Machine Learning and NeuroEngineering

机器学习与神经工程

Lecture 7 – Brain-Computer Interface (BCI)

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Lecture 6 – EEG data analysis

- Electroencephalography (EEG) measurements
- EEG preprocessing
  - Bad channel detection/repairmen
  - Filtering
  - Artifact removal
  - Re-referencing
- EEG sensor-level analysis
  - ERP
  - ERD/ERS

目录

脑机接口技术：背景介绍

脑机接口技术是研究什么？

External World (外部刺激)

A model to encode (simulate) neural signals

10^{12} neurons （神经元）

A model to decode neural signals

Senses（感觉）
Motion （运动）
Emotion（情绪）
Attention（注意力)
Cognition（认知）
…

神经编码

- 给一个外界刺激，神经会有怎样的反应

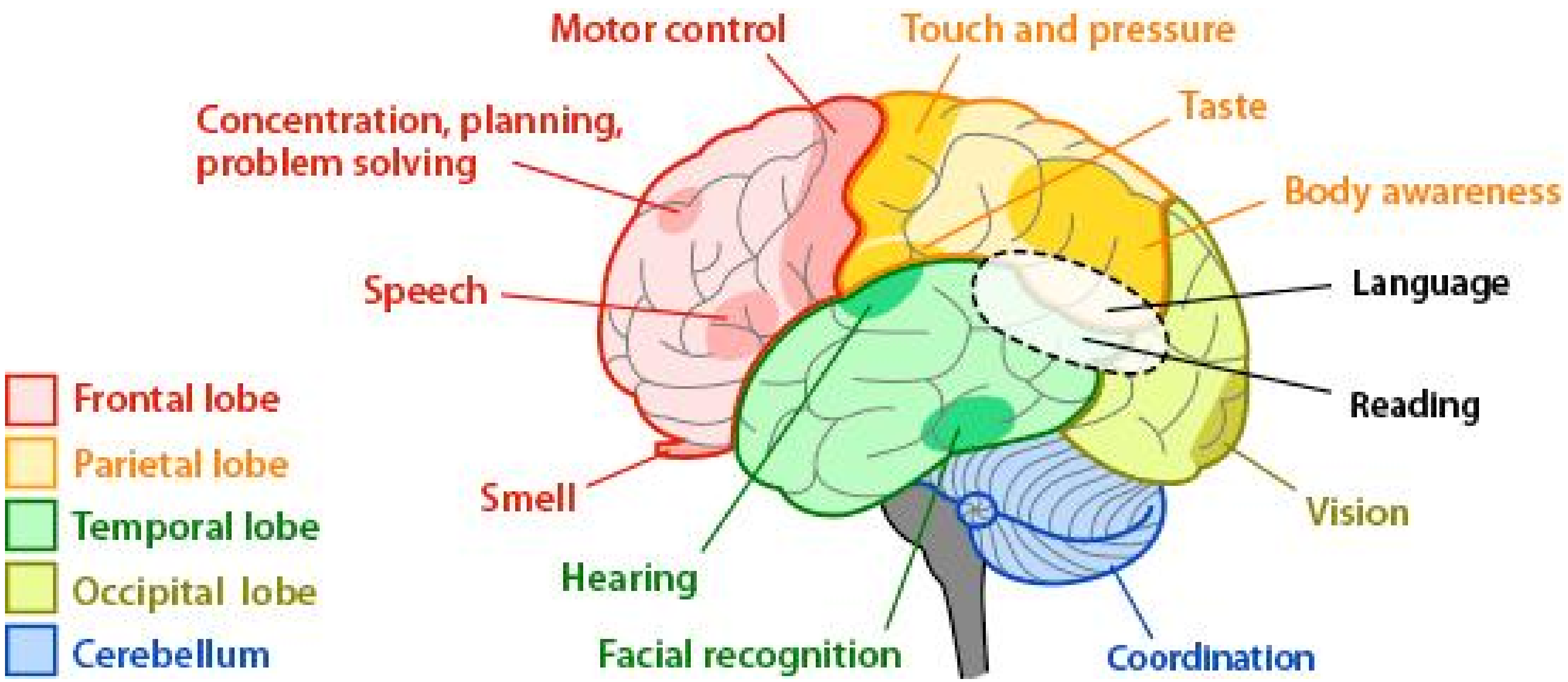
神经解码

- 给一段神经信号，判断我们在想什么

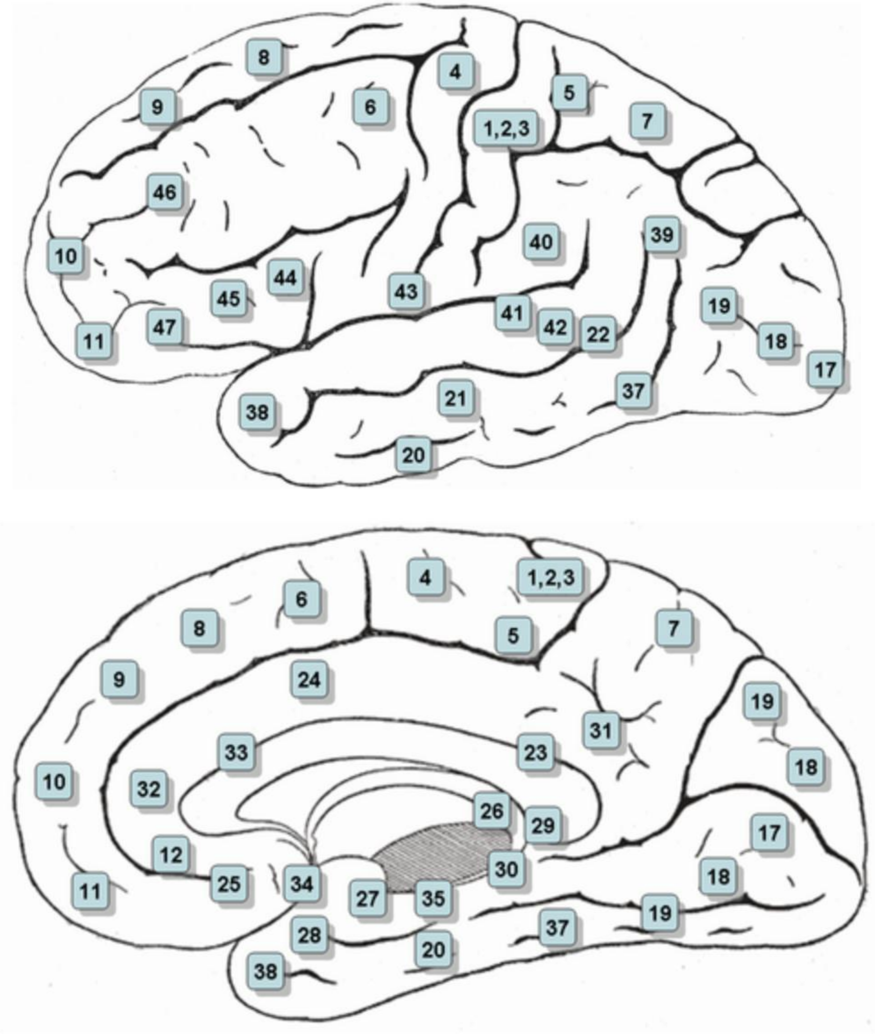
脑机接口就是基于神经解码模型做的应用
其实现方案有多种
取决于任务、涉及的脑区、计算模型等等

大脑的分区

宏观分区 (5大区域)



Broadmann分区 (52个脑区)

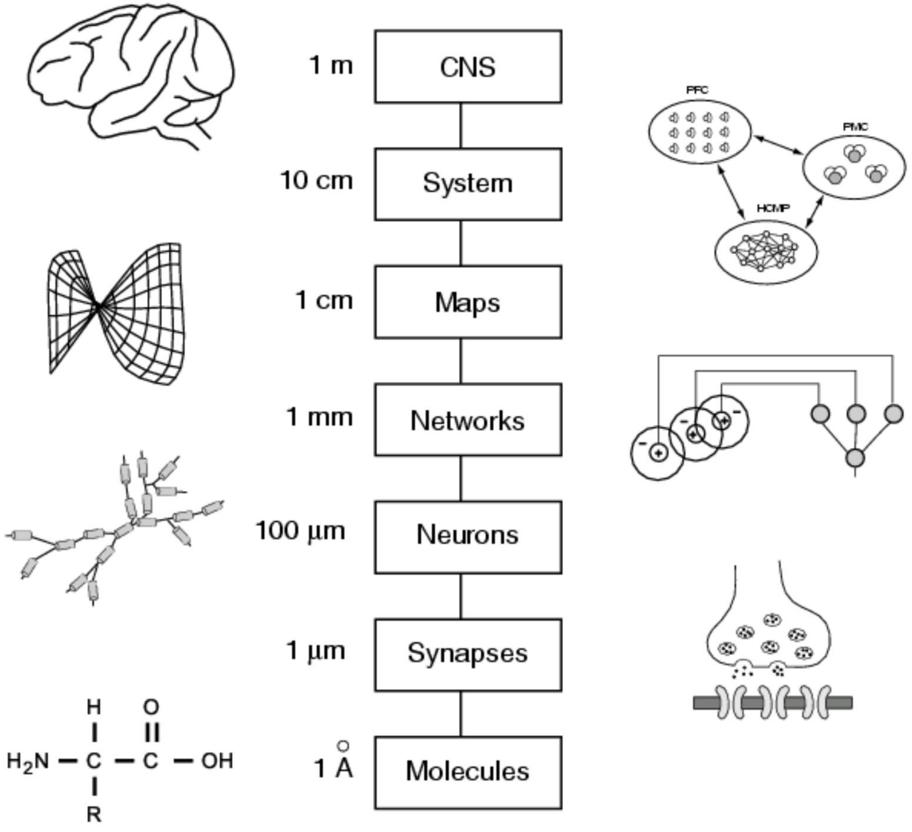


还有一些更精细的分区方式

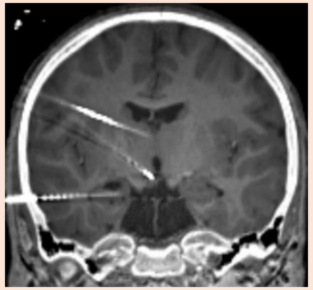
将大脑分为几百个或者上千个脑区！

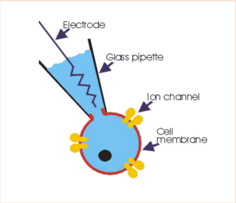
神经信号采集技术

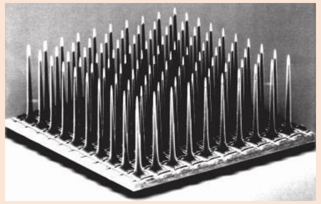
不同的尺度



- MRI, fMRI
- EEG, MEG
- SEEG
- ECoG
- Local field potential (extracellular)
- Utah Array
- Patch clamp (intracellular recording)







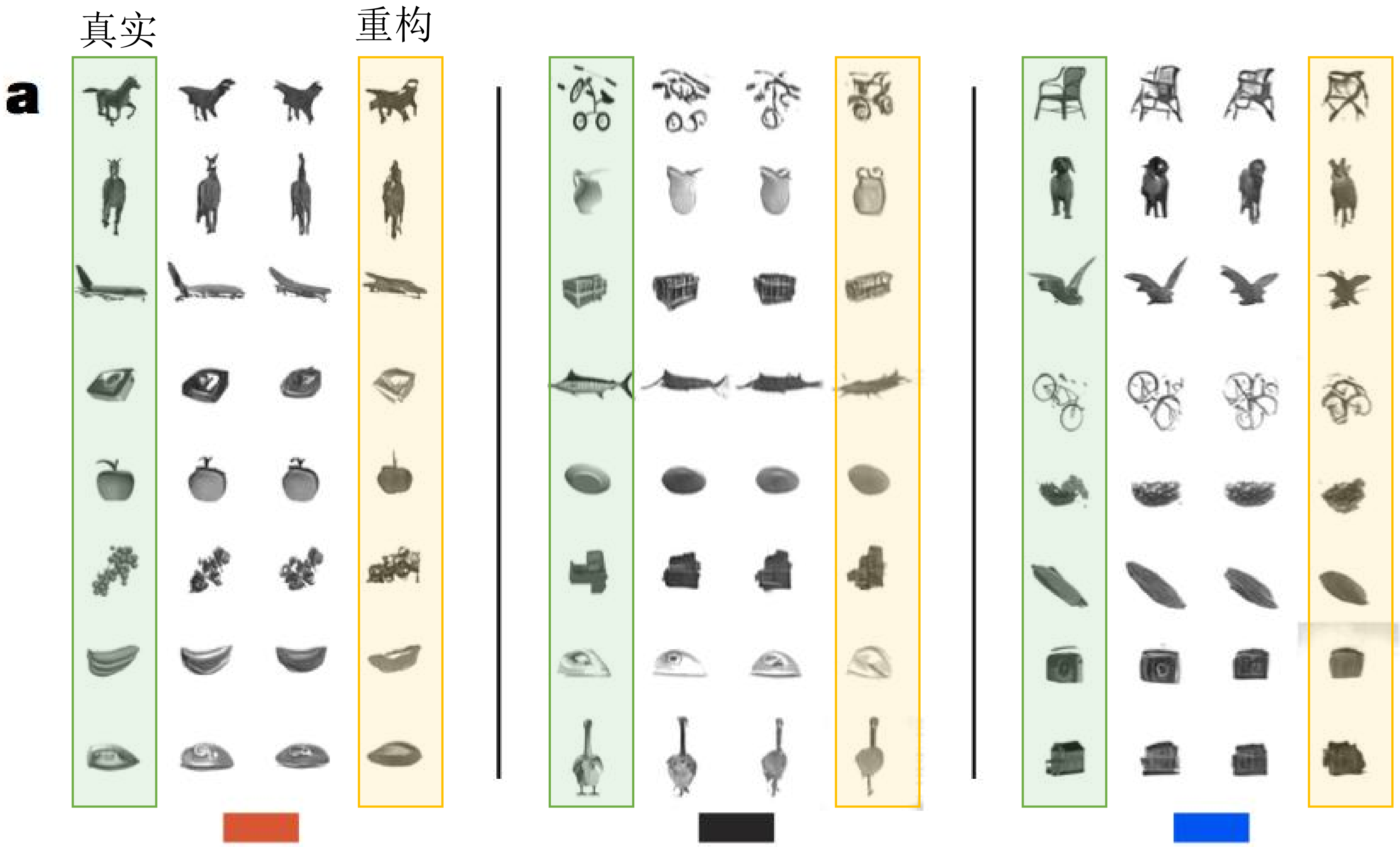
基于有创神经信号的语音合成

可能的应用场景：

- 病患？
- 意识传输？
- Atari？

Anumanchipalli et al (2019) Speech synthesis from neural decoding of spoken sentences, *Nature*

用生成对抗网络（GAN）重构视觉影像



真实　重构

可能的应用场景：

- 影像压缩？
- 侦查？
- 视觉共享？

Pinglei Bao, Liang She, Mason McGill & Doris Y. Tsao (2020). A map of object space in primate inferotemporal cortex. *Nature*

基于人工智能技术的情绪识别

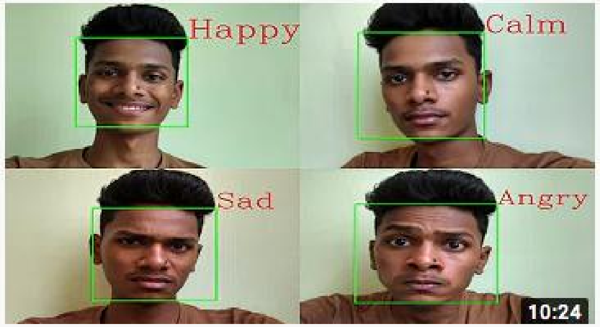
Dialoguernn: An attentive rnn for **emotion detection** in conversations
N Majumder, S Poria, D Hazarika, R Mihalcea… - Proceedings of the AAAI …, 2019 - aaai.org
Emotion detection in conversations is a necessary step for a number of applications,
including op
mining, und
☆ 99 C

Robust real-time **emotion detection** system using cnn architecture
S Jaiswal, GC Nandi - Neural Computing and Applications, 2020 - Springer
… auto encoders are also used to build a model for classifying 7 **emotions** in [16 … A survey in various
emotion detect
a brief review ab
☆ 99 Cited

Survey on **emotional** body **gesture recognition**
F Noroozi, D Kaminska, C Corneanu… - IEEE transactions on …, 2018 - ieeexplore.ieee.org
Automatic **emotion recognition** has become a trending research topic in the past decade.
While works based on facial expressions or speech abound, recognising affect from body
to …

Automatic human **emotion recognition** in surveillance video
J Arunnehru, MK Geetha - Intelligent Techniques in Signal Processing for …, 2017 - Springer
… [1] proposed human **emotion recognition** of four performed **emotional** states (angry … are helpful
for indexing and retrieving the multimedia information based on **emotion**-specific information
[13] … an intelligent classifier that has the ability to discriminate four **emotions**, namely angry …
☆ 99 Cited by 21 Related articles All 3 versions

基于人工智能技术的情绪识别



Facial Expression Detection with Deep Learning & OpenCV

98K views • 2 years ago

Ritesh Kumar Maurya

Recognizing or Detecting Emotions from Faces has never been an easy task. For making this easy, I'm presenting this video.

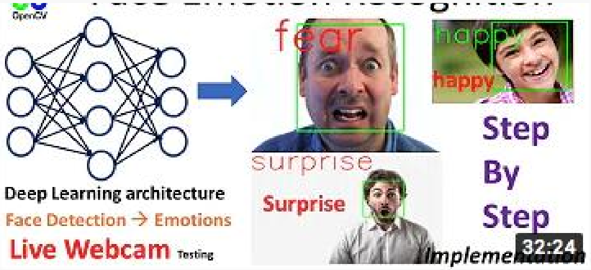
CC

Emotion Detection in Python | Emotion detection in 5 lines | Machine Learning | Data Magic

2.3K views • 4 months ago

Data Magic

Hello Friends, Today we are going to do emotion detection for the face images with the help of DeepFace library which is ...



5.6K views • 2 months ago

DeepLearning_by_PhDScholar

This video contains python implementation of Realtime Face Emotion Recognition 1) Brainstorming (background of facial emotion ...

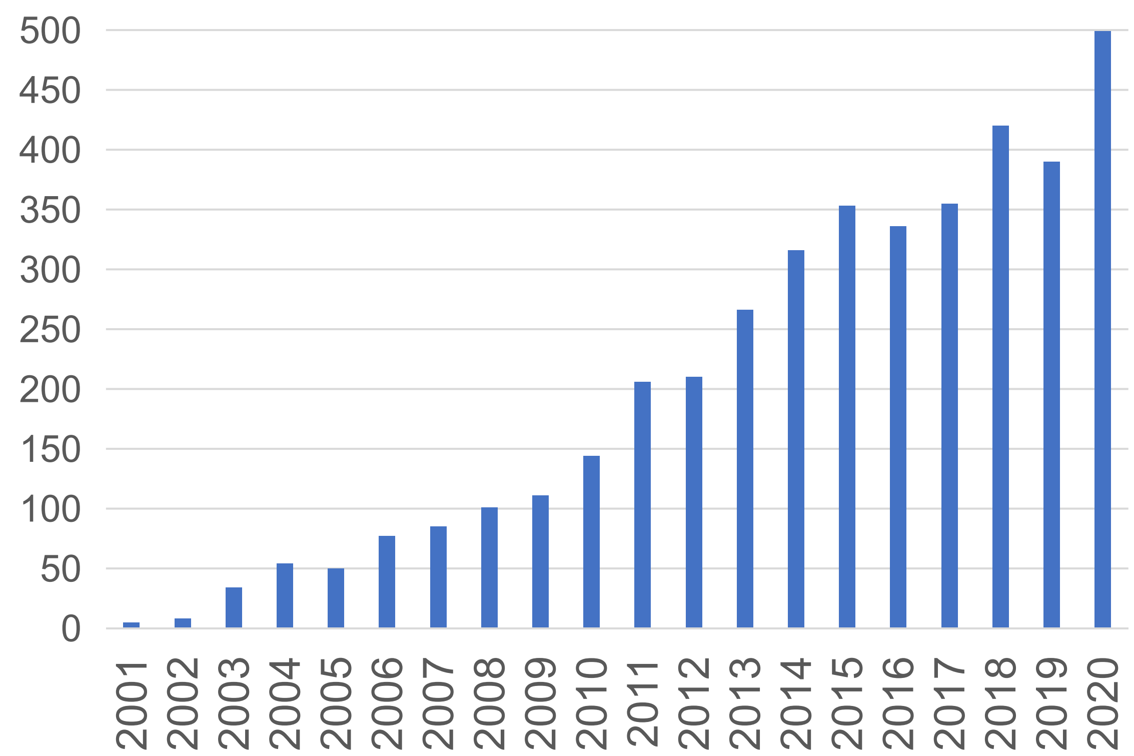
Plenty of Youtube videos

基于无创神经信号的运动意图识别

脑机接口的热度

研究热度

PubMed上发表论文的数量



工业界热度



Neurolink：艾伦马斯克的脑机接口公司

Neurable：脑控虚拟现实游戏

Emotiv：基于脑电的脑疾病诊断

Kernel：体外存储记忆

NextMind：无创脑机接口

Meltin MMI：脑控机械臂

BitBrain：脑机接口算法

脑机接口的热度

NASA项目

COLLECTIONS

- physics 882
- general 624
- astronomy 5

仅2021年
就已有31篇论文

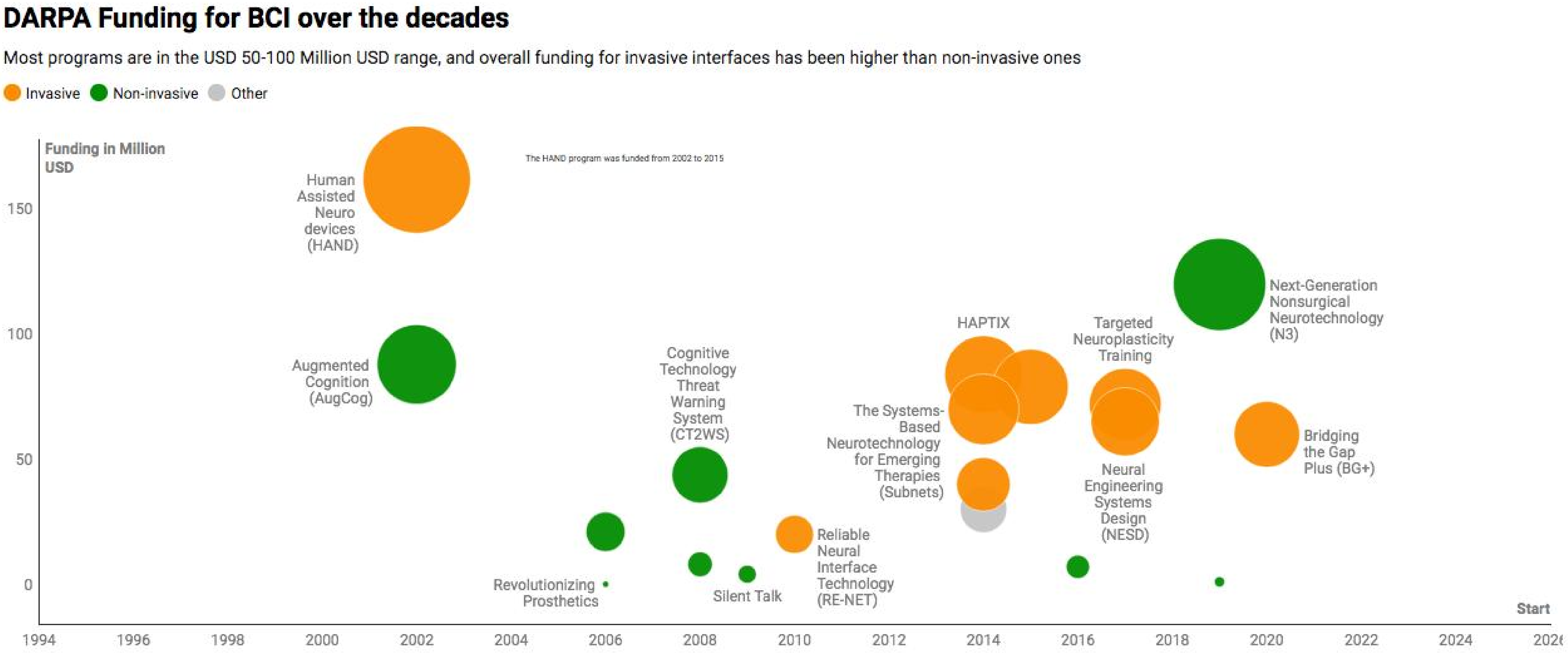
1. 2021arXiv210305351W 2021/03
   Inter-subject Deep Transfer Learning for Motor Imagery EEG Decoding
   Wei, Xiaoxi; Ortega, Pablo; Aldo Faisal, A.
2. 2021arXiv210305334O 2021/03
   Deep Real-Time Decoding of bimanual grip force from EEG & fNIRS
   Ortega, Pablo; Zhao, Tong; Faisal, Aldo
3. 2021arXiv210302851K 2021/03
   Visual Motion Imagery Classification with Deep Neural Network based on Functional Connectivity
   Kwon, Byoung-Hee; Jeong, Ji-Hoon; Lee, Seong-Whan
4. 2021arXiv210302238S 2021/03
   EmoWrite: A Sentiment Analysis-Based Thought to Text Conversion
   Shahid, A.; Raza, I.; Hussain, S. A.
5. 2021arXiv210302197L 2021/03
   Decoding Event-related Potential from Ear-EEG Signals based on Ensemble Convolutional Neural Networks in Ambulatory Environment
   Lee, Young-Eun; Lee, Seong-Whan
6. 2021arXiv210302169G 2021/03
   Real Time Vigilance Detection using Frontal EEG
   Ganesh, Siddarth; Gurumoorthy, Ram
7. 2021arXiv210209188W 2021/02
   Edge Sparse Basis Network: A Deep Learning Framework for EEG Source Localization
   Wei, Chen; Lou, Kexin; Wang, Zhengyang *and 3 more*
8. 2021arXiv210209050S 2021/02
   End-to-end learnable EEG channel selection with deep neural networks
   Strypsteen, Thomas; Bertrand, Alexander
9. 2021arXiv210205194C 2021/02
   Boosting Template-based SSVEP Decoding by Cross-domain Transfer Learning
   Chiang, Kuan-Jung; Wei, Chun-Shu; Nakanishi, Masaki *and 1 more*
10. 2021arXiv210204456S 2021/02
    Common Spatial Generative Adversarial Networks based EEG Data Augmentation for Cross-Subject Brain-Computer Interface
    Song, Yonghao; Yang, Lie; Jia, Xueyu *and 1 more*

DARPA项目

The Defense Advanced Research Projects Agency (**DARPA**) has funded innovative scientific research and technology developments in the field of **brain–computer interfaces (BCI)** since the **1970s**. This review highlights some of DARPA's major advances in the field of BCI, particularly those made in recent years. Two broad categories of DARPA programs are presented with respect to the ultimate goals of supporting the nation's warfighters: (1) BCI efforts aimed at restoring neural and/or behavioral function, and (2) BCI efforts aimed at improving human training and performance. The programs discussed are synergistic and complementary to one another, and, moreover, promote interdisciplinary collaborations among researchers, engineers, and clinicians. Finally, this review includes a summary of some of the remaining challenges for the field of BCI, as well as the goals of new DARPA efforts in this domain.

数据来源 Review论文，DARPA-funded efforts in the development of novel brain–computer interface technologies

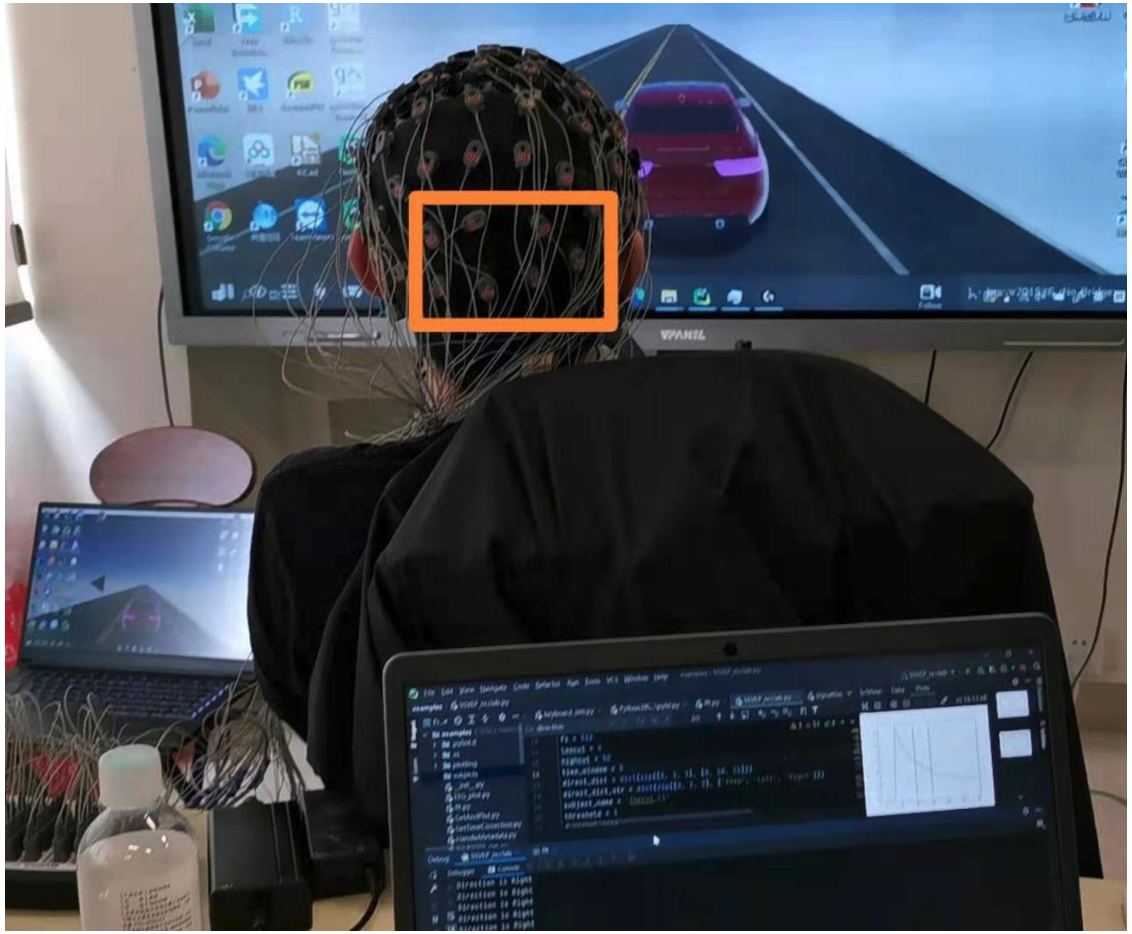
脑机接口的热度

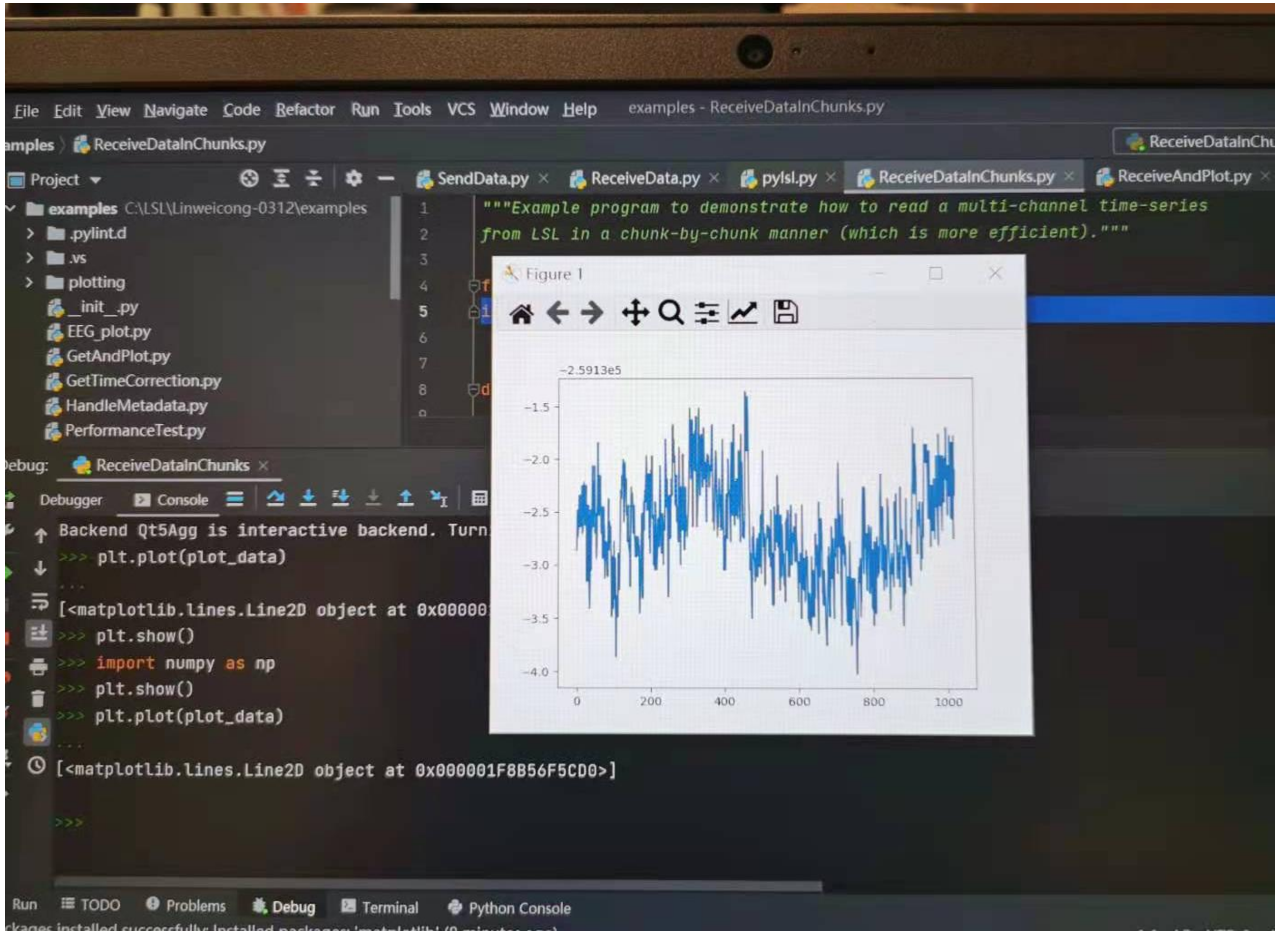


数据来源 https://www.from-the-interface.com/DARPA-funding-BCI-research/

BCI中脑电信号的实时读取与分析

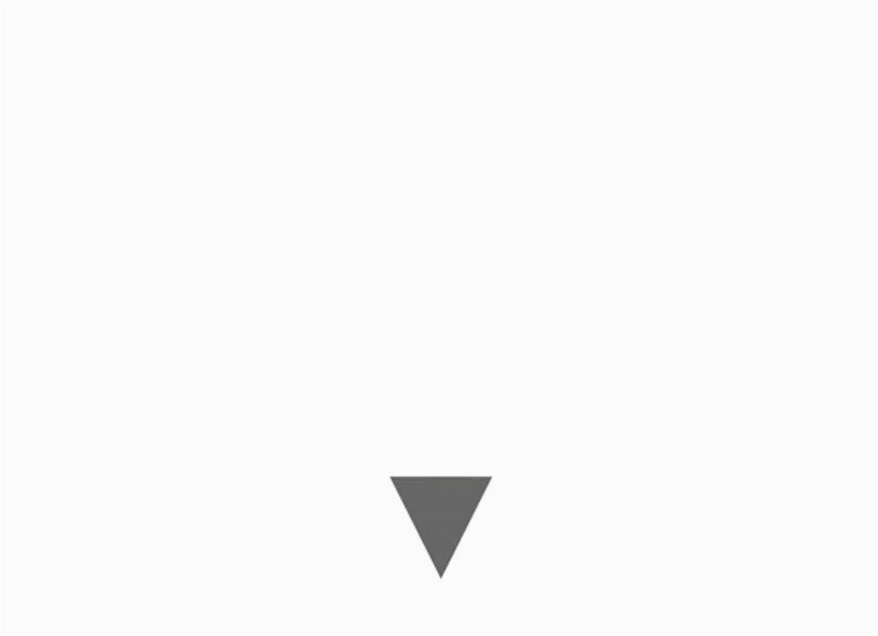
脑电信号的实时(real-time)读取



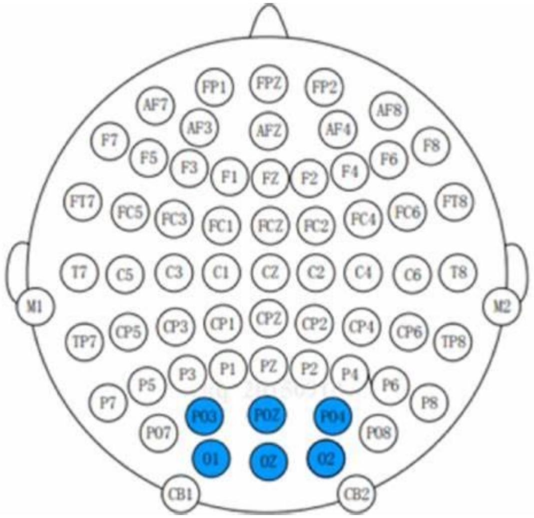


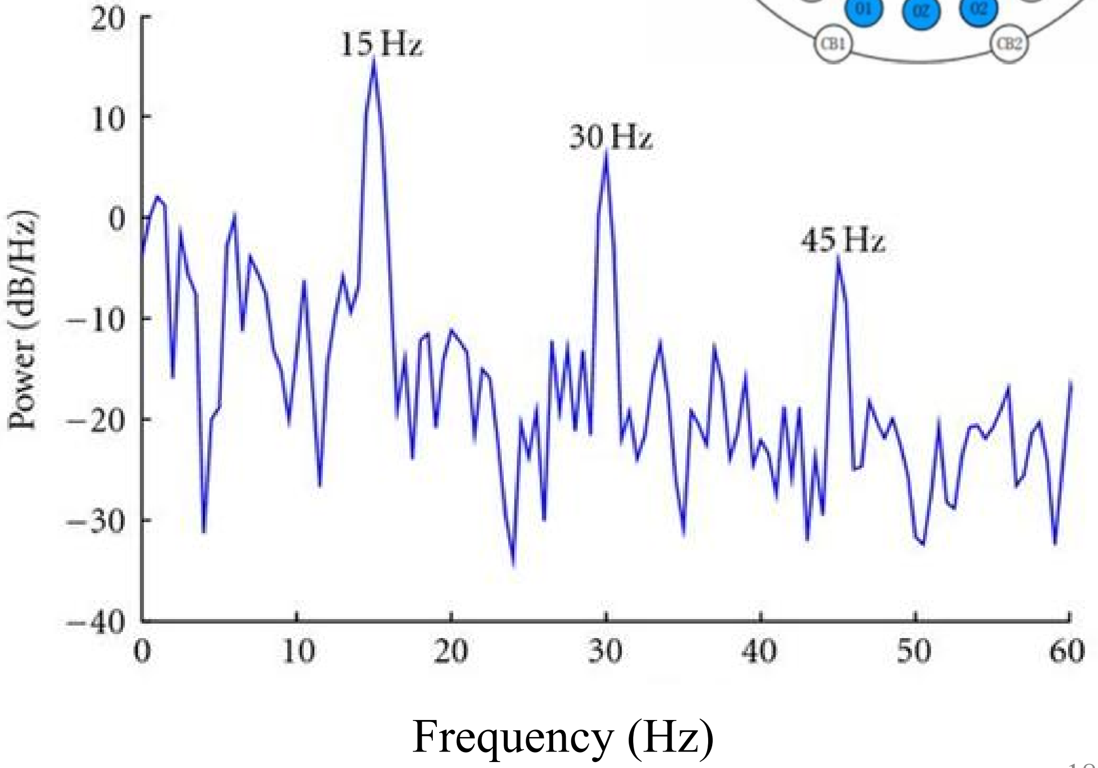
LSL (LabStreamingLayer)

视觉相关的脑电信号



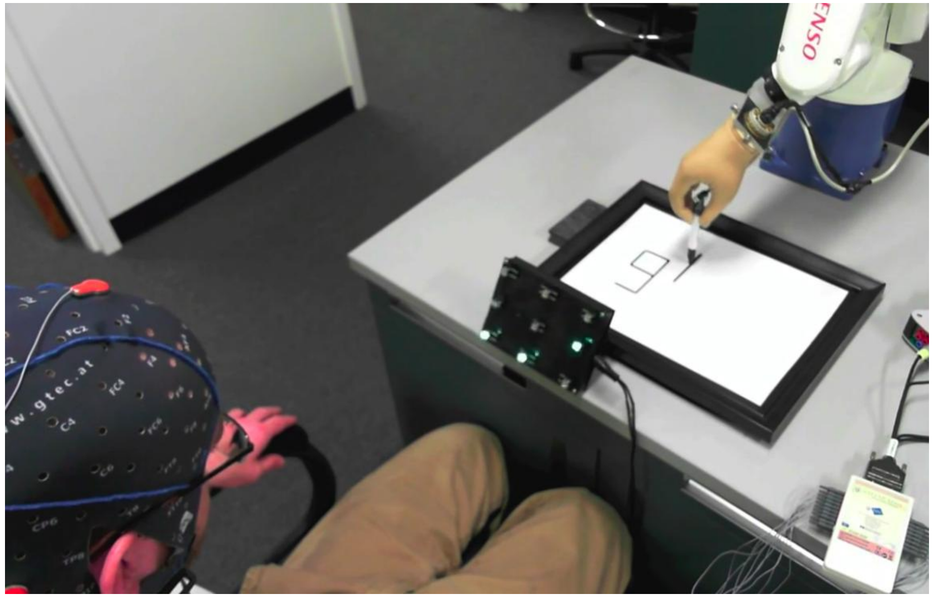
识别闪烁的频率





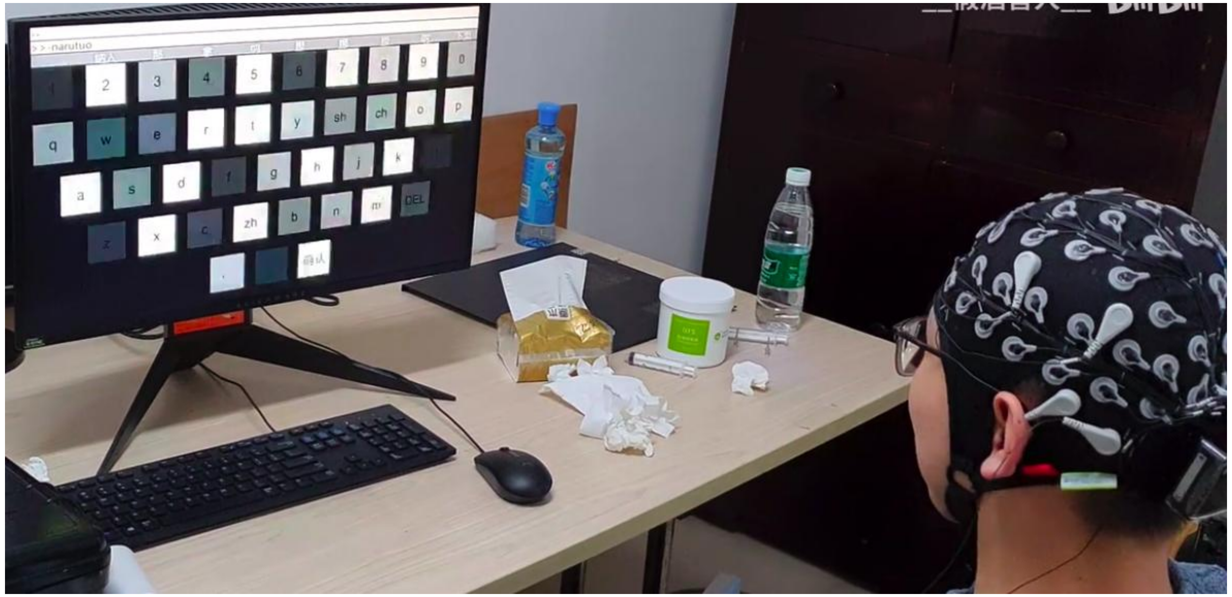
Li, Shi, Qi, Feng et al. (in prep)

稳态视觉诱发电位 (SSVEP) 在BCI中的应用



https://www.bilibili.com/video/BV1YN411X79t

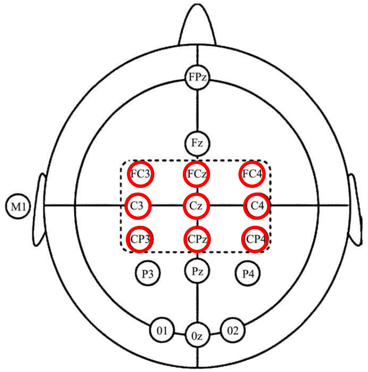
美国欧道明大学工程与神经科学实验室(阿斯彭实验室)



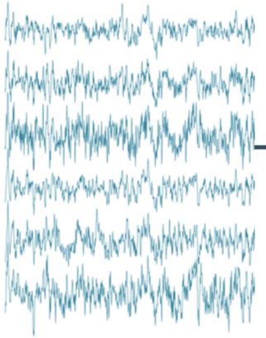
https://www.bilibili.com/video/BV14i4y1E7Ak

北邮EMB&EMC实验室

运动相关的脑电信号



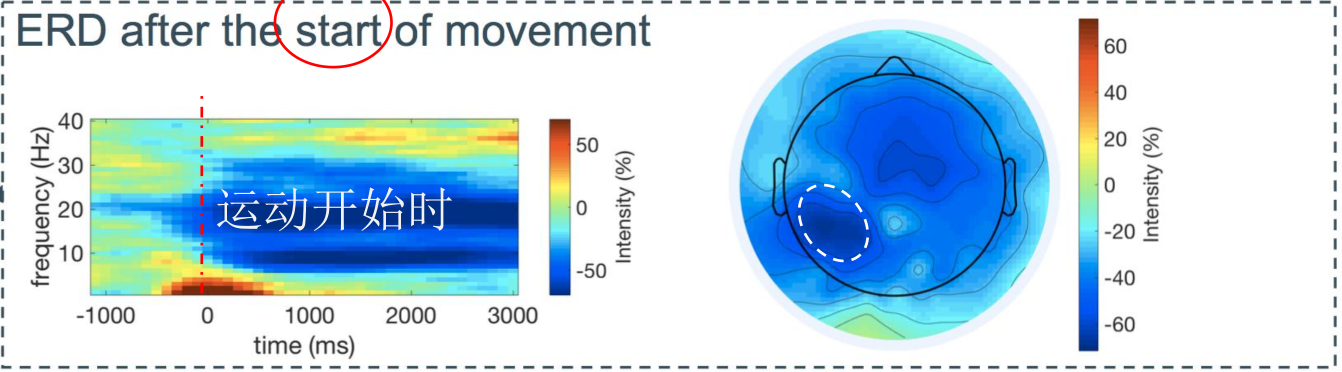
An example of ERD/ERS

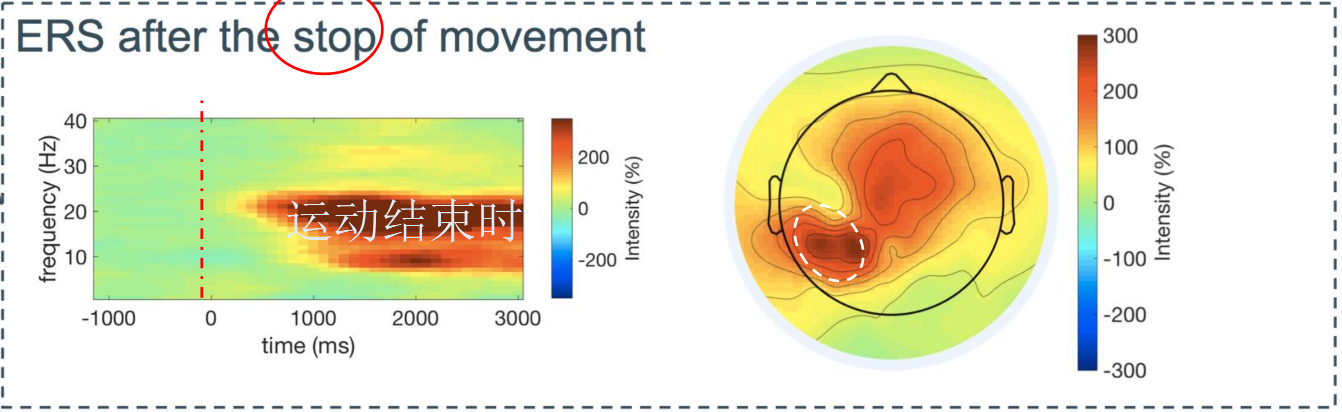


Time-frequency decomposition

$p_i(f, t)$

$$ERD/ERSi(f,t) = \frac{P_i(f,t) - P_{Bi}(f)}{P_{Bi}(f)} \times 100\%$$

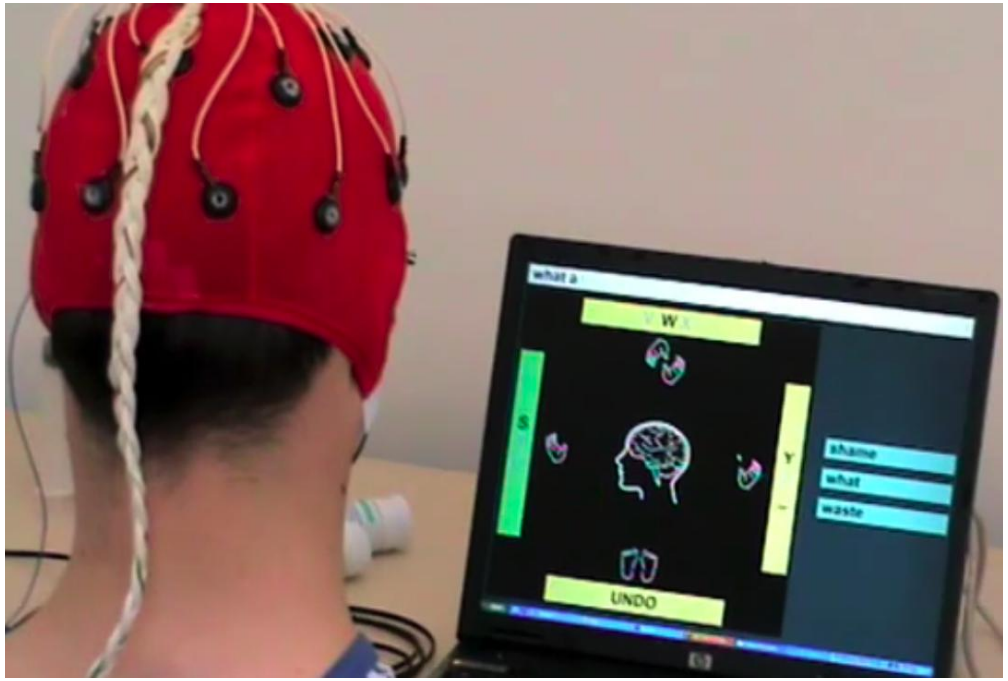




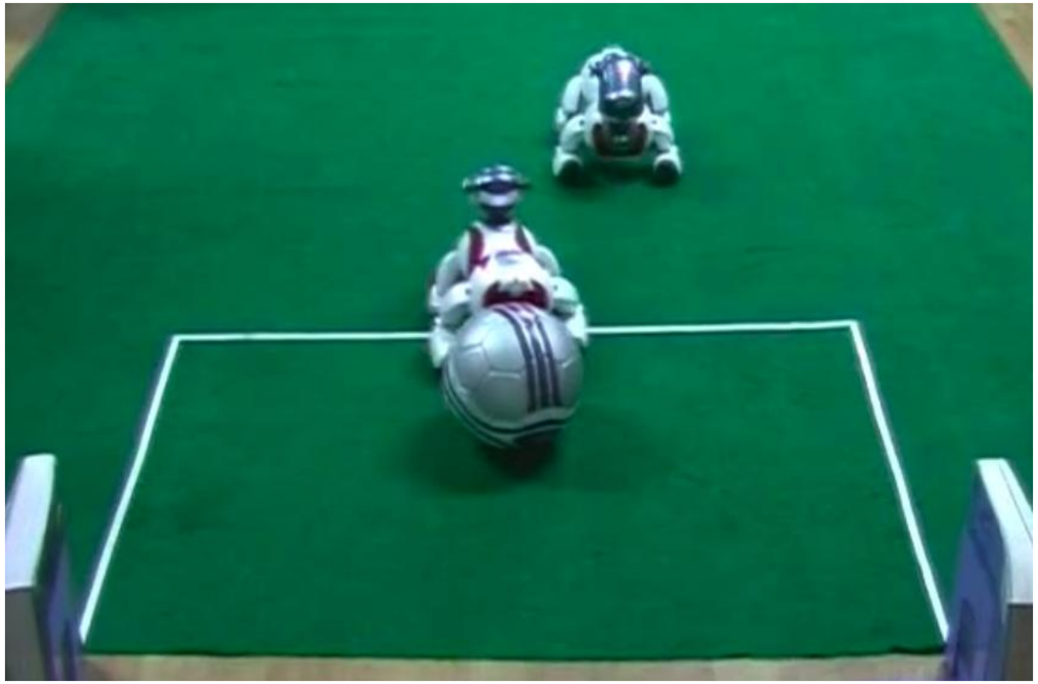
1. 识别运动的起止
2. 识别运动的方向

Li, Shi, Qi, Feng et al. (in prep)

想象运动在BCI中的应用



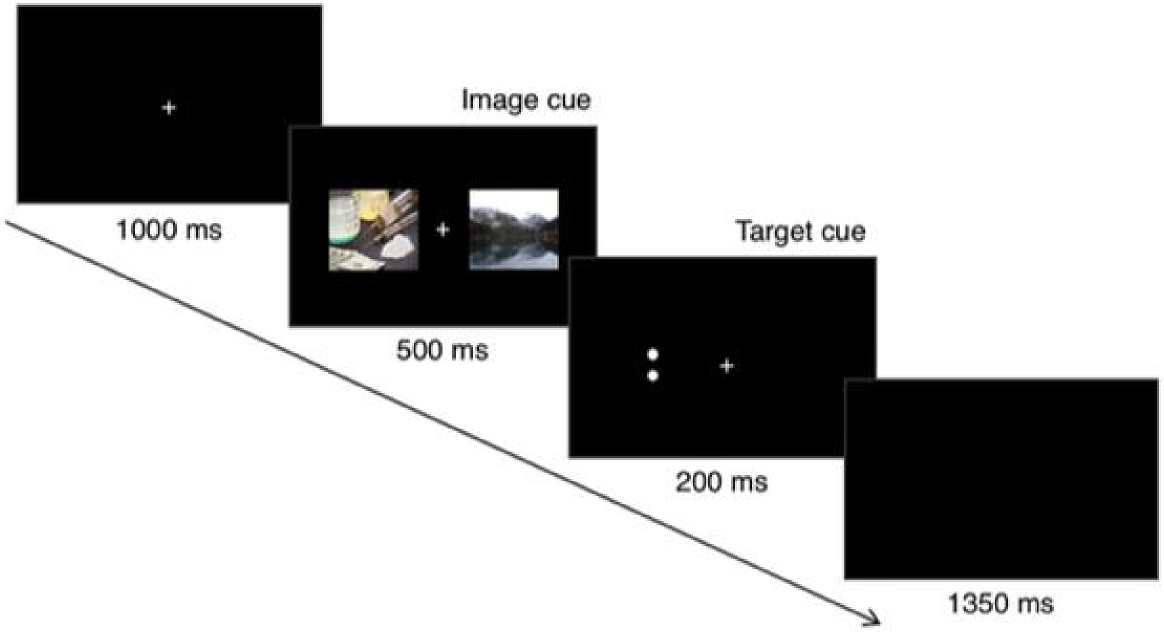
https://www.bilibili.com/video/BV1T7411N7yc



https://www.bilibili.com/video/BV19f4y1m7GD

清华大学神经工程实验室的脑机接口团队

注意力相关的脑电信号



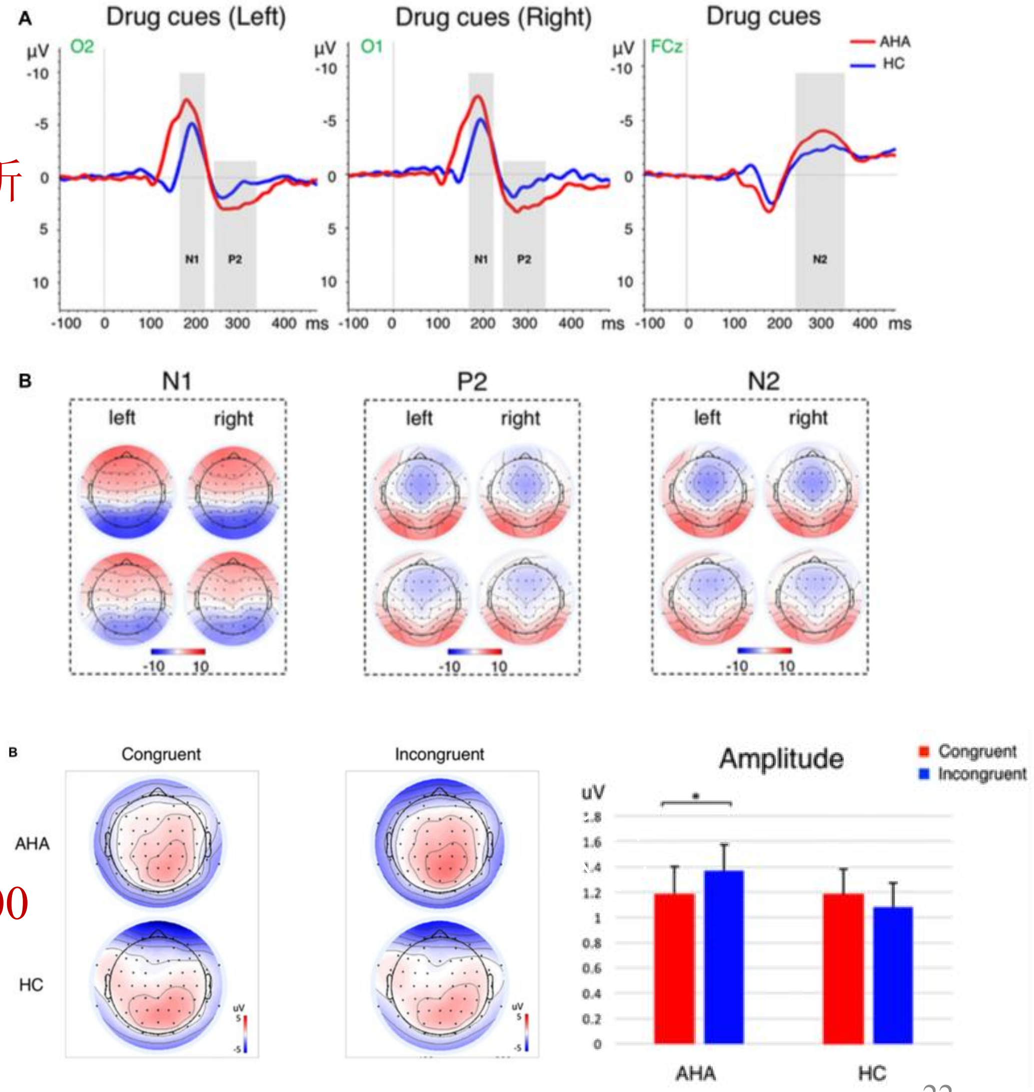
ERP分析

N1

P2

N2

P300



识别毒品相关图片对戒毒所戒毒人员注意力的影响

Zhao et al. (2018)

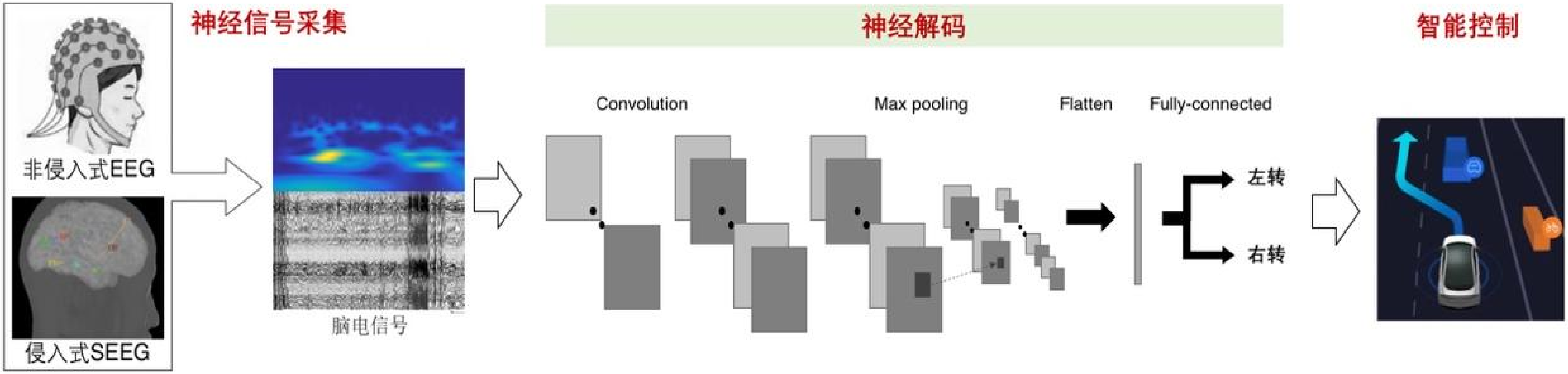
无创脑机接口的实现方式

控制无人机或其他设备

脑机接口的实现方式

脑机接口实现策略	算法实现难度	成熟度	智能级别
稳态视觉诱发电位 (SSVEP)	容易	成熟	初级
P300事件诱发电位 (ERP)	容易	成熟	初级
特征提取+分类/回归	中等	成熟	中级
卷积/循环神经网络	偏难	逐渐成熟	高级
脑源定位	偏难	初步成型	高级
强化学习 (RL)	难	研发阶段	高级
逆强化学习 (IRL)	难	研发阶段	高级

深度学习在BCI中的应用



不提取特定的脑电特征

直接用deep learning models来做end-to-end学习

基于逆强化学习的高级脑机接口

不同于以往的脑机接口（仅识别运动方向、视觉方向等**低级功能**）

我们拟开发基于拟强化学习（inverse reinforcement learning）的高级脑机接口，用于识别运动意图、高级决策、价值函数等**高级功能**

$$P \propto \exp(\theta^T \Psi(x, u))$$

$$r(x, u) = \theta^T \Psi(x, u),$$

最大IRL模型原理：利用最大熵原理恢复满足约束条件的概率分布P

人类司机驾驶行为的**奖赏函数**是一系列环境特征因素加权

环境特征因素：

道路进度：驾驶速度与道路的切线关系

驾驶舒适性：惩罚大的方向盘角度变化以及加速度控制

期望速度：驾驶速度在限速范围内

避免碰撞：避免与其他车辆在横向和纵向的距离过短

车道中心偏移：驾驶过程中偏离道路中心的程度

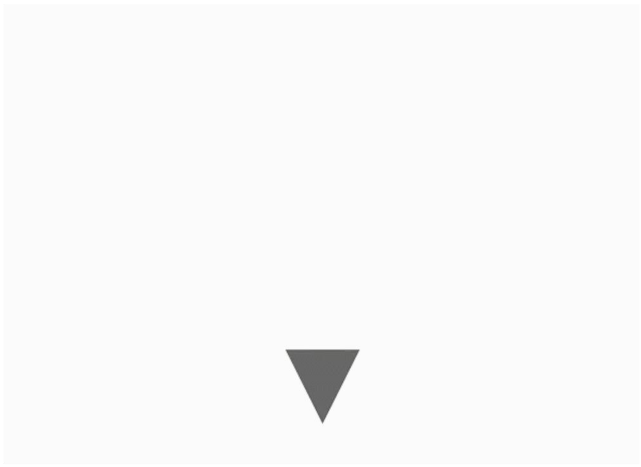
讨论：BCI的研究方向or产业化方向

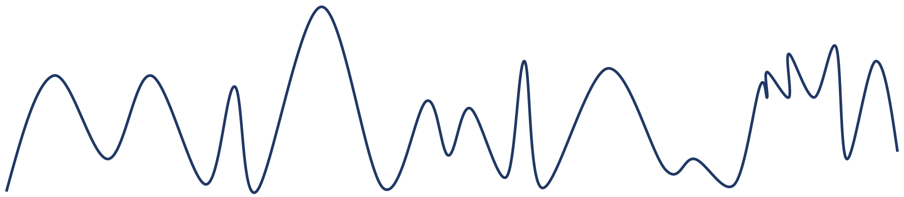
1. 控制类：控制无人机或其他设备
2. 医疗类：康复训练，脑功能康复
3. 系统类：软硬件一体化脑控系统
4. 数据类：脑机大数据平台，个人大脑档案
5. 培训类：大脑相关任务（例如，提高注意力）
6. 评估类：测试和评估，提供量化指标

培训类：训练思维方式，提高大脑功能

训练1：想象运动

训练2：稳态视觉诱发电位





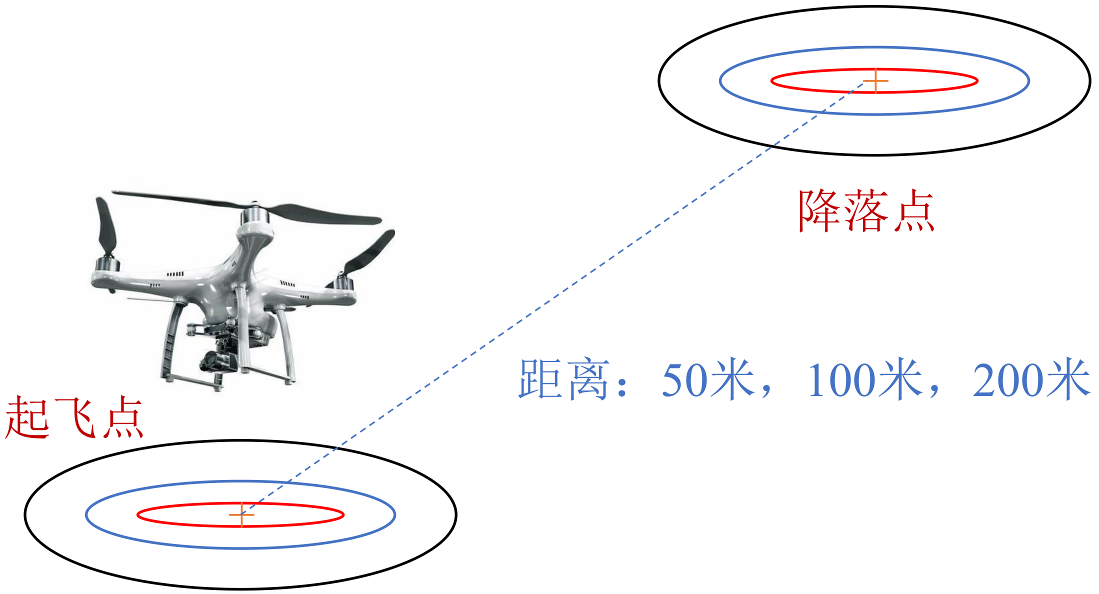
评估类：设计BCI考核任务、考核指标

考核 1：脑机接口操控无人机

- 设计3种不同距离的飞行任务
- 用大脑控制无人机飞行
- 实现起飞、方向控制、降落

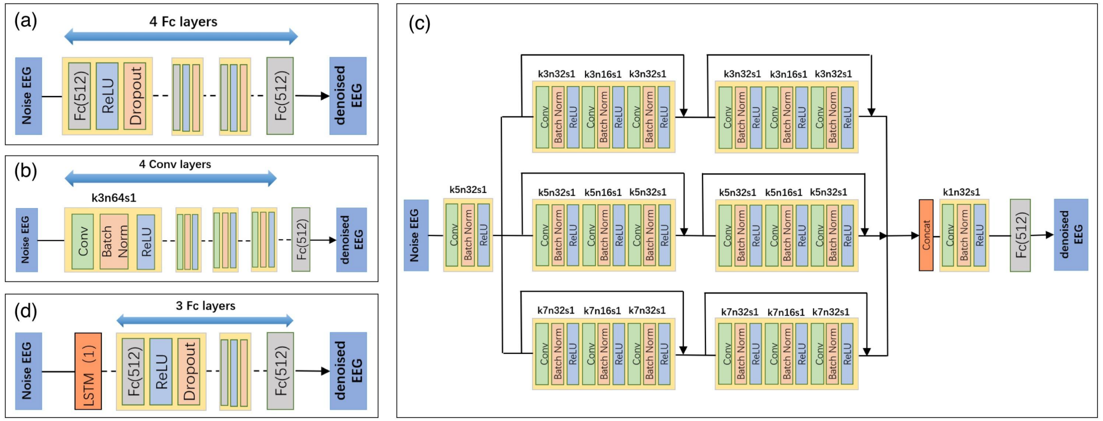
考核 2：脑机接口操控汽车

- 模拟3段不同难度的驾驶路线
- 用大脑控制汽车行驶1公里
- 实现拐弯、加速、减速等操作

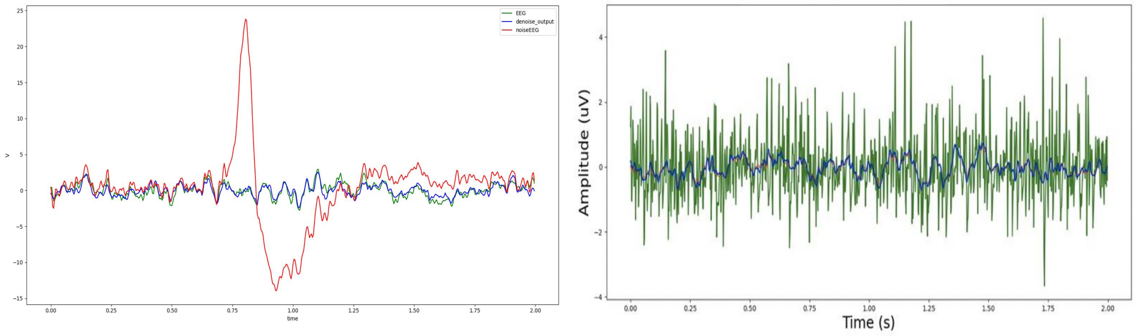


NCC lab的相关研究成果

1 脑电的去噪技术



脑电去噪效果

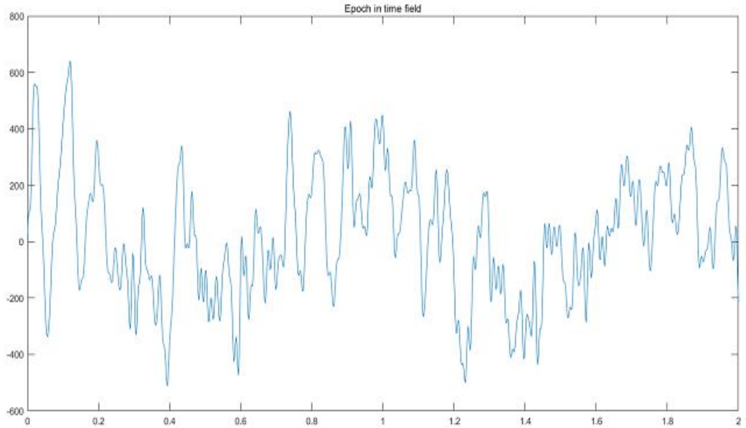


- 利用深度学习网络实现**脑电的实时去噪**
- 去噪效果显著高于传统算法，速度提高数十倍

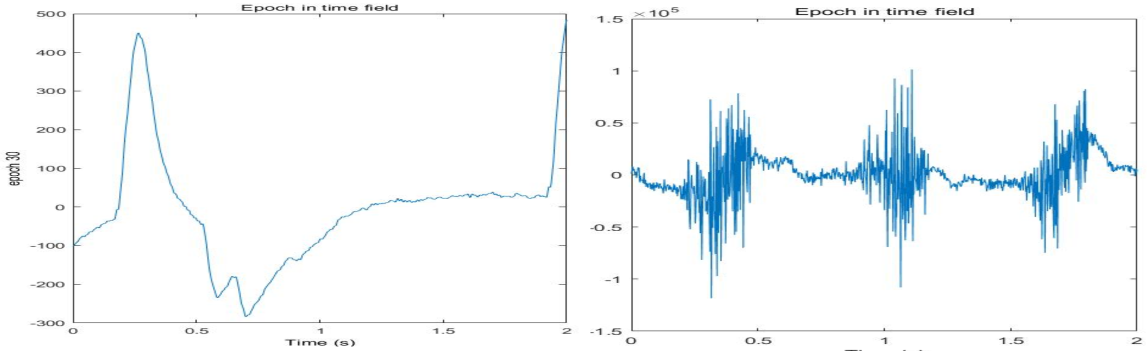
Haoming Zhang (2020a); Haoming Zhang (2020b)

2 脑电大数据集(dataset)

干净的脑电
4514 条



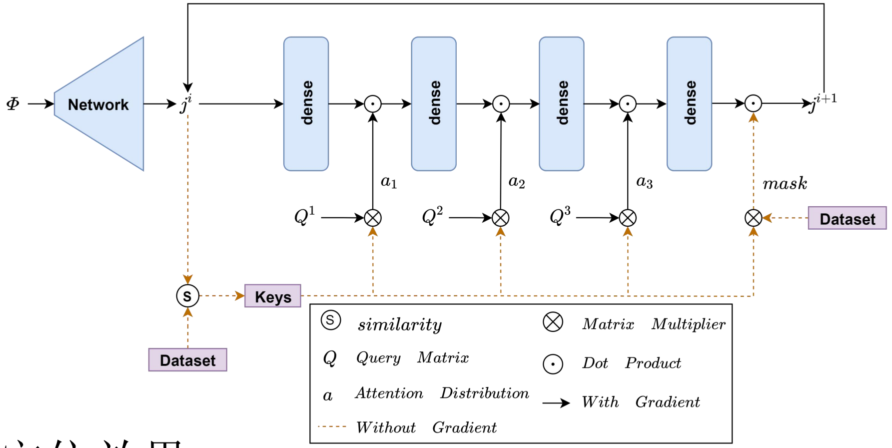
眼电噪声 3400 条　　肌电噪声 5598 条



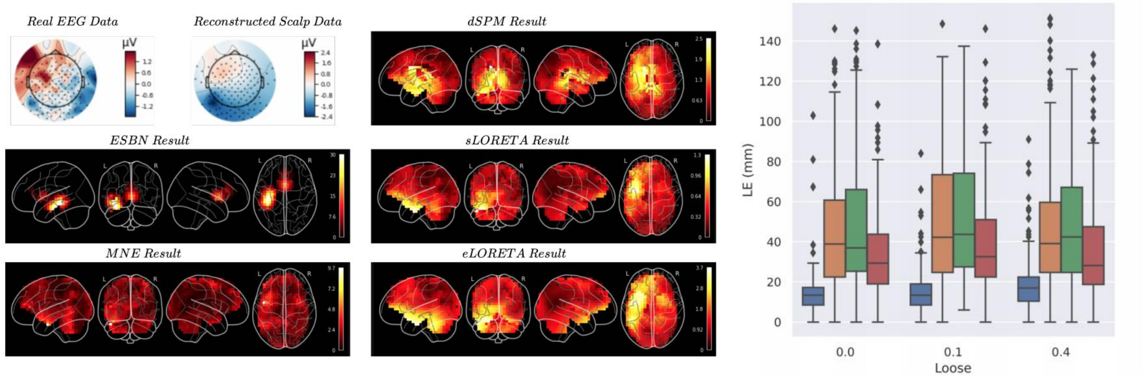
- 世界首例用于训练深度去噪网络的**脑电数据集**
- 包含多种任务、多被试的脑电、眼电、肌电

Download at Github: https://github.com/ncclabsustech/EEGdenoiseNet

3 脑电的(实时)源定位技术



源定位效果

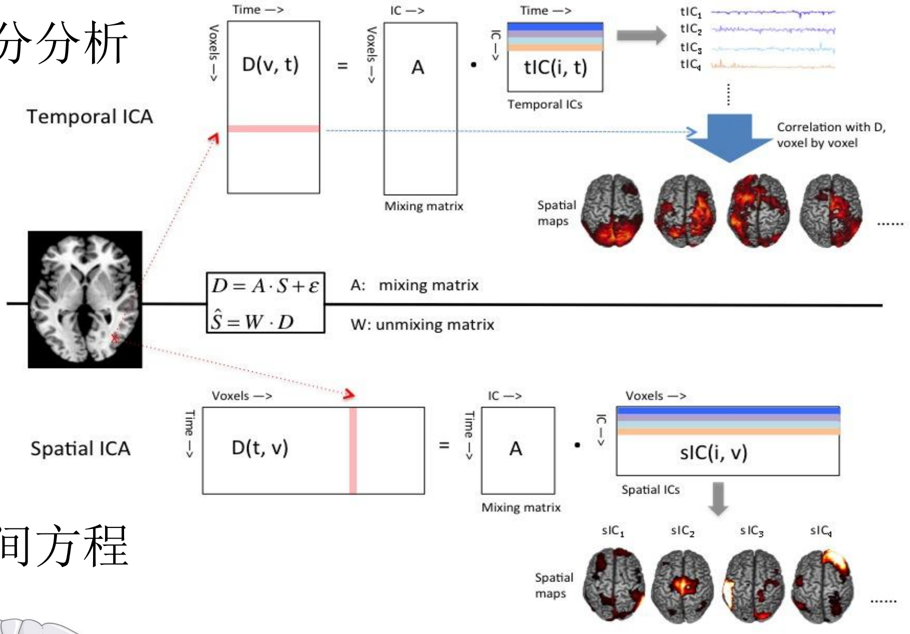


- 利用深度学习实现**高密度脑电的源定位**
- 重构全脑神经电活动动态，实时且高效

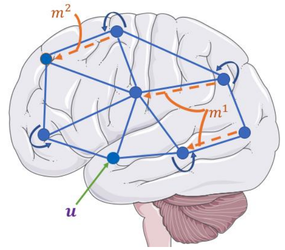
Chen Wei et al (2021)

4 脑源功能连接分析算法

独立成分分析



状态空间方程



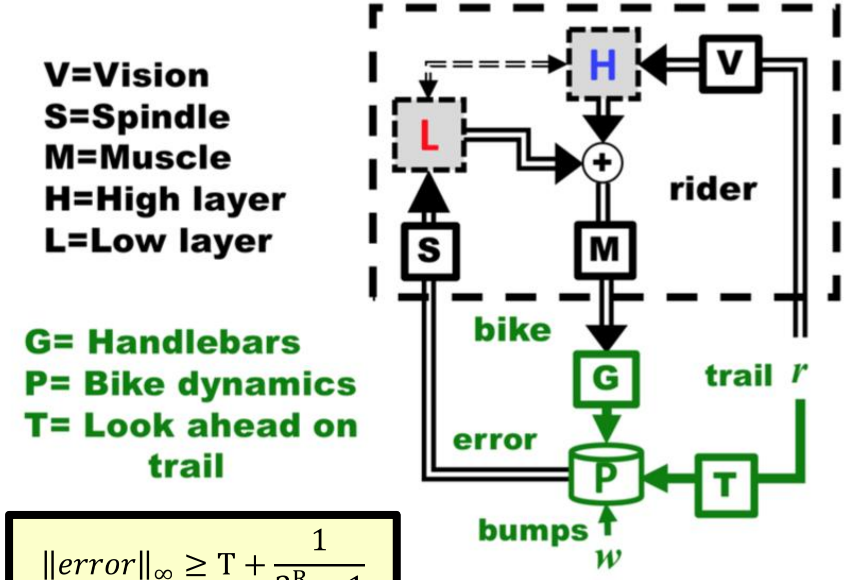
$$s_t = As_{t-1} + \sum_{k=1}^{K} B^k m_t^k s_{t-1} + Du_t + \omega_t$$

$$y_t = Cs_t + \emptyset_t$$

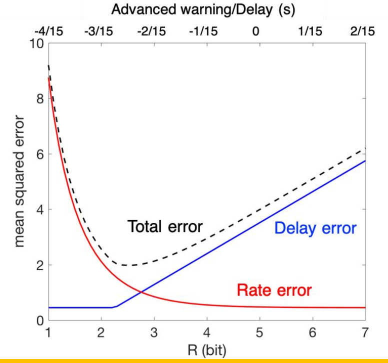
- 提出基于ICA算法的EEG**脑源功能连接**分析
- 提出基于state-space model的**脑源因果**分析

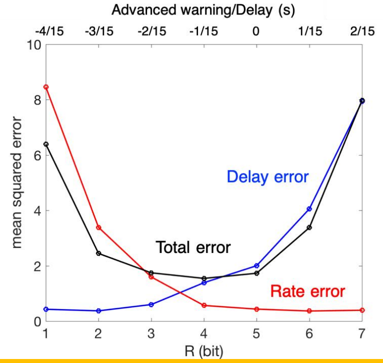
Quanying Liu et al (2017); Quanying Liu et al (2018); Samogin et al (2020);

5 大脑分层架构理论



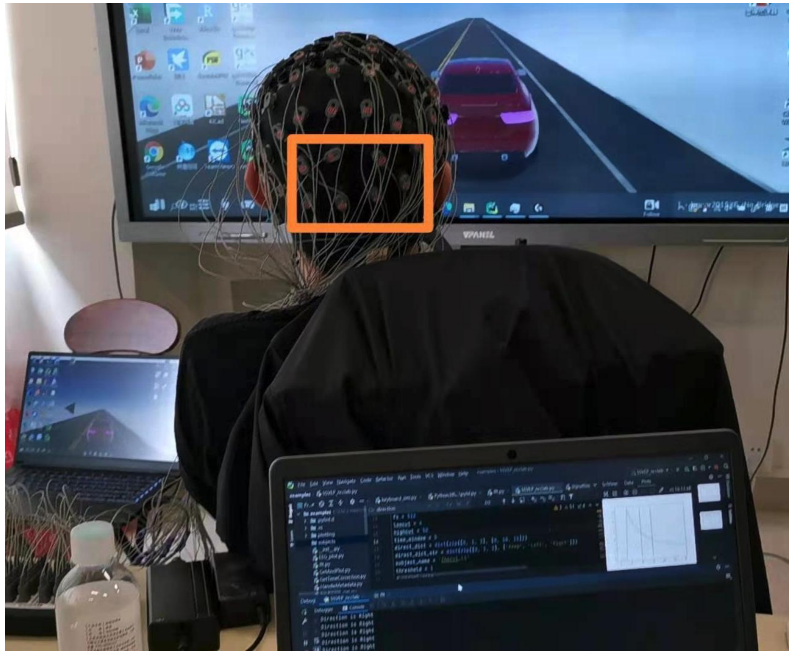
$$\|error\|_\infty \geq \mathrm{T} + \frac{1}{2^{\mathrm{R}} - 1}$$

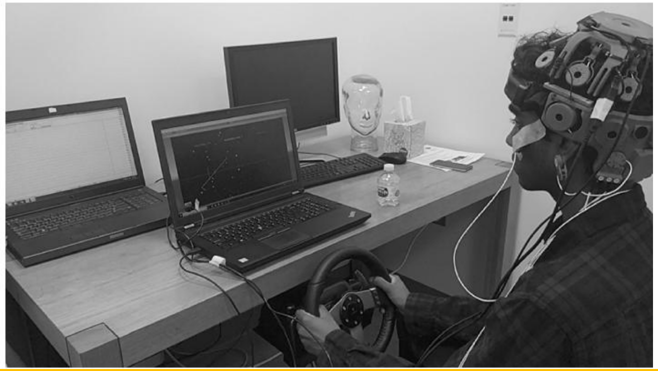




- 提出分层架构理论，**决策层与反射层**
- 不同层直接的运动控制误差具有**叠加**性质

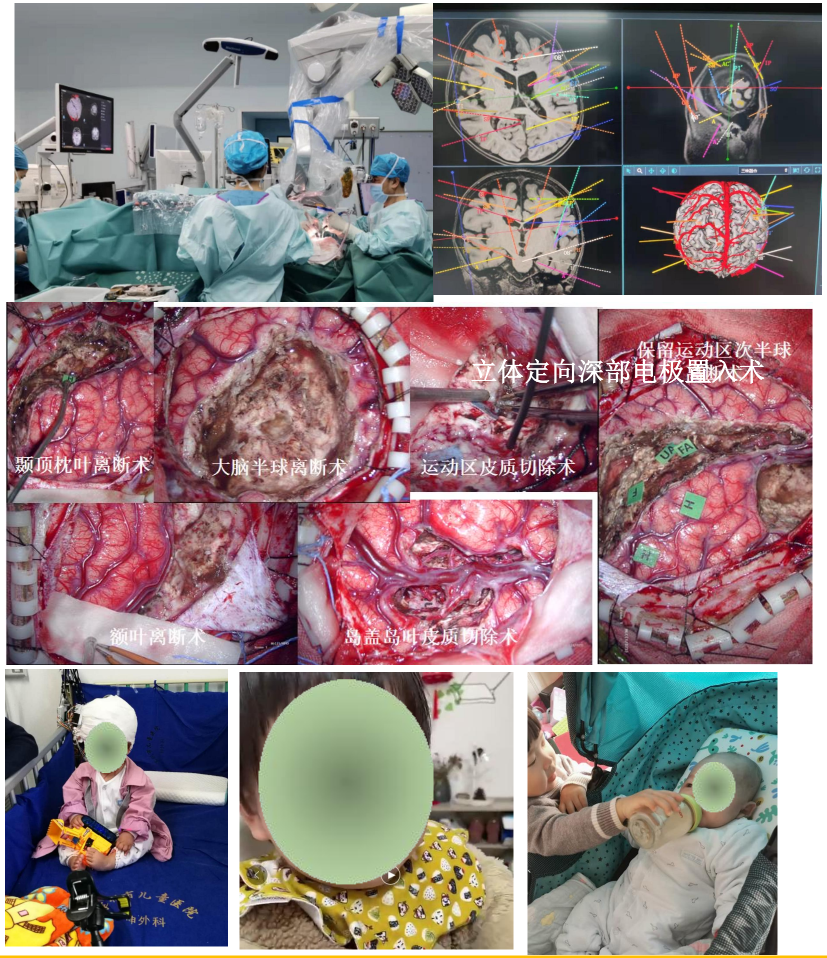
6 基于BCI的辅助驾驶技术



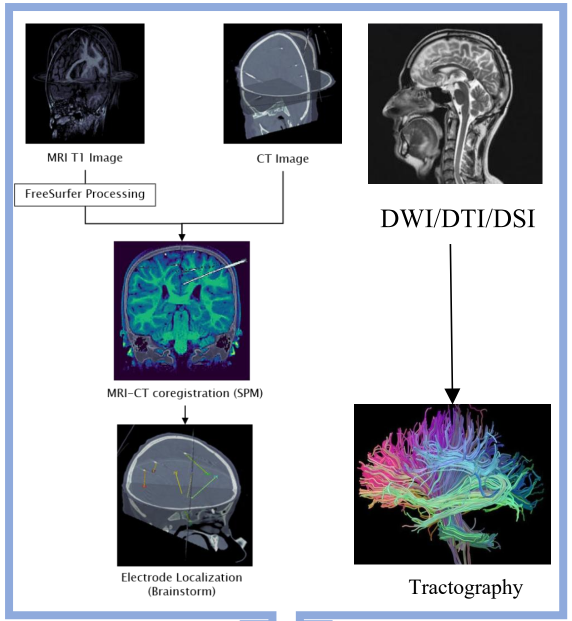


- 利用LGSVL与Appollo联合**模拟驾驶环境**
- 利用**双模态**脑机接口，进行驾驶控制

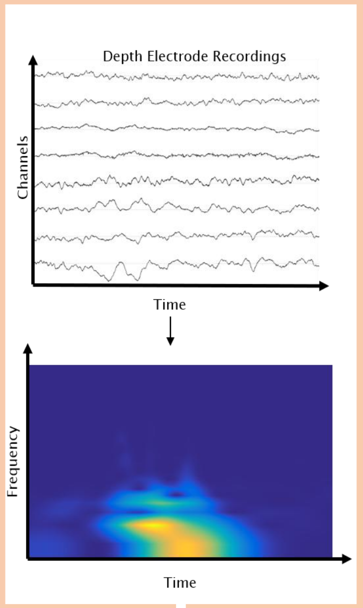
7 与多家医院合作，针对植入电极的癫痫病人，开发有创脑机接口技术



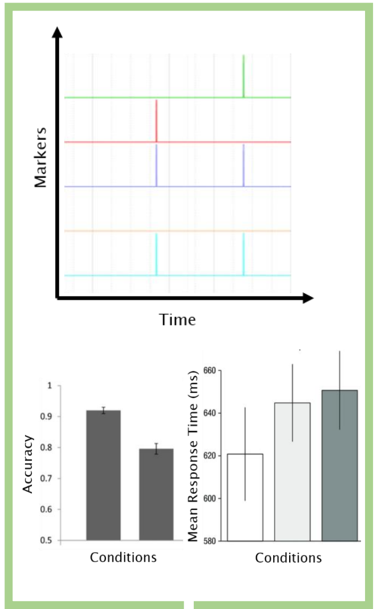
脑结构分析

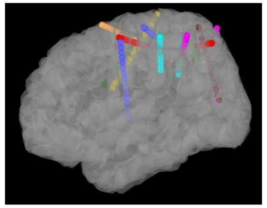


脑功能分析

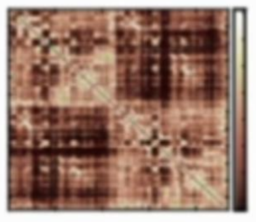


行为分析

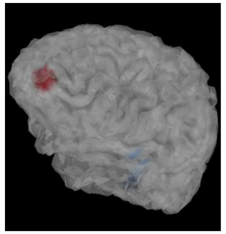




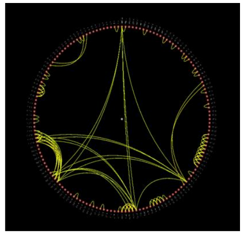
Electrode Visualization



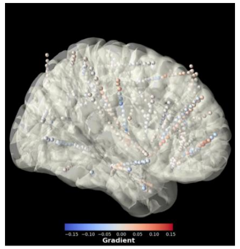
Structural Connection



Brain Activity



Electrode Connectivity



Group Analysis and Modeling

- 在各类癫痫患者SEEG植入之后采集神经信号
- 单个患者的神经信号采集时间长达 6 天

- 提出脑结构、脑功能、行为多维度分析算法
- 实现神经振荡的预测、行为的预测

讨论：BCI的未来

1. **人与人(人与机)之间的信息传输**：用动作和语言传输信息 → 用大脑信号直接传输信（data rate更大）
2. **人机融合**（ or 机器替代人类）：人脑和机器实现信息共享(输入)、计算模型融合(计算)、硬件增强(输出)

Homework 2

EEG data processing with MNE-python

DDL: March 29, 2021

Tips:

- Watch the tutorial video
  https://www.bilibili.com/video/BV1YK411T7H8
- Read the official website of MNE-python
  https://mne.tools/stable/index.html

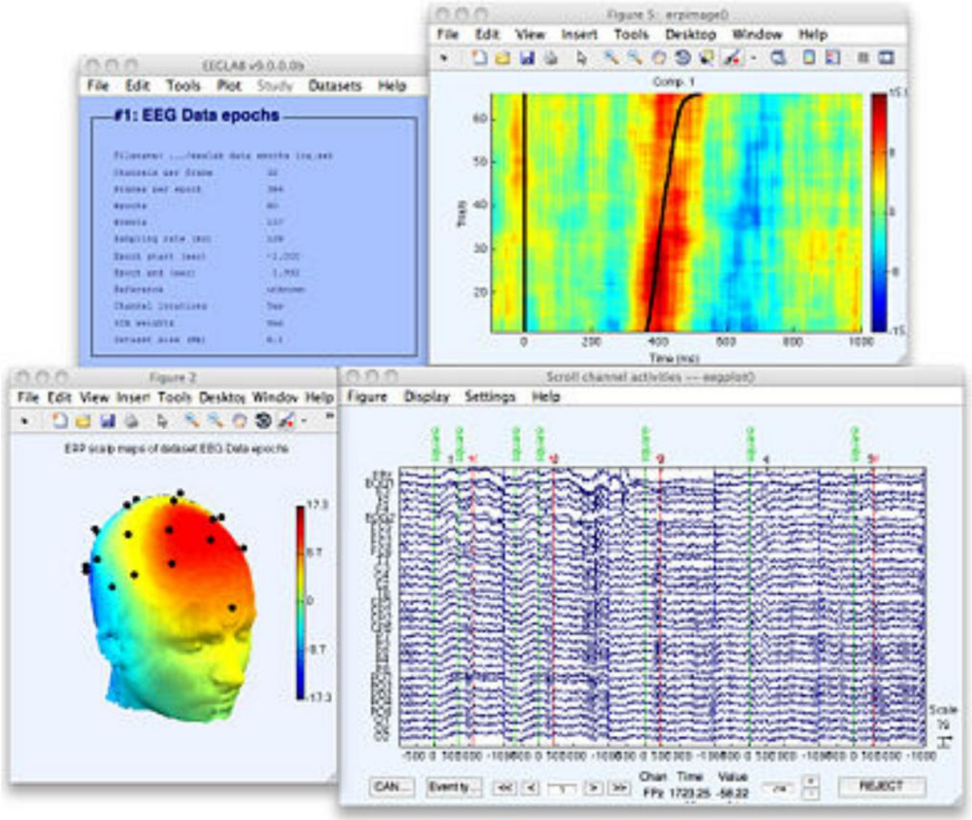
Requirements

1. Read the paper https://www.nature.com/articles/s41597-020-0535-2
2. Download the raw EEG data from [26] in the paper (https://doi.org/10.7910/DVN/RBN3XG)
   学生ID为奇数的同学下载sub-001；学生ID为偶数的同学下载sub-002
3. Plot the **time course** of raw EEG signals with 10-second window (as Figure 4 in the paper).
4. Data preprocessing, artifacts removal
5. Plot the **time course** of preprocessed EEG signals
6. Plot the **time-frequency maps** of the subject (as Figure 6 in the paper)
7. Plot the **topographical distribution** of power of the subject (as Figure 7 in the paper)
8. **Comparison** of power (in dB) changes with time (in s) during hand, elbow motor imagery, and resting state for electrode C3, and electrode C4 (as Figure 8 in the paper)

Toolbox for EEG analysis

EEGlab (matlab)

Official webpage https://sccn.ucsd.edu/eeglab/index.php
Tutorial https://www.bilibili.com/video/BV1mJ411s7vH



MNE-python

Official webpage https://mne.tools/stable/index.html
Tutorial https://www.bilibili.com/video/BV1YK411T7H8

MNE

MEG + EEG ANALYSIS & VISUALIZATION

Open-source Python package for exploring, visualizing, and analyzing human neurophysiological data: MEG, EEG, sEEG, ECoG, NIRS, and more.