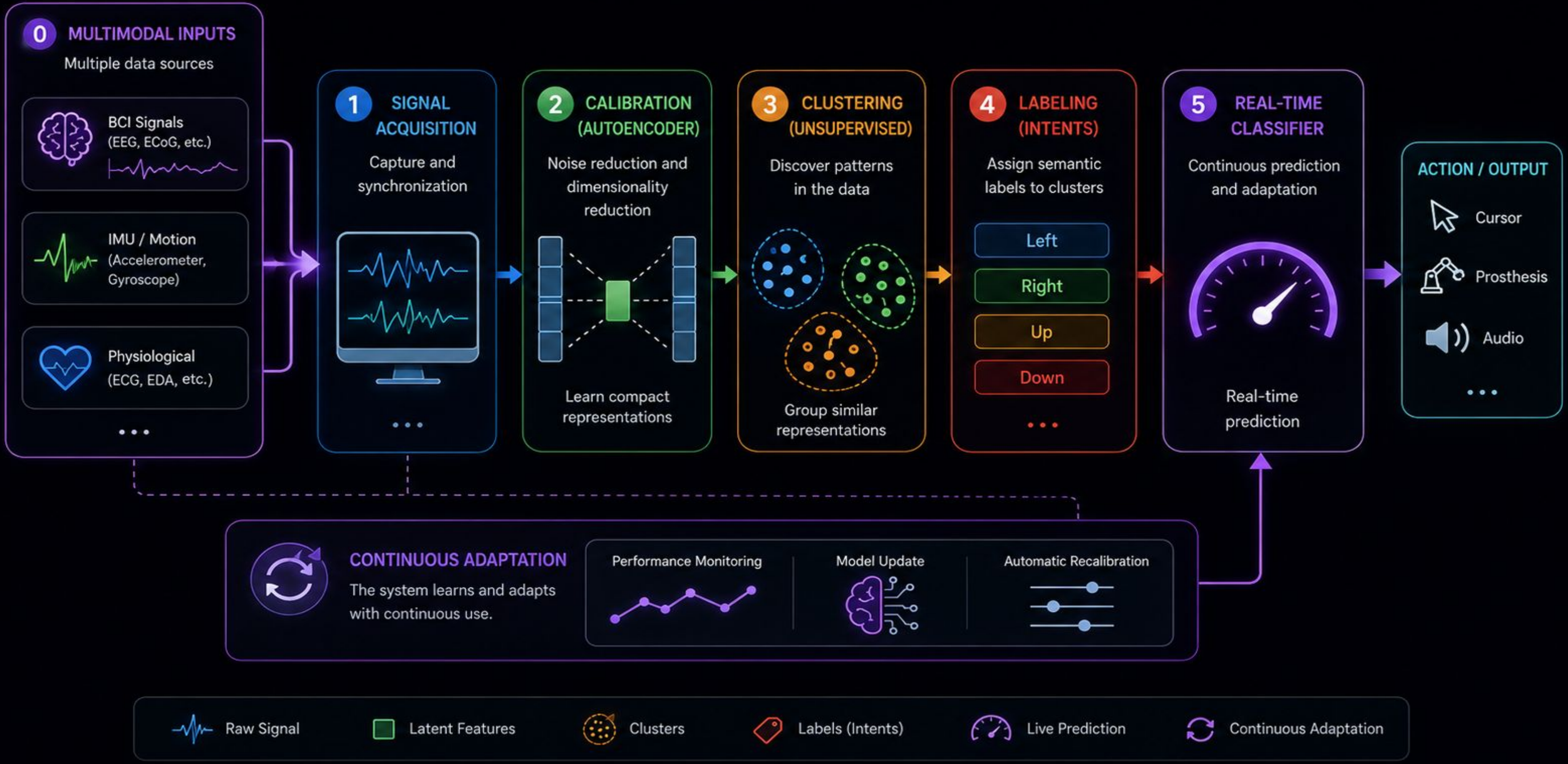
- ✓ Sensitive electrodes detect microvolt-level brain signals
- ✓ Low-noise amplification preserves signal quality
- ✓ Smart processing extracts meaningful patterns
- ✓ Real-time decoding translates thoughts into actions

Hardware + Algorithms = Brain–Computer Interface

Hardware EEG

BCI WORKFLOW: FROM SIGNAL TO REAL-TIME CLASSIFICATION

From multimodal signal acquisition to continuous, adaptive, real-time prediction.



APPLICATIONS OF BCI

BCIs can be used in two main ways depending on the user's role: actively generating commands or passively being monitored.

ACTIVE BCIs

The user actively generates brain signals to control or interact with a system.

1. Attention-based control systems

(Soft control of interfaces)

Using attention to select, navigate or modulate interface elements.

2. Brain-driven game interactions

(Hard interface control, P300)

Using brain responses (e.g. P300) to trigger actions in games or virtual environments.

3. User-intent detection

(Motor imagery)

User imagines a movement to control a device or software (e.g., move left or right).

PASSIVE BCIs

The system passively monitors brain activity to infer the user's mental or emotional state.

1. Cognitive workload monitoring

(Meditation, TDAH, Sleep ...)

Continuously assesses mental load, focus or relaxation levels.

2. Neuroadaptive interfaces

(Neurofeedback, audio, emotion...)

Systems adapt in real-time to the user's brain state.

3. Implicit human-state assessment

(Emotion Recognition...)

Detects emotions or affective states without requiring explicit input.

KEY TAKEAWAY

Active BCIs empower users to control systems with their minds. | Passive BCIs provide valuable insights about the user's internal state.

EXAMPLES OF ACTIVE AND PASSIVE BCIs

BCIs can either actively gontrol external systems or passively monitor brain activity to provide insights and feedback.

ACTIVE BCIs

The user actively generates brain signals to control devices or systems.

1. Video game intention recognition

(Soft control, light commands)

Detect intentions (e.g., move, select, jump) to control actions in a game.

2. Brain wave authentication

Use unique brain patterns to authenticate users securely.

3. Robot / Limb Control

Control robotic arms or assistive devices using motor imagery or neural commands.

PASSIVE BCIs

The system passively monitors brain activity to assess mental or emotional states.

1. TDAH detectors in classroom

Monitor attention levels in real time to help teachers support students with ADHD.

2. Meditation apps for Yoga, etc.

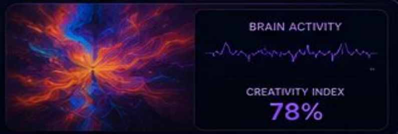
Track brain activity (e.g., calmness, focus) to guide and improve meditation practice.

3. Audio feedback applications

Provide real-time auditory feedback based on brain states (e.g., concentration, relaxation).

4. Art BCI

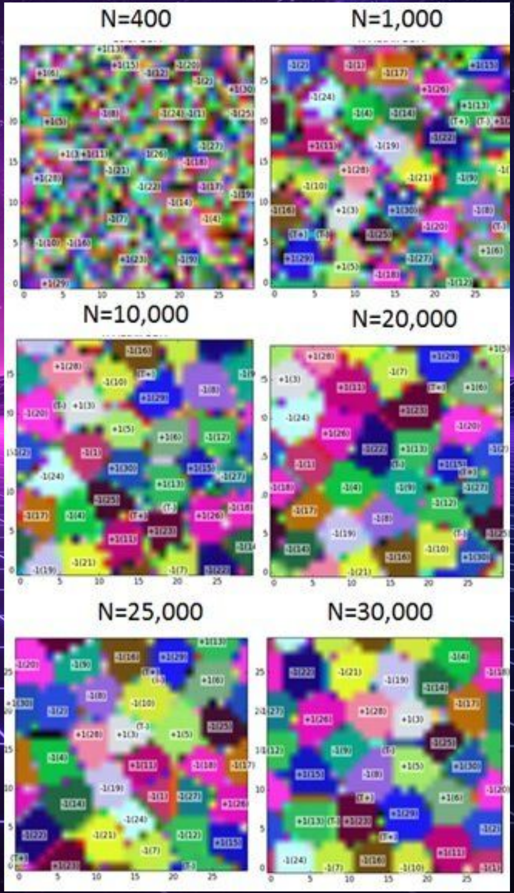
Translate brain activity into visual art, music or interactive creative experiences.

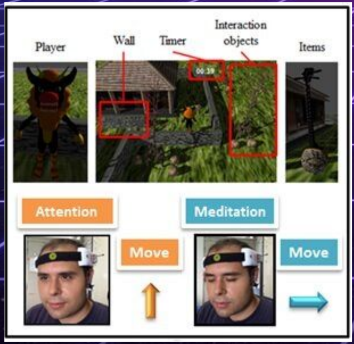


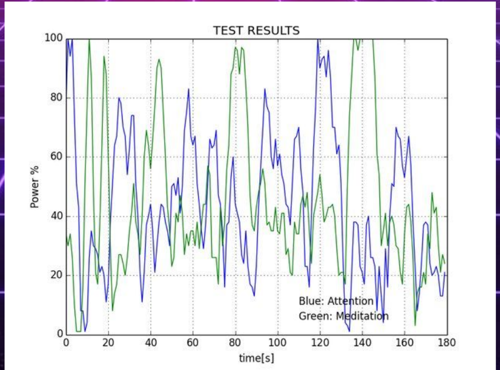
ACTIVE BCIs = Control
You use your brain to do something.

PASSIVE BCIs = Insight
The system observes and understands your state.

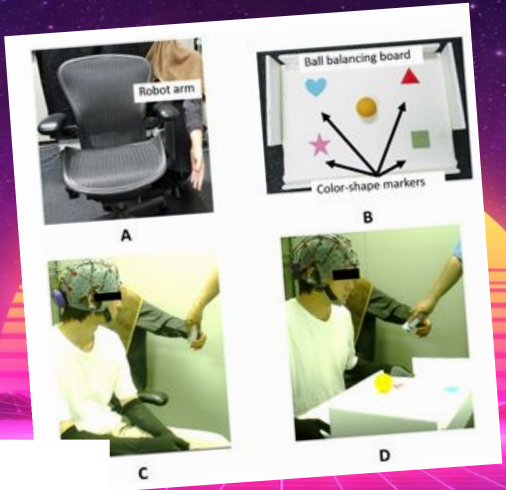
A little BCI here, a little BCI there…







Supernumerary Limb Control



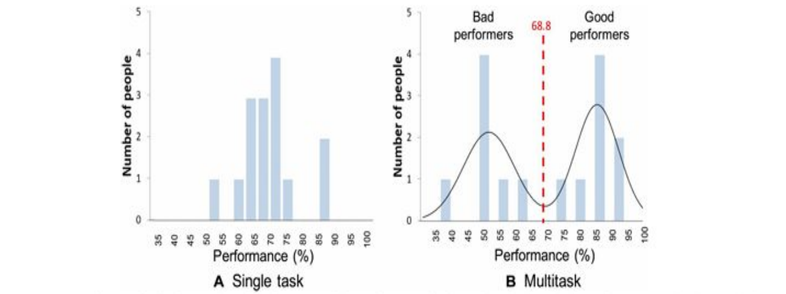


Fig. 2. Histograms showing the distribution of people with respect to their performances for the single task and multitask conditions. (**A**) Single task. (**B**) Multitask. Panel (B) also shows a visual representation of the probability function resulting from the GMM-EM algorithm. The performance score (68.8) corresponding to the boundary between the two modalities was used to separate the two groups: good performers (above the boundary) and bad performers (below the boundary).

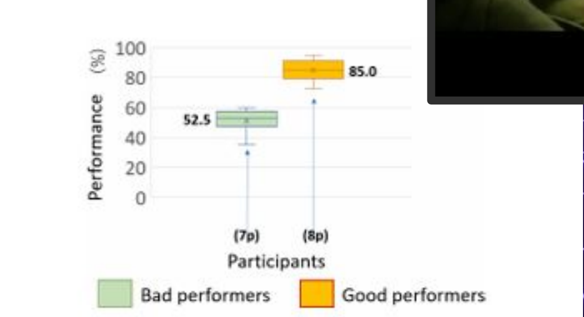


Fig. 3. The two modalities for the multitask condition. Performance median score and the number of good performers (eight people, median = 85) and bad performers (seven people, median = 52.5) for multitask condition. Error bars indicate min/max values.

BCI COMBINED WITH OTHER SIGNALS

Multimodal interfaces for more robust, accurate and intuitive human–machine interaction.

More Accurate
Combining signals reduces false positives and errors.

More Robust
Works better in real-world conditions and variability.

More Intuitive
Leverages complementary information from the user.

COMPLEMENTARY SIGNALS

BCI
Brain Signals

Measures brain activity (EEG) to infer mental states, intentions or cognitive workload.

Examples: Motor imagery, attention, workload, emotion

EMG
Muscle Activity

Measures electrical activity produced by muscles to detect movement or muscle activation.

Examples: Hand grasp, arm movement, facial expressions

EYE TRACKING
Gaze & Pupils

Tracks eye movement, gaze direction, blink rate and pupil size to infer intent and engagement.

Examples: Gaze direction, blink detection, pupil dilation

MULTIMODAL FUSION
Data Integration

Sensor fusion and machine learning combine signals to improve performance and reliability.

APPLICATIONS

Assistive Communication & Control
Enable users with severe motor disabilities to communicate and control devices more reliably.

Gaming & Entertainment
Enhanced immersion and control by combining brain signals with muscle activity and gaze.

Robotics & Prosthetics
More natural and precise control of robotic arms or prosthetic devices using multimodal inputs.

Driving & Mobility
Monitor driver attention and intent, detect drowsiness and enhance adaptive assistance.

Wellness & Mental Health
Monitor stress, focus and emotions through combined neurophysiological signals.

WHY COMBINE SIGNALS?

Higher Accuracy
Complementary signals reduce ambiguity and improve detection.

Greater Robustness
Performance is maintained even when one signal is noisy or weak.

Faster & More Reliable Responses
Faster intent detection and more stable control.

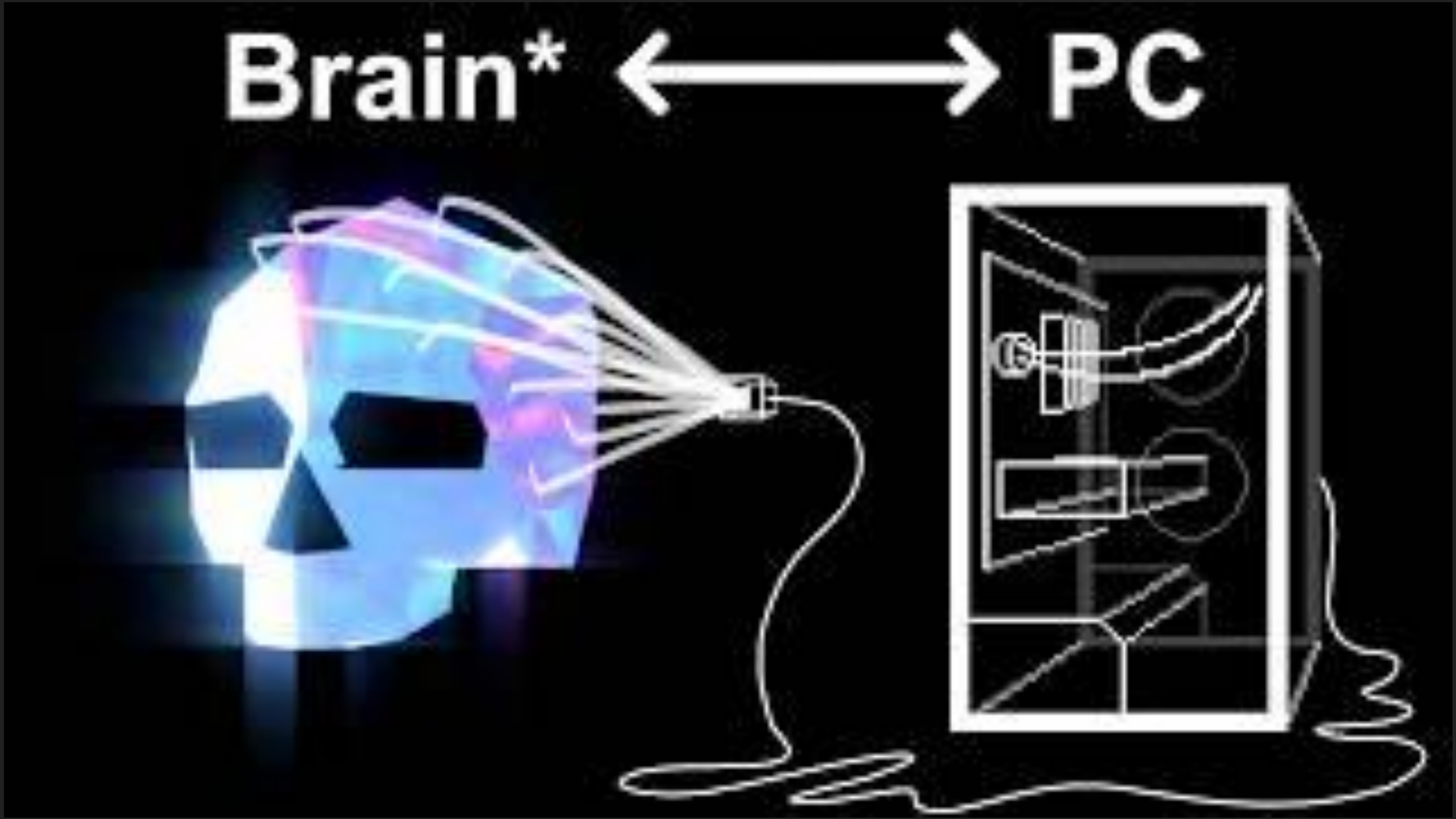
Richer Context Understanding
More complete picture of the user's state and environment.

TYPICAL MULTIMODAL BCI PIPELINE

1. **Signal Acquisition** — EEG + EMG + Eye Tracking
2. **Preprocessing** — Filtering, artifact removal, normalization
3. **Feature Extraction** — Time, frequency, spatial and statistical features
4. **Fusion & ML Model** — Feature fusion and machine learning / deep learning
5. **Decision & Output** — Intent recognition and command generation
6. **Action / Application** — Control device, feedback or display output

KEY TAKEAWAY

Combining BCI with EMG and Eye Tracking unlocks the full potential of human intent decoding and enables smarter, more natural and reliable interfaces.


Brain*
PC

Explore limitless possibilities!
無限の可能性を探求しよう！

https://bsenzio.github.io/bmitutorialALIFE26/

Test your hand tracking and classification HP on a NES Party 🎉

NESパーティーで手のトラッキングと分類性能 (HP) をテストしよう!

PyGesture Studio

Capture. Train. Predict. Interact.

キャプチャ・学習・予測・インタラクト

PyGesture Studio

Real-time hand gesture recognition powered by Python, MediaPipe and Machine Learning.

PyGesture Studio

Python、MediaPipe、機械学習を活用したリアルタイムのハンドジェスチャー認識ツールキットです。

Webcam
ウェブカメラ
→ MediaPipe Hand Tracking
MediaPipe ハンドトラッキング
→ Feature Extraction (63 Features)
特徴量の抽出 (63個の特徴量)
→ Dataset Recording
データセット記録
→ Model Training
モデル学習
→ Real-Time Prediction
リアルタイム予測

[GitHub - Bsenzio/pygesture: A free classifier for quick gesture command interpretation · GitHub]

FEATURES
主な機能

- ✓ Real-time webcam acquisition
  リアルタイムのウェブカメラ取得
- ✓ Automatic 21 hand landmarks
  自動21点ランドマーク検出
- ✓ Multi-class gesture dataset
  マルチクラスのジェスチャーデータセット
- ✓ Multiple machine learning models
  複数の機械学習モデルに対応
- ✓ Real-time gesture prediction
  リアルタイムのジェスチャー予測
- ✓ Save & load models (Joblib)
  モデルの保存と読み込み (Joblib)
- ✓ Build your own HCI applications
  独自のHCIアプリケーションを構築

MACHINE LEARNING ALGORITHMS
機械学習アルゴリズム

- Random Forest / ランダムフォレスト
- Extra Trees / エクストラツリー
- Support Vector Machine (SVM) / サポートベクターマシン
- K-Nearest Neighbors (KNN) / k近傍法
- Gradient Boosting / 勾配ブースティング
- Multi-Layer Perceptron (MLP) / 多層パーセプトロン

Best Model Automatically Selected
最適なモデルを自動で選択

CURRENT STATUS
現在のステータス

- Webcam Acquisition
  ウェブカメラ取得
- Hand Detection
  ハンド検出
- Feature Extraction
  特徴量の抽出
- Dataset Recording
  データセット記録
- Model Training
  モデル学習
- Real-Time Prediction
  リアルタイム予測

Play NES with your hands
手でNESをプレイ

Custom gestures as controllers
カスタムジェスチャーをコントローラーに

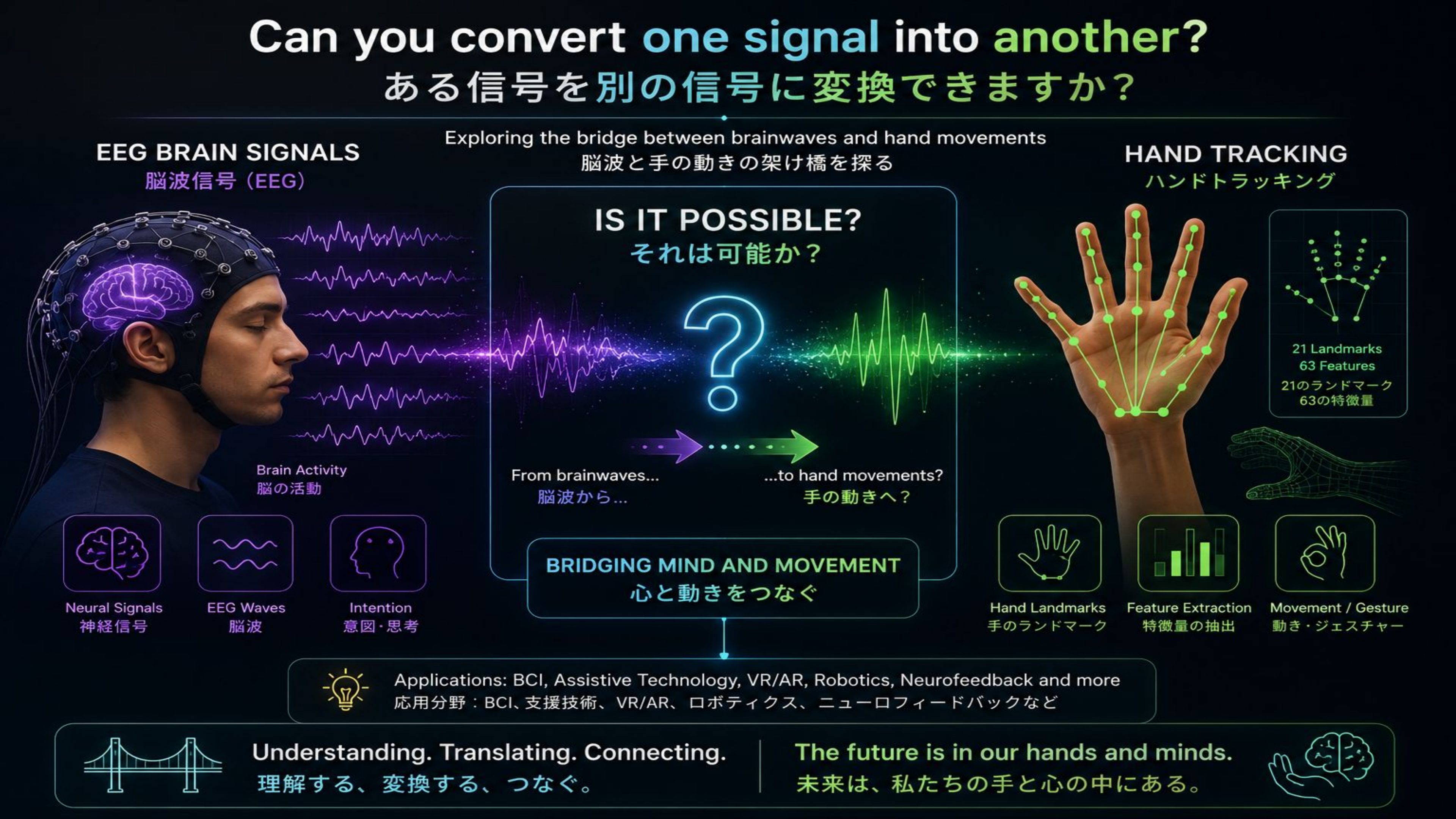
Real-time ML predictions
リアルタイムの機械学習予測

Fun for everyone
All you need is a webcam!
みんなで楽しめる
必要なのはウェブカメラだけ！

Perfect for HCI, education & research
HCI、教育、研究に最適

Open Source on GitHub
GitHubで公開中！

Build. Train. Play. The future of Human-Computer Interaction starts with your hands.
作る。学ぶ。遊ぶ。人とコンピュータの未来は、あなたの手から始まる。


Can you convert one signal into another?
ある信号を別の信号に変換できますか？
Exploring the bridge between brainwaves and hand movements
脳波と手の動きの架け橋を探る
EEG BRAIN SIGNALS
脳波信号（EEG）
HAND TRACKING
ハンドトラッキング
IS IT POSSIBLE?
それは可能か？
21 Landmarks
63 Features
21のランドマーク
63の特徴量
Brain Activity
脳の活動
From brainwaves...
脳波から...
...to hand movements?
手の動きへ？
Neural Signals
神経信号
EEG Waves
脳波
Intention
意図・思考
BRIDGING MIND AND MOVEMENT
心と動きをつなぐ
Hand Landmarks
手のランドマーク
Feature Extraction
特徴量の抽出
Movement / Gesture
動き・ジェスチャー
Applications: BCI, Assistive Technology, VR/AR, Robotics, Neurofeedback and more
応用分野：BCI、支援技術、VR/AR、ロボティクス、ニューロフィードバックなど
Understanding. Translating. Connecting.
理解する、変換する、つなぐ。
The future is in our hands and minds.
未来は、私たちの手と心の中にある。