Courtois NeuroMod - scaling up AI models of individual brains in a massive individual fMRI dataset

Pierre Bellec
Département de Psychologie
pierre.bellec@criugm.qc.ca

Université de Montréal

cerebrum

Centre de recherche iugm
Institut universitaire de gériatrie de Montréal

Acknowledgments

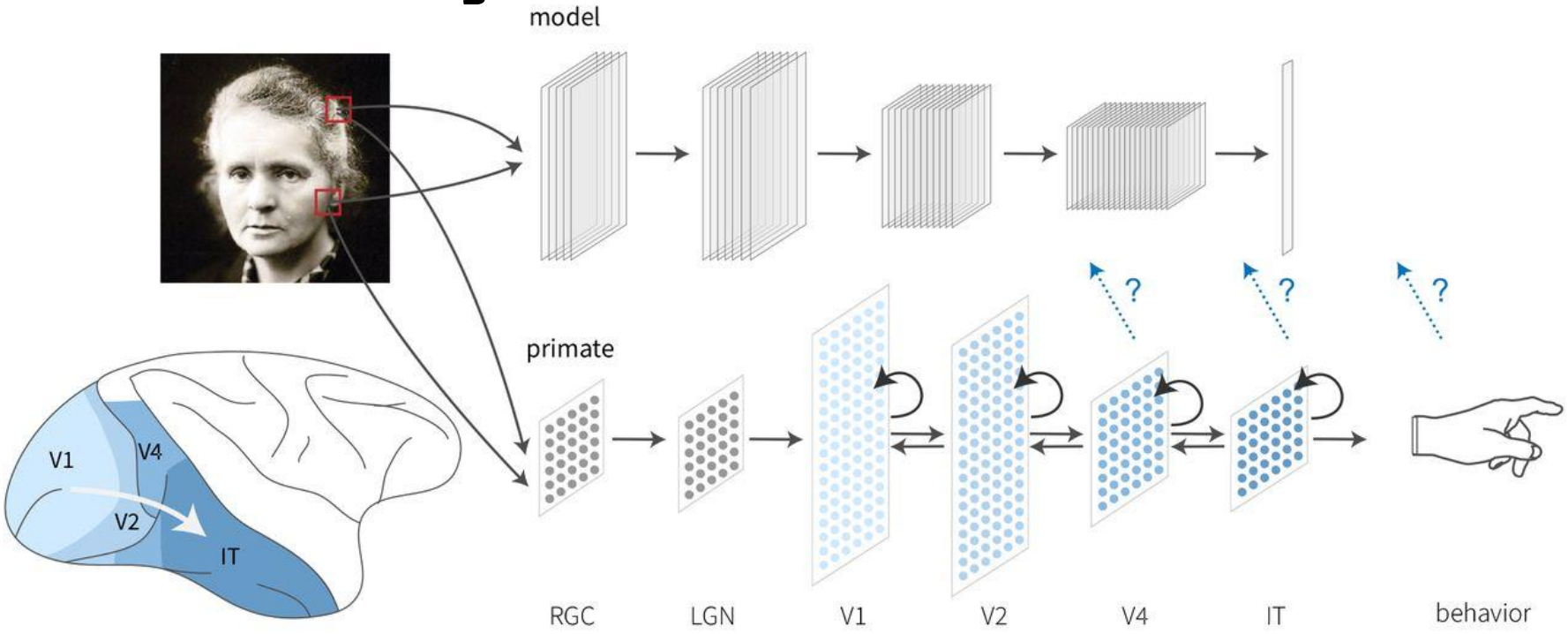
Fondation Courtois

The CNeuroMod Team

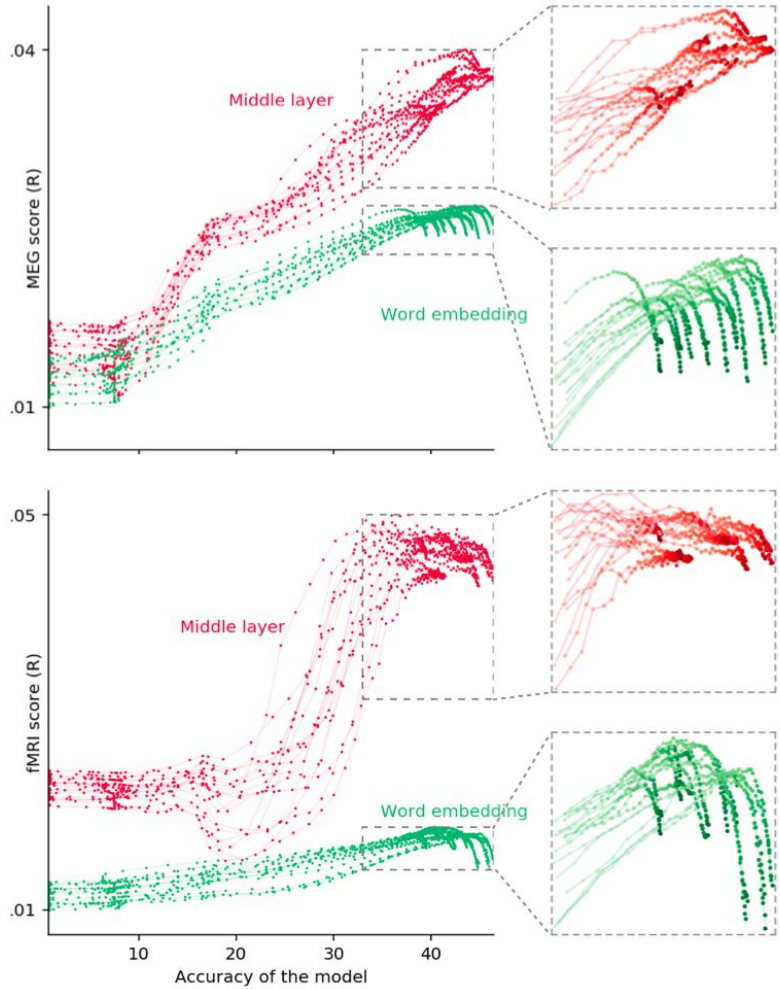
The **Subjects**
& the **Scanning Team**

Project manager Julie Boyle
Data manager Basile Pinsard

Brain encoding



One way to test the consistency of representations in artificial neural networks (ANNs) and the brain is to **encode** brain activity based on ANN presented with identical stimuli. Figure from Schrimpf et al. Biorxiv 2020 reused under CC-BY license.



Task performance vs brain encoding

The quality of brain encoding has improved with the emergence and scaling of large language networks (red) over word embeddings (green), with some of the top performing models for behaviour showing a downwards trend for their brain score.

Brain encoding based on 2 hours of fMRI and MEG for N=102 subjects.

From Caucheteux and King, Communications biology, 2022.

CNeuroMod main objective

Brain-augmented learning: train artificial neural networks to imitate individual human brain activity and behaviour.

Large amount of **individual** data will scale up performance of artificial neural networks, and enable breakthroughs both for modelling the brain and training better AI.

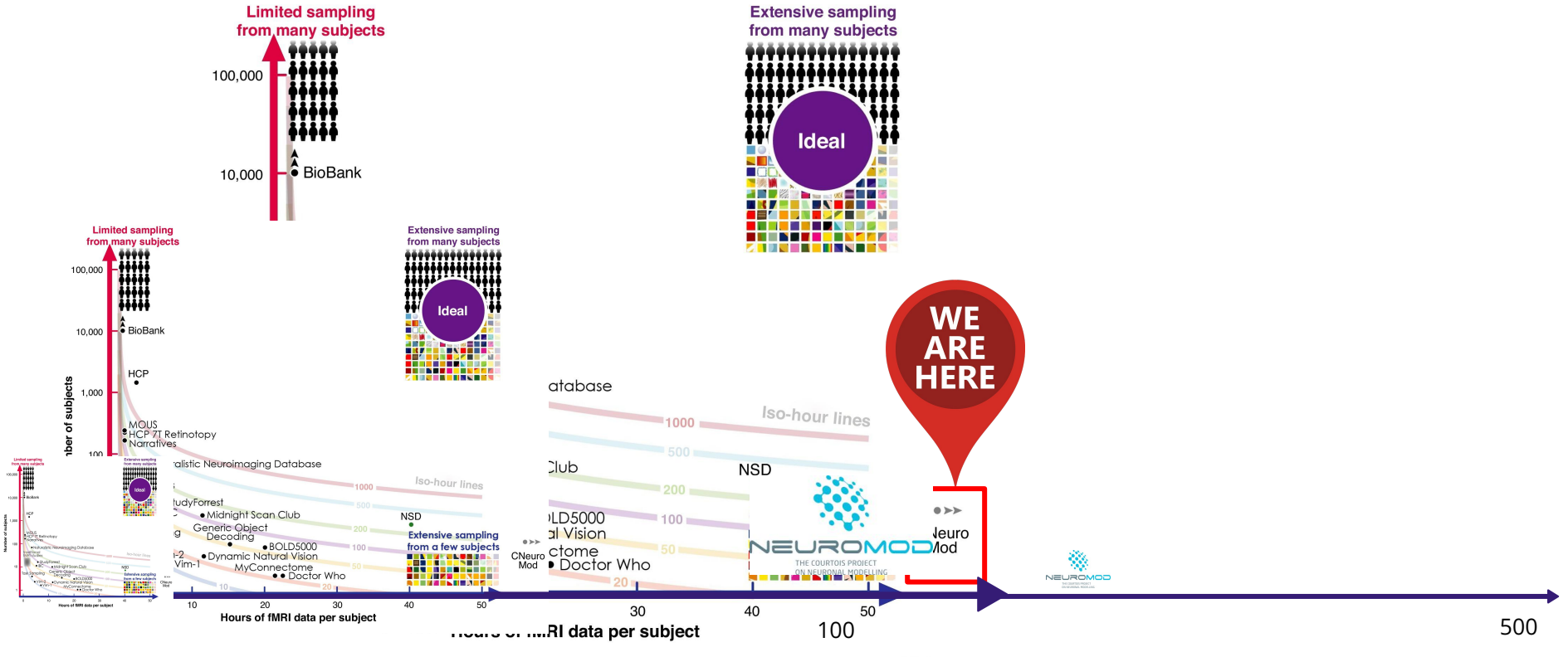
CNeuroMod databank

Julie A Boyle
Project Manager
CNeuroMod

Basile Pinsard
Data Engineer
CNeuroMod

CNeuroMod
community

Mega individual fMRI sample



Nassaleris et al. 2021. Figure under CC-BY (Biorxiv)

Participants

Inclusion criteria:

1) Generally **healthy**
2) **MRI** & **MEG** compatible
3) Have **normal hearing** for their age
4) Solid comprehension of English language
5) Be willing to be scanned for **1.5 - 3h/ week** for at least **5 years!**

Participant ID	Sex	Age at recruitment	Handedness*	Maternal language*
Sub-01	m	41	right	french
Sub-02	m	47	right	french
Sub-03	f	39	right	english/french
Sub-04	f	31	right	french
Sub-05	m	46	right	english/czech
Sub-06	f	37	right	english

Scanning set-up

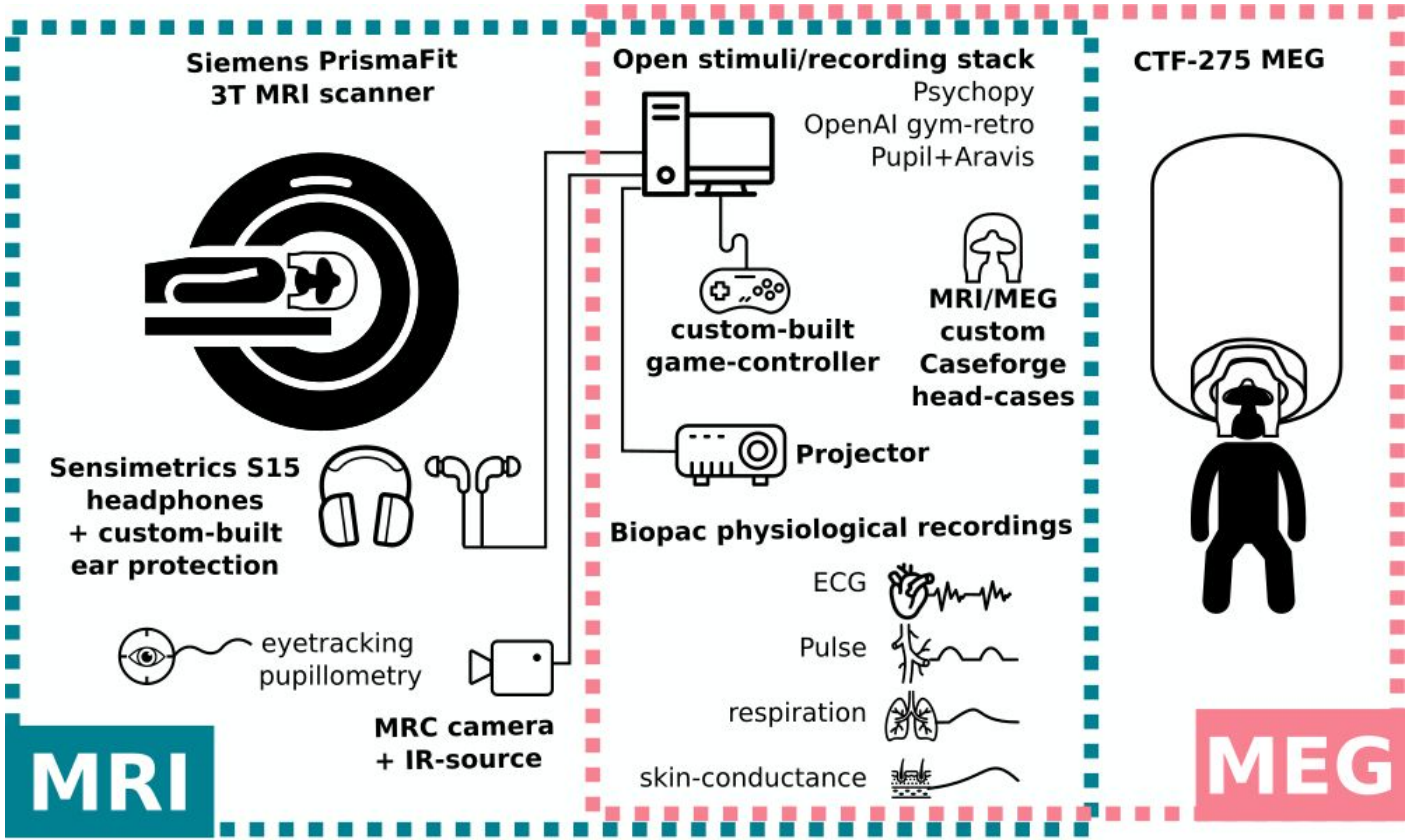


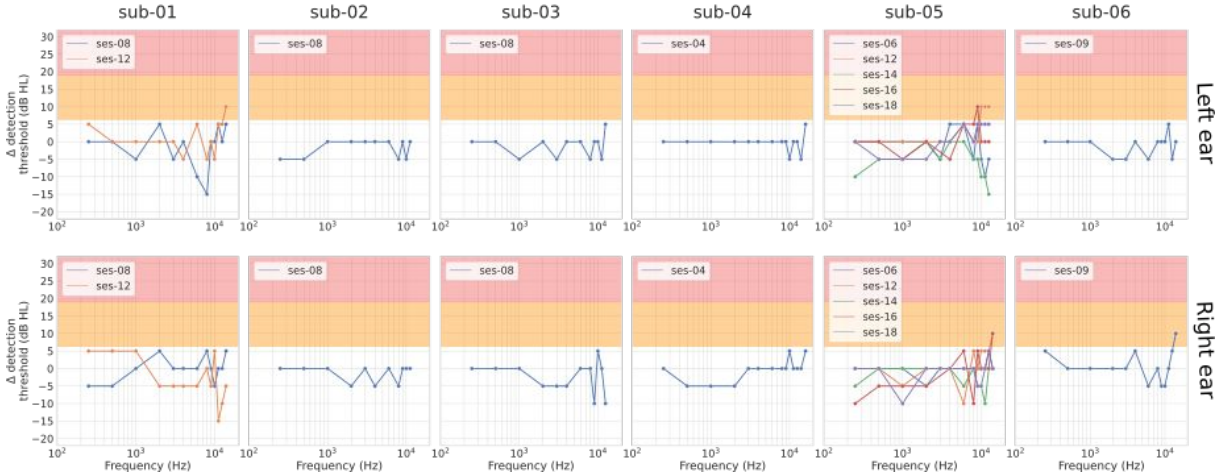
Figure by Dr. Pinsard.

Auditory safety

We found no evidence of acute damages to the hear, by comparing pre- post-scan hearing measures.

Long-term follow-up identified loss in hearing performance in some subjects, but may reflect processes unrelated to scanning, or test-retest reliability of cutting-edge metrics.

[Fortier et al., preprint 2022]



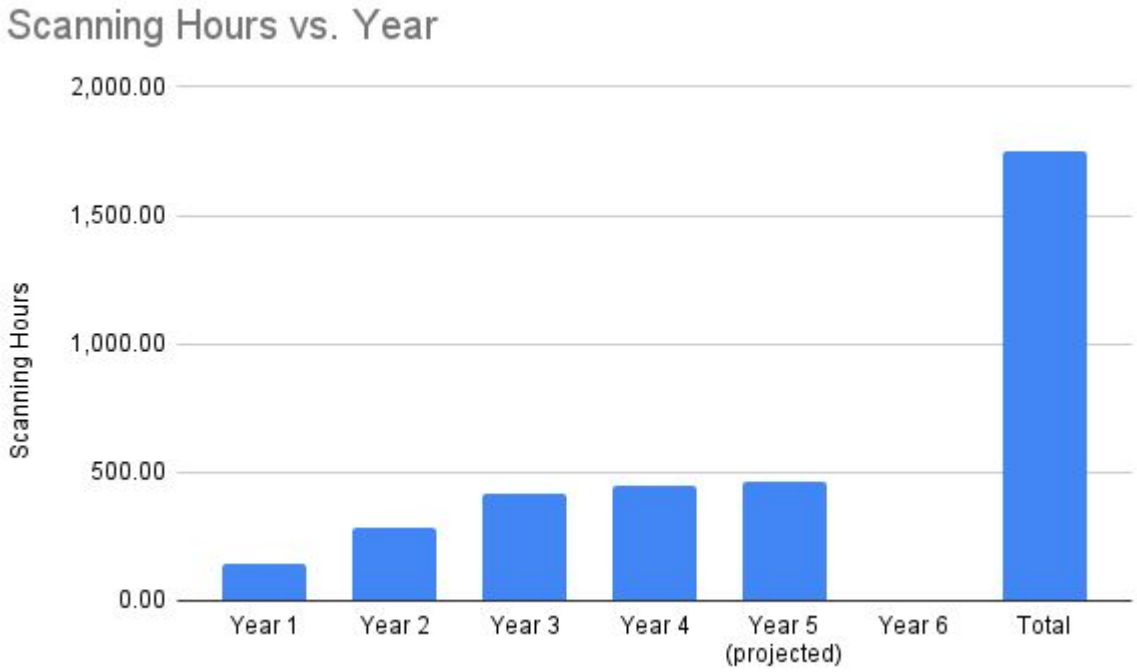
Acquisitions

The full sample is **N=6**.

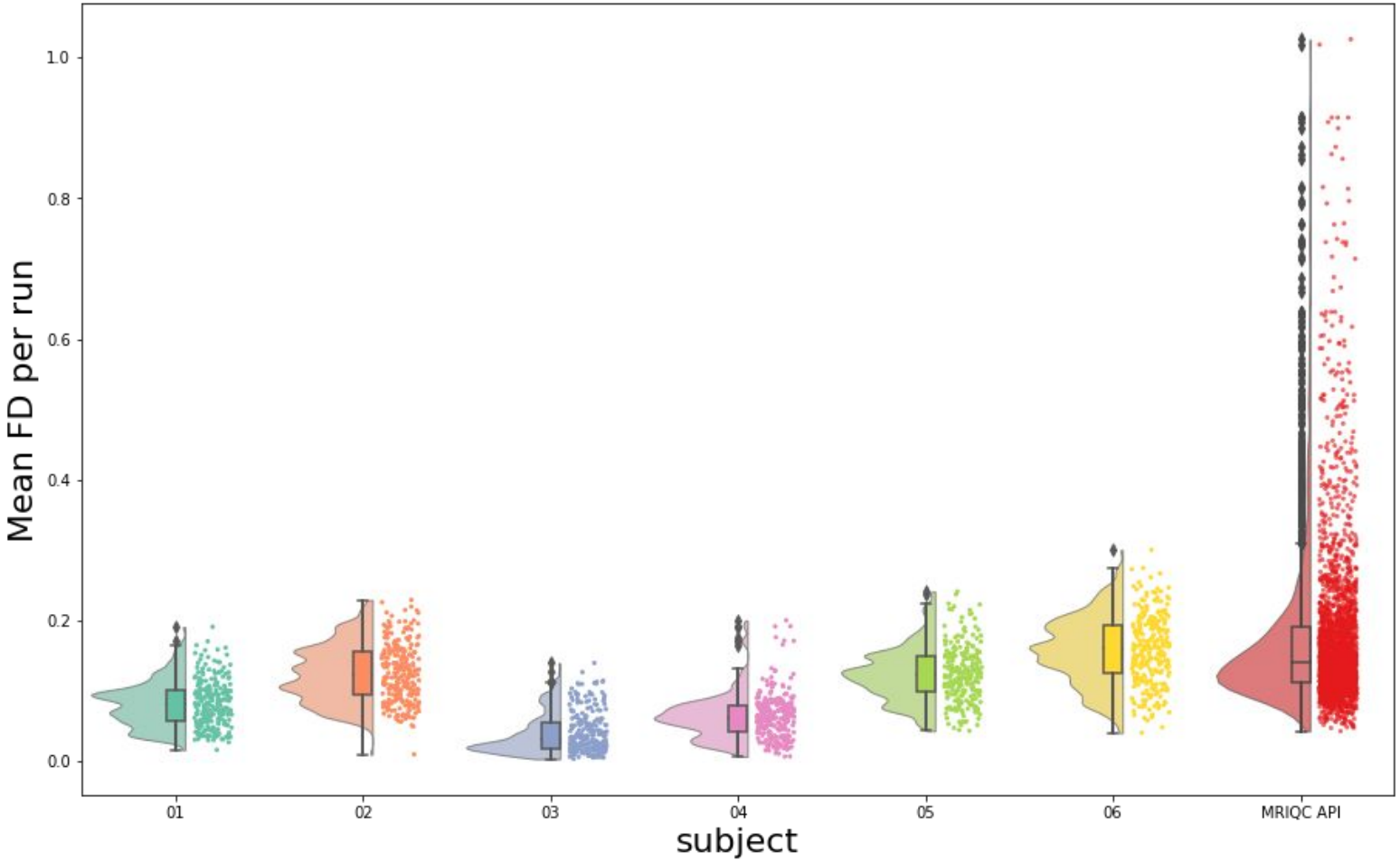
For Years 3-5, N=4 are scanned about 100 hours per year, representing about 50 hours of functional neuroimaging data.

One subject paused acquisitions in Year 4. One subject has limited availability and is scanned about 50 hours per year.

Data from February 2023 (end of Year 5).

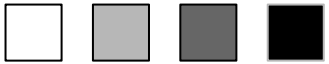


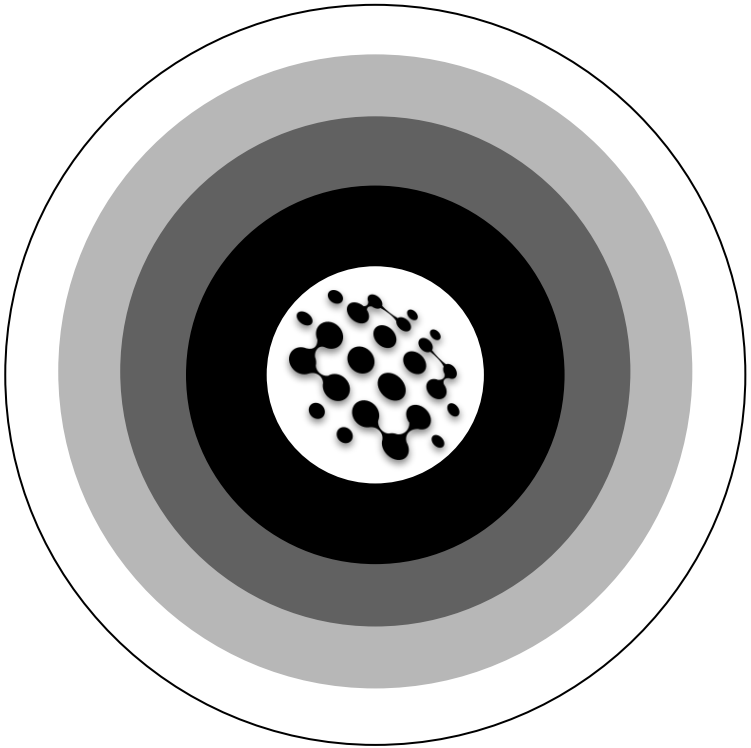
Data quality: motion

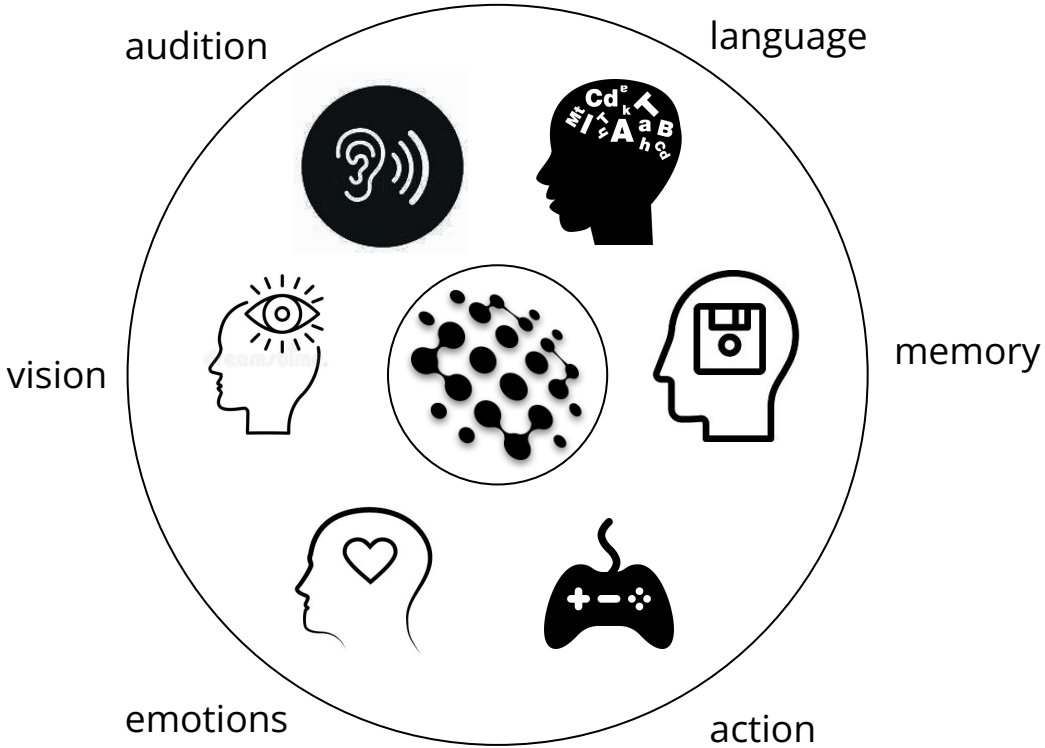


Release 2020

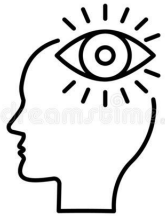
CNeuroMod datasets

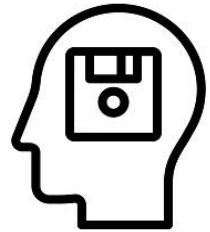
controlled  naturalistic





CNeuroMod datasets





CNeuroMod community

Anatomical datasets

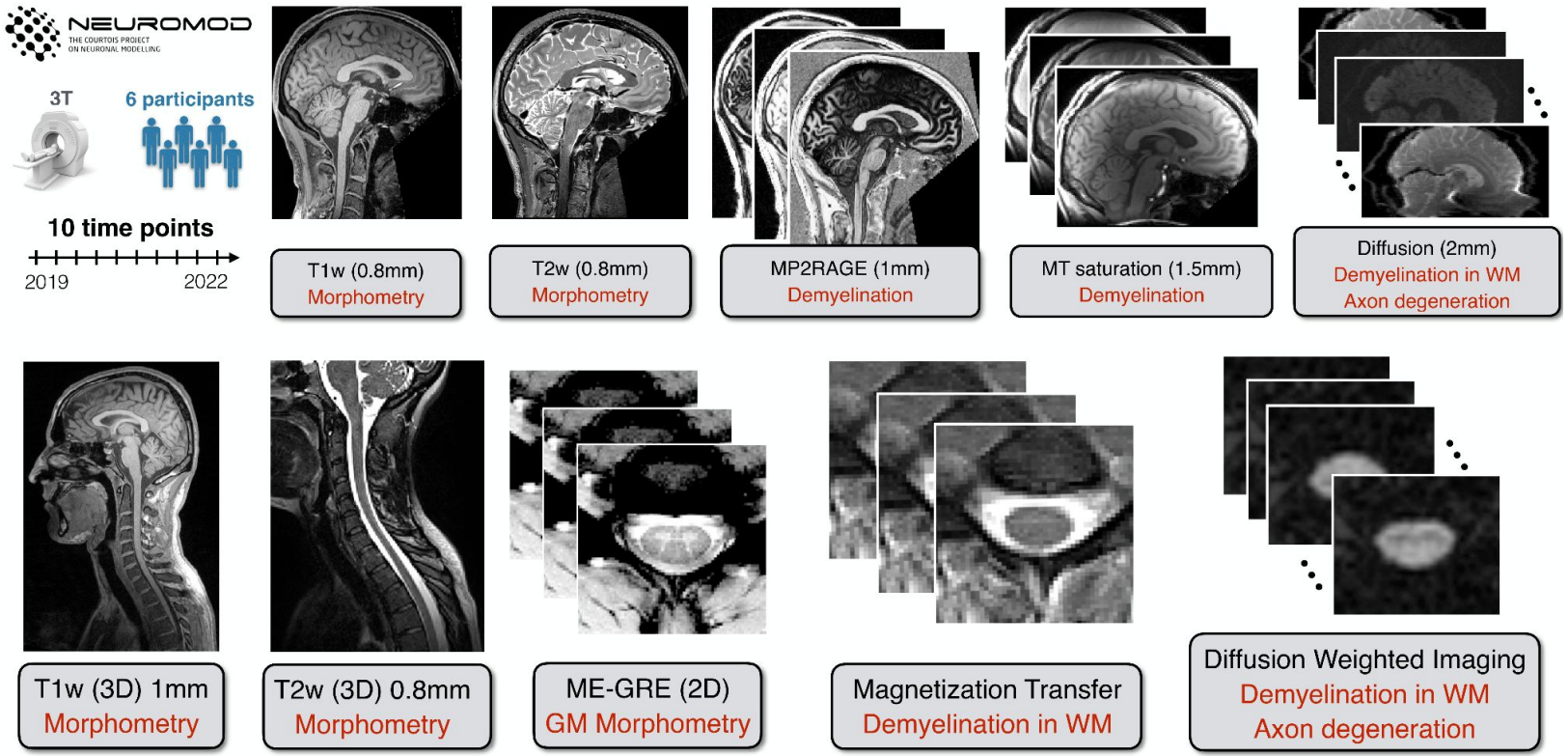
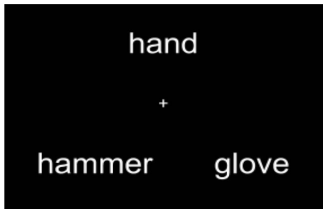
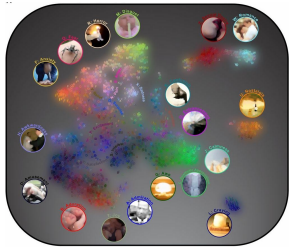


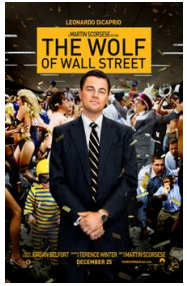
Figure by Dr Mathieu Boudreau

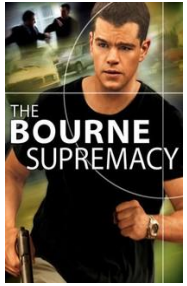
Large controlled datasets

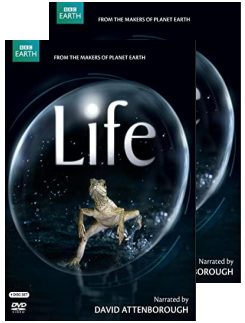
things (~15h)	triplets (~10h)	emotions (~10h)	hcptrt (~10h)	MULTFS (~10h)
				MULTFS
Release 2023 N=4	Release 2024 N=5	Release 2024 N=5	Release 2024 N=6	Release 2024 N=5
4K+ unique image from the things dataset x 3 repetitions = 12k+ image presentation. Long-term memory task.	709 triplets, and 1588 single words x 3 repetitions = 6.8k+ trials. Word familiarity and similarity tasks.	1.8k+ short videos 14 emotional dimensions.	7 functional localizers (HCP) with 21 conditions across varied domains. 15 repetitions per task.	Design upcoming.

Story datasets

movie10 (~10h N=6) release 2020

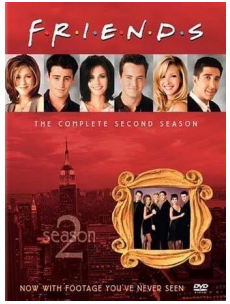


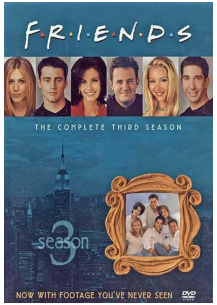


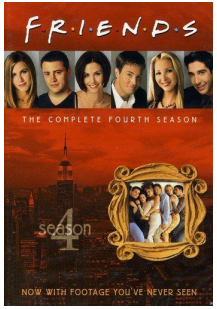


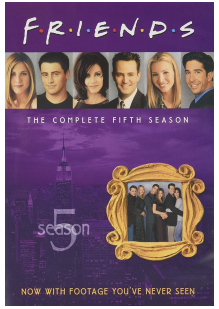
narratives (~5h) N=5 release 2024

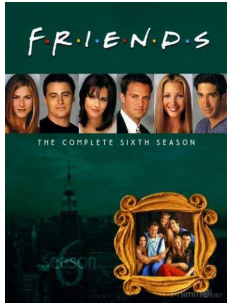
friend s01-s06 (~60h N=5-6) release 2022-23











Videogame datasets

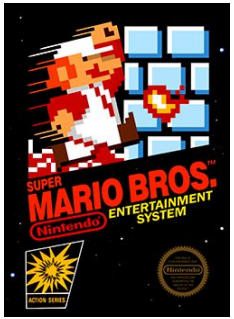
controller (~1h)

Release 2023
N=4

shinobi (~10h)

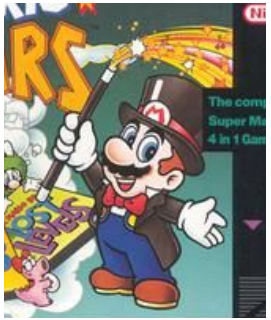
Release 2022
N=4
3 levels

mario (~15h)



Release 2023
N=5
24 levels

mariostars (~3h)



Release 2023
N=5
24 levels

same as mario
but
different sprites

mario3 (~10h)

Release 2024
N=5
80 levels

Databank

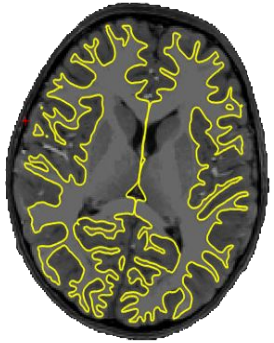
Registered access

1) Principal investigator with university credentials

2) Short text about research

3) Sign data transfer agreement with institutional representative.

BIDS
BRAIN IMAGING DATA STRUCTURE



fMRIprep

DataLad

Website: www.cneuromod.ca

2022 data release features hcptrt, movie10, friends s01-05 and shinobi

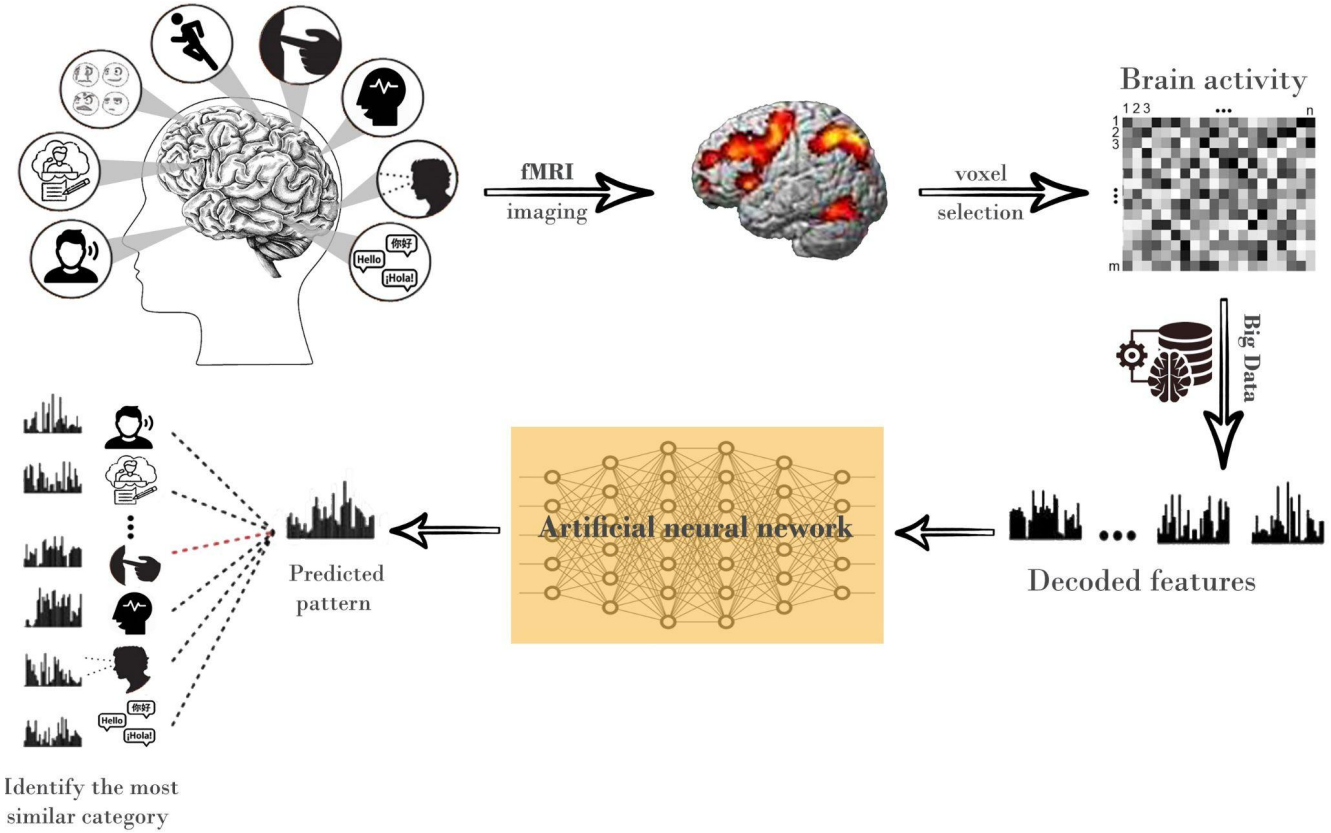
Scaling up brain decoding

Yu Zhang, PhD
Post-doctoral fellow
IVADO, University of Montreal, CA

Valentina Borghesani, PhD
Associate professor
Geneva University, CH

Shima Rastegarnia, MSc
DIRO, University of Montreal, CA

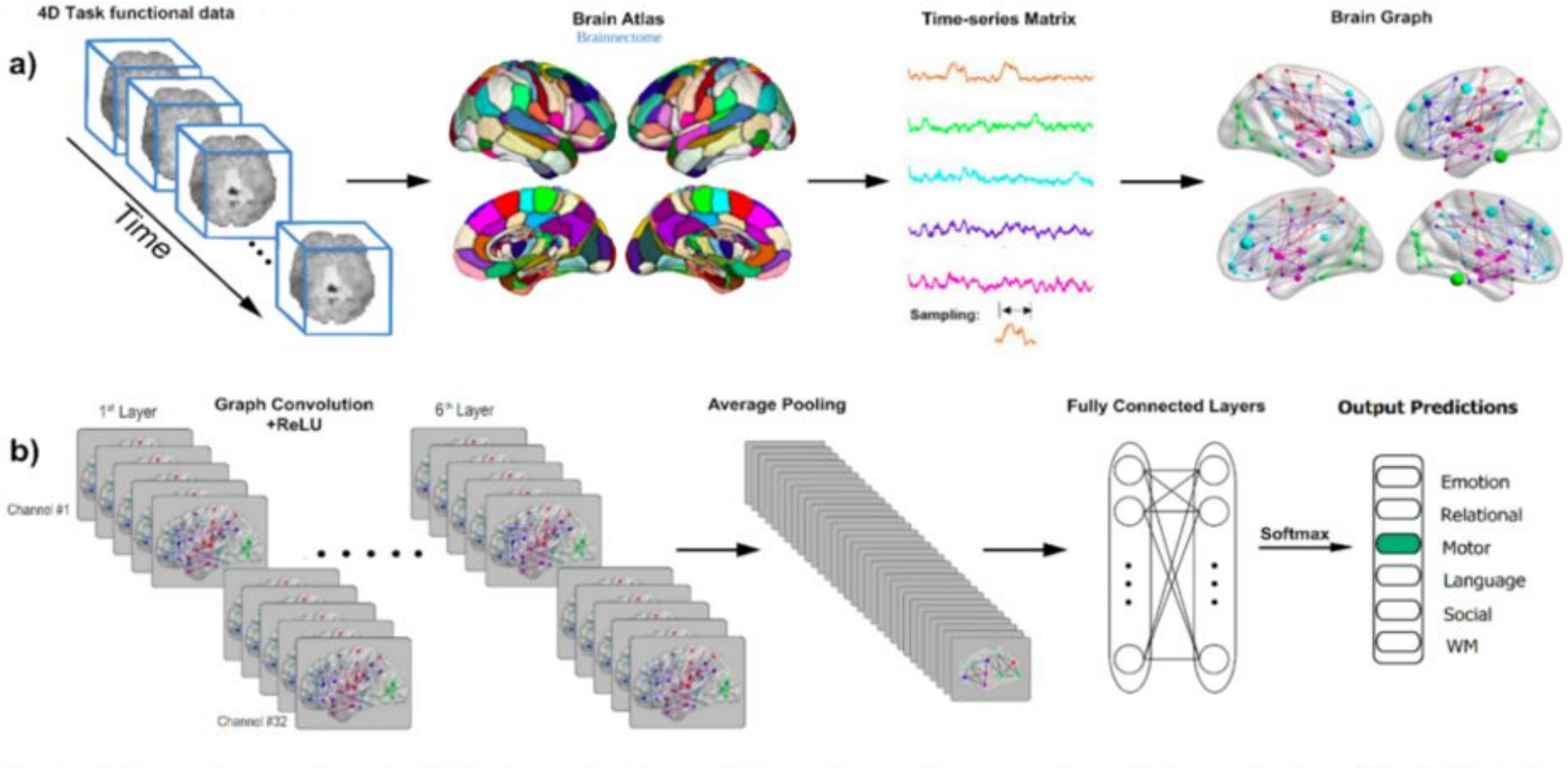
Brain Decoding



- 1206 healthy subjects
- 21 experimental conditions across 7 cognitive domains.
- fMRI acquisition: TR=0.72s, 2mm iso-resolution

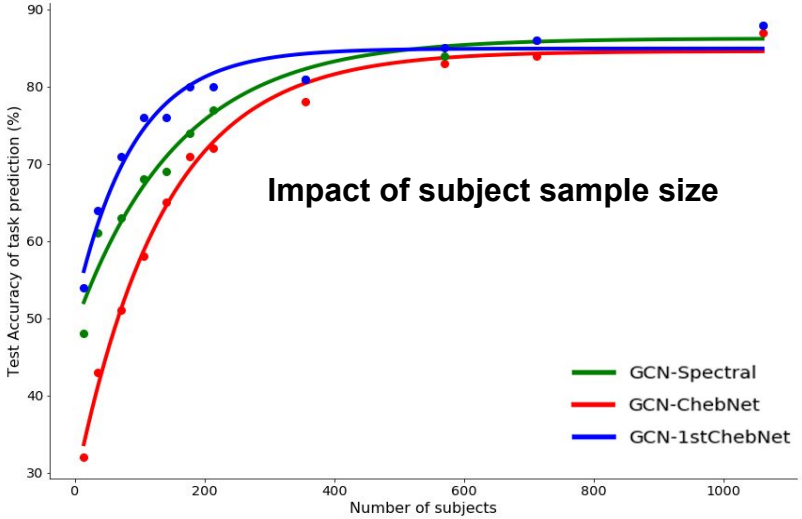
Task Domains	#Subjects	#Runs	#Volumes per run	#Trials per run	#Conditions	Minimal duration per block (sec)
Working memory	1085	2	405	8	8	25
Motor	1083	2	284	10	5	12
Language	1051	2	316	8	2	10
Social Cognition	1051	2	274	5	2	23
Relational processing	1043	2	232	6	2	16
Emotion	1047	2	176	6	2	18

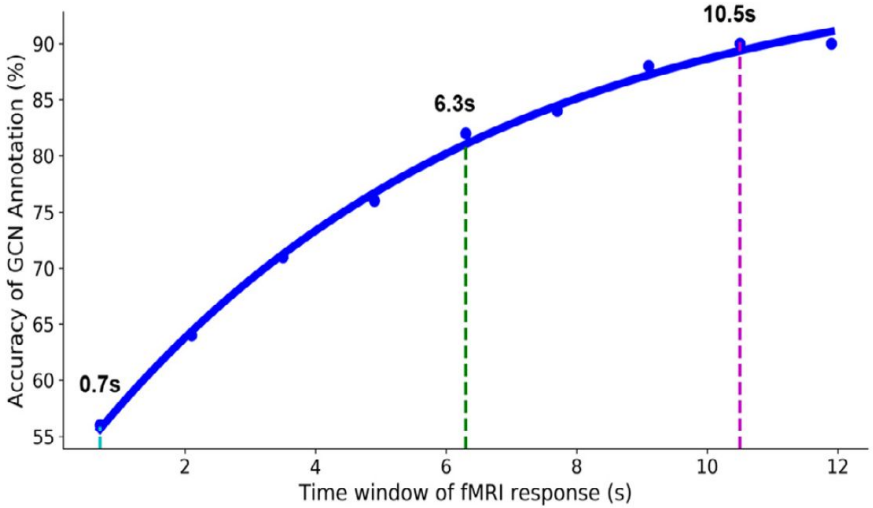
Graph convolutional network schematic view



Zhang et al., 2021; Fan et al., 2016; Xia et al., 2013

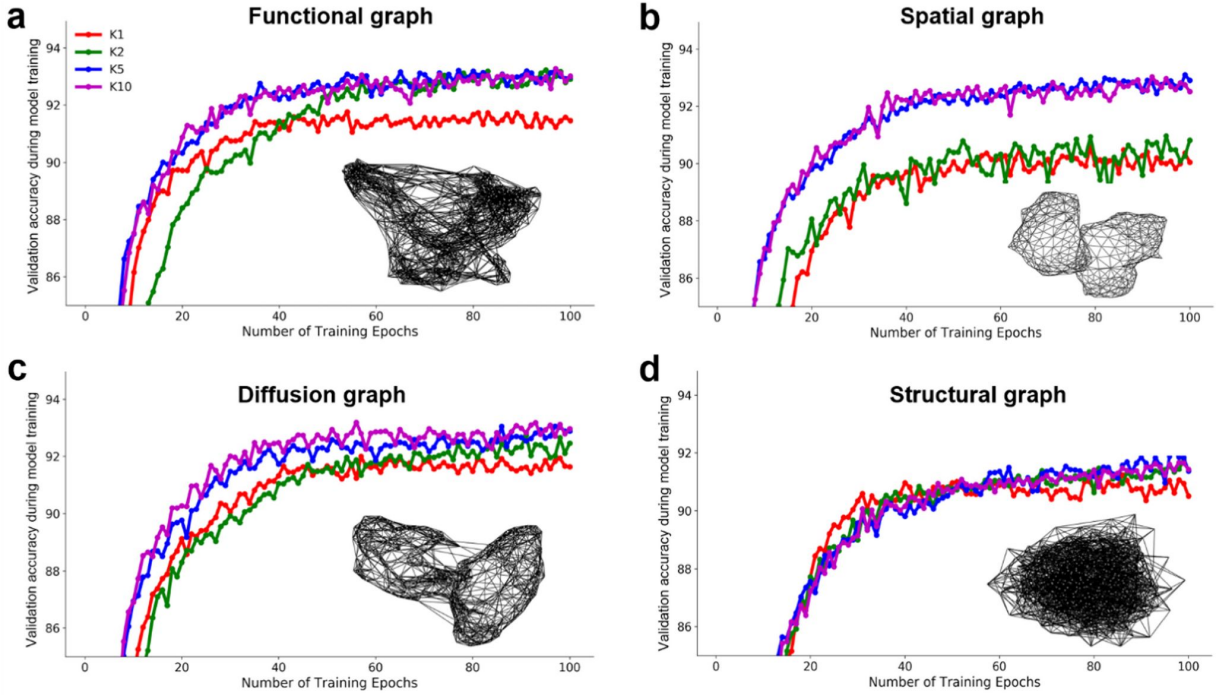
HCP group decoding performance





Zhang, Tetrel, Thirion & Bellec, Neuroimage 2021

Optimal ChebNet



[Zhang, Farrugia & Bellec, Medical Image Analysis 2022]

HCP test-retest (HCPtrt) experimental design

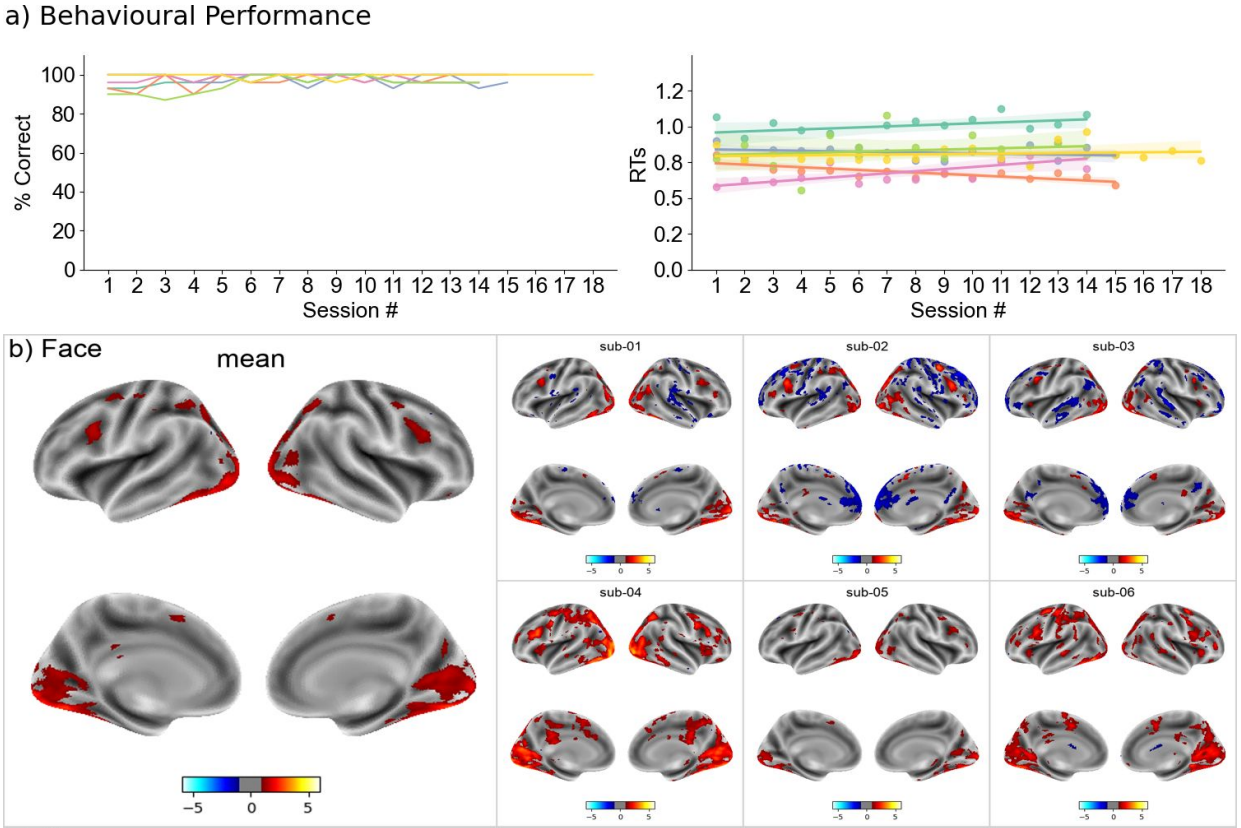
Main Objective Assess performance of decoding at the individual level using established tasks.

- 15 repetitions of HCP tasks
- TR= 1.49 s, 2mm iso-resolution
- Over 8h per subject

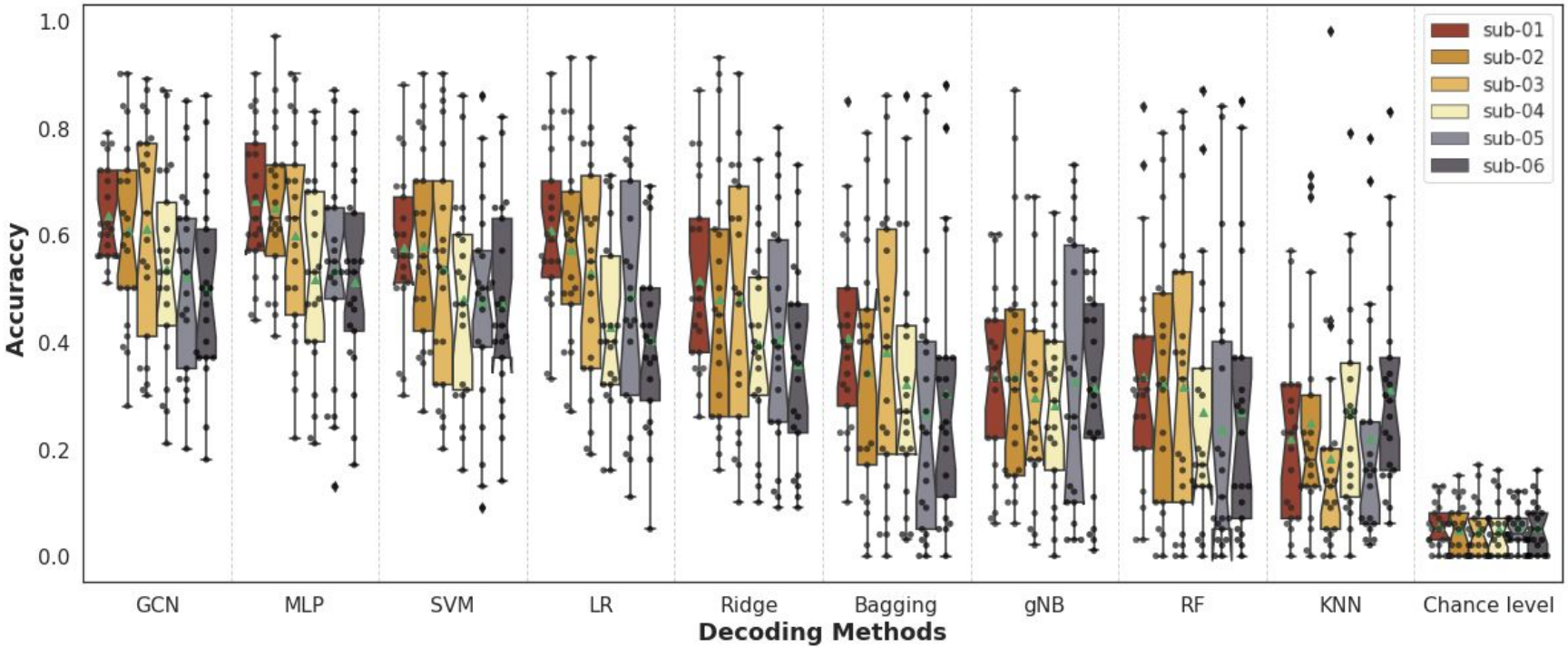
Task Domains	#Subjects	#Runs	#Volumes per run	#Conditions
Working memory	6	15	202	8
Motor	6	15	144	5
Language	6	15	159	2
Social Cognition	6	15	139	2
Relational processing	6	15	119	4
Emotion	6	15	92	2
Gambling	6	15	129	3

Individual activation maps

Example of GLM activation, working memory task, face contrast. Figure by Dr Valentina Borghesani)

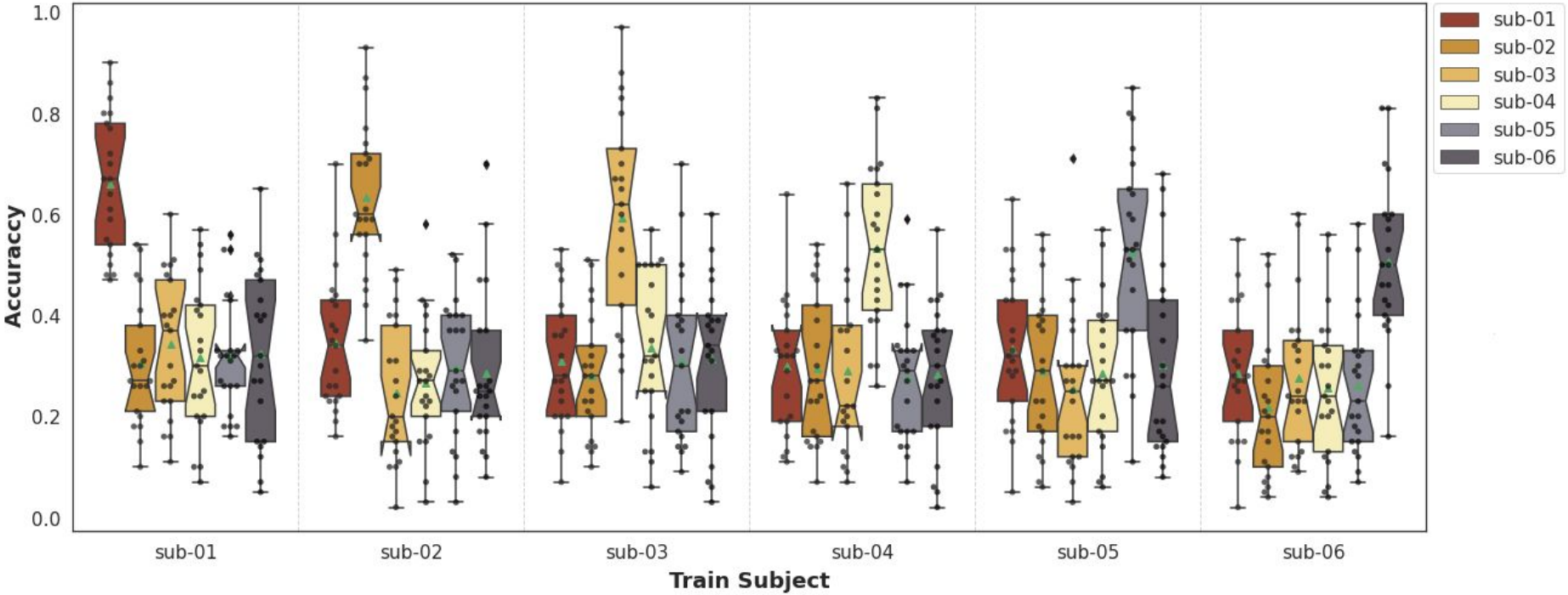


Single time point decoding performance



Rastegarnia et al., Preprint 2022

Subject specificity



Rastegarnia et al., Preprint 2022

Scaling up: group vs individual

HCP decoding across 21 domains

State of the art group model (Zhang et al., 2022)
~3.5M single time point samples
best accuracy (high-order ChebNet functional graph): **76%**

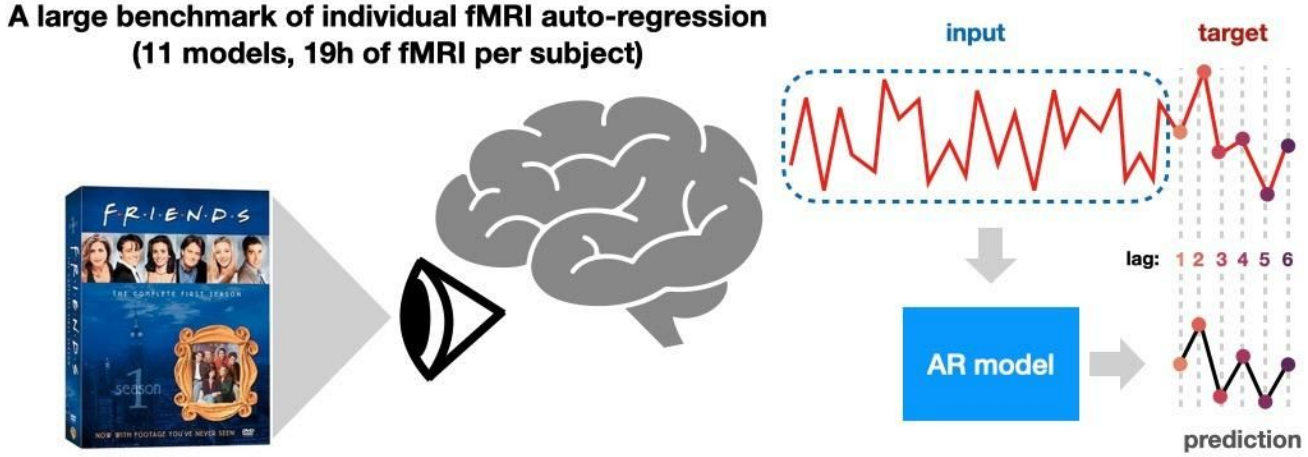
Individual models (Rastegarnia et al, 2022)
~7k single time point samples
best accuracy (multi-level perceptron): **58%-67%**

Rastegarnia et al., Preprint 2022

Scaling up auto-regression

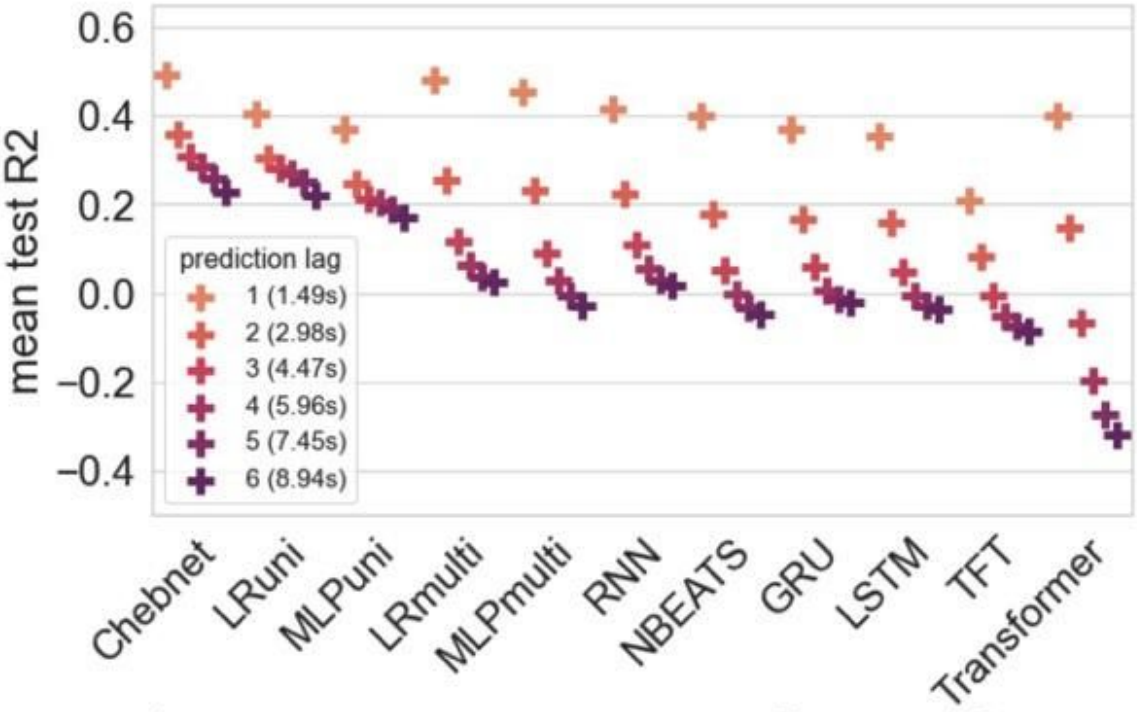
François Paugam
PhD student
DIRO, Mila, UdeM

Individual auto-regression benchmark



Paugam et al., preprint 2023

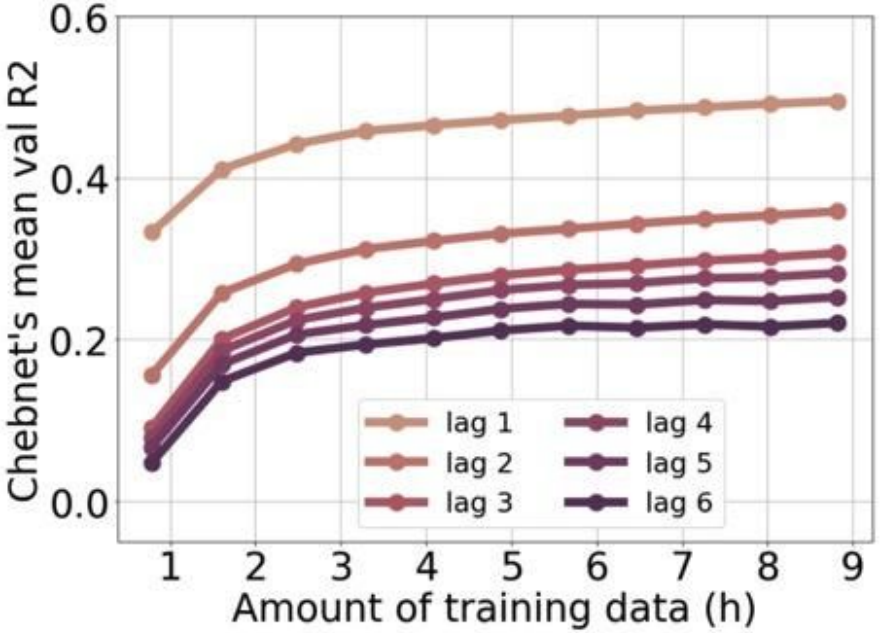
Model comparison



Graph convolutional models (Chebnets) explain the most variance

Paugam et al., preprint 2023

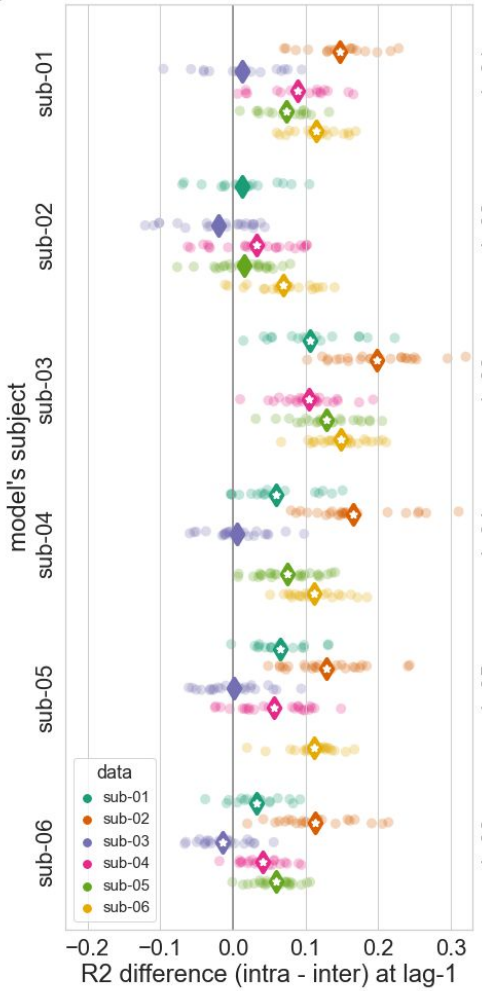
Model scaling



The performance of Chebnets scale with the amount of training data, without ceiling

Paugam et al., preprint 2023

Subject specificity



Paugam et al., preprint 2023

Conclusions

1. CNeuroMod is an open dataset of **dense individual data**, including neuroimaging, physiological and behavioral activity.

2. **Individual subject design** enables training of highly subject-specific models, with competitive performance with large group samples.

3. Individual models benefit from **data scaling** up to 10 hours, and likely much more for complex multimodal models.

Resources like Courtois NeuroMod may result both in novel computational models of brain representations, as well as AI agents with improved generalization abilities.