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A theory-driven approach to data analysis: practical applications

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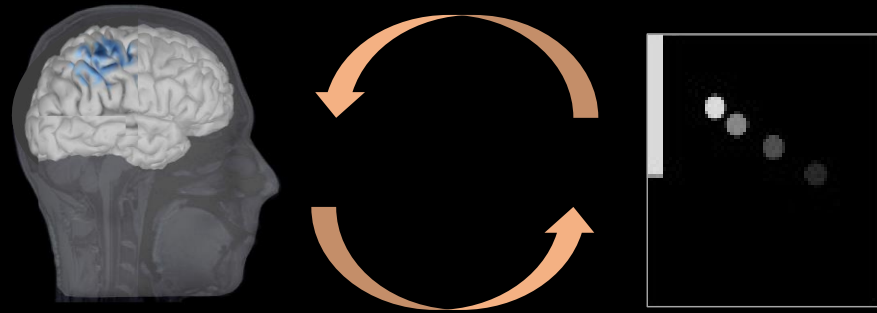
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A theory-driven approach to data analysis:
practical applications



Marie-Constance Corsi,

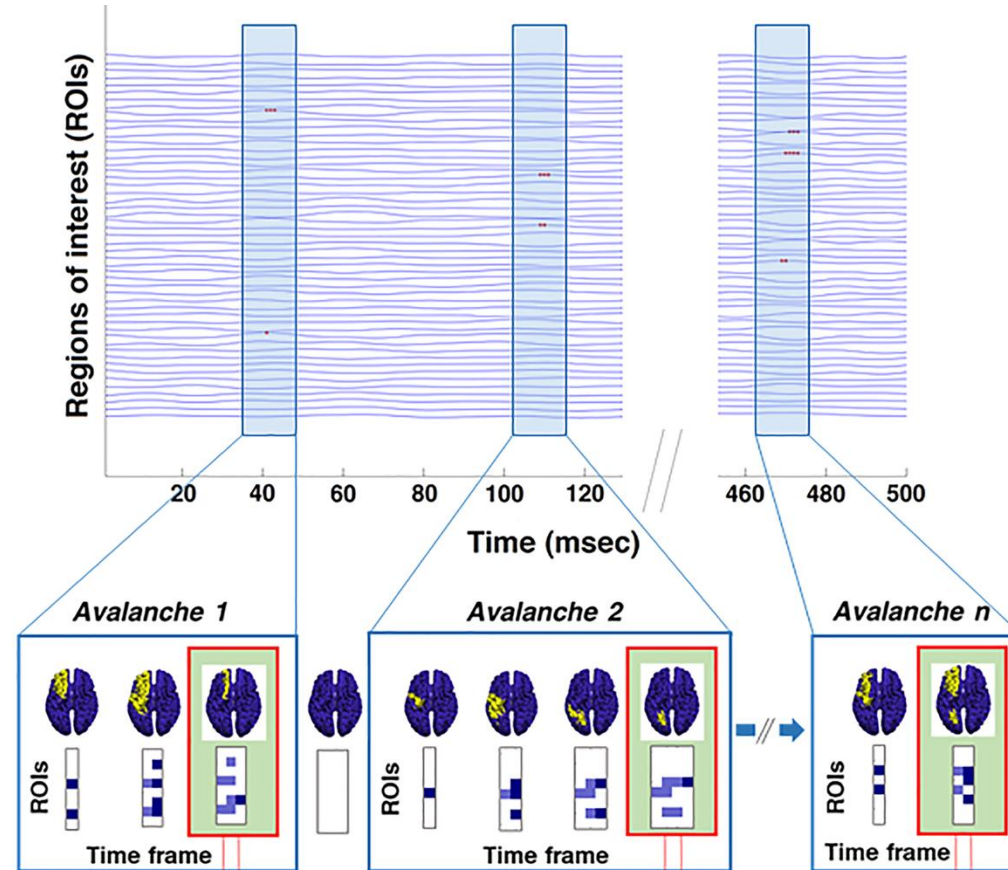
Inria research scientist

NERV team, Paris Brain Institute



Capturing fast, non-linear brain dynamics

Neuronal avalanches: bursts of enhanced activity observed across neuroimaging modalities

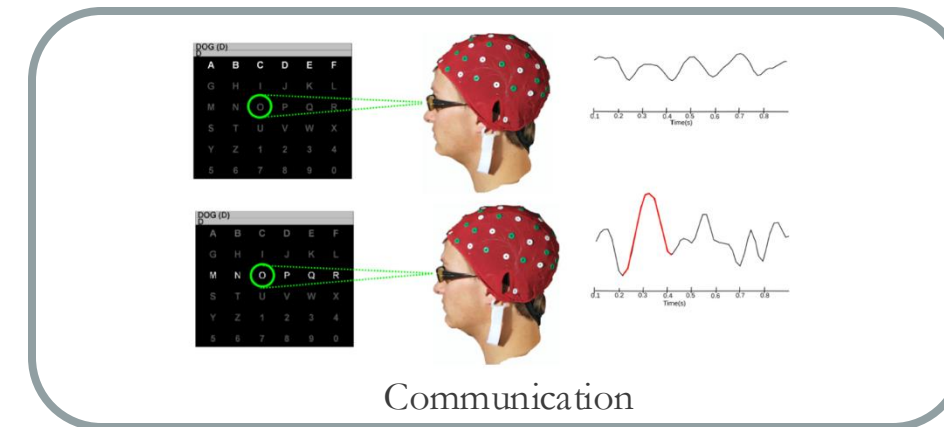
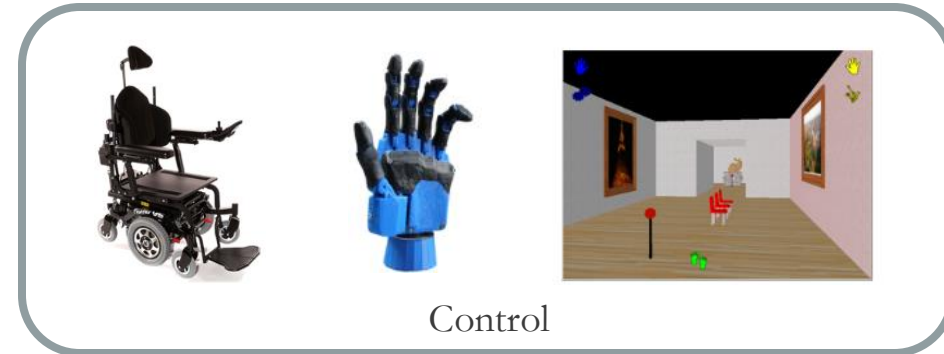
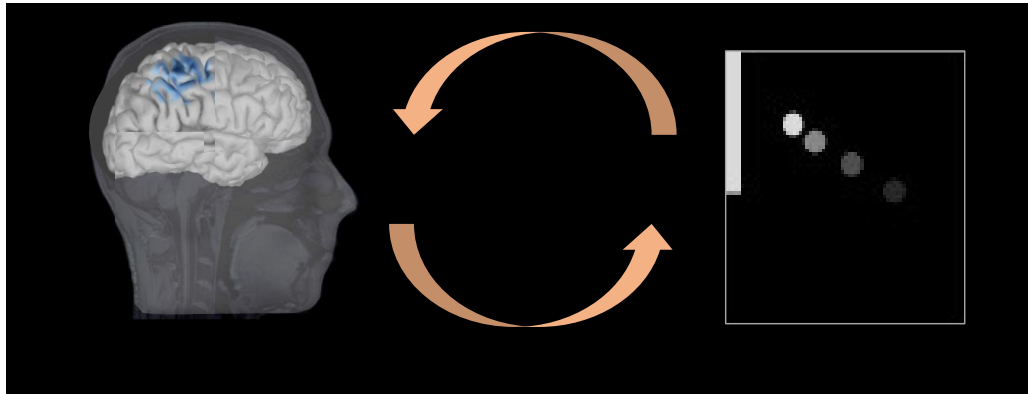


Adapted from [Polverino et al, Neurology, 2022]

Hypothesis:

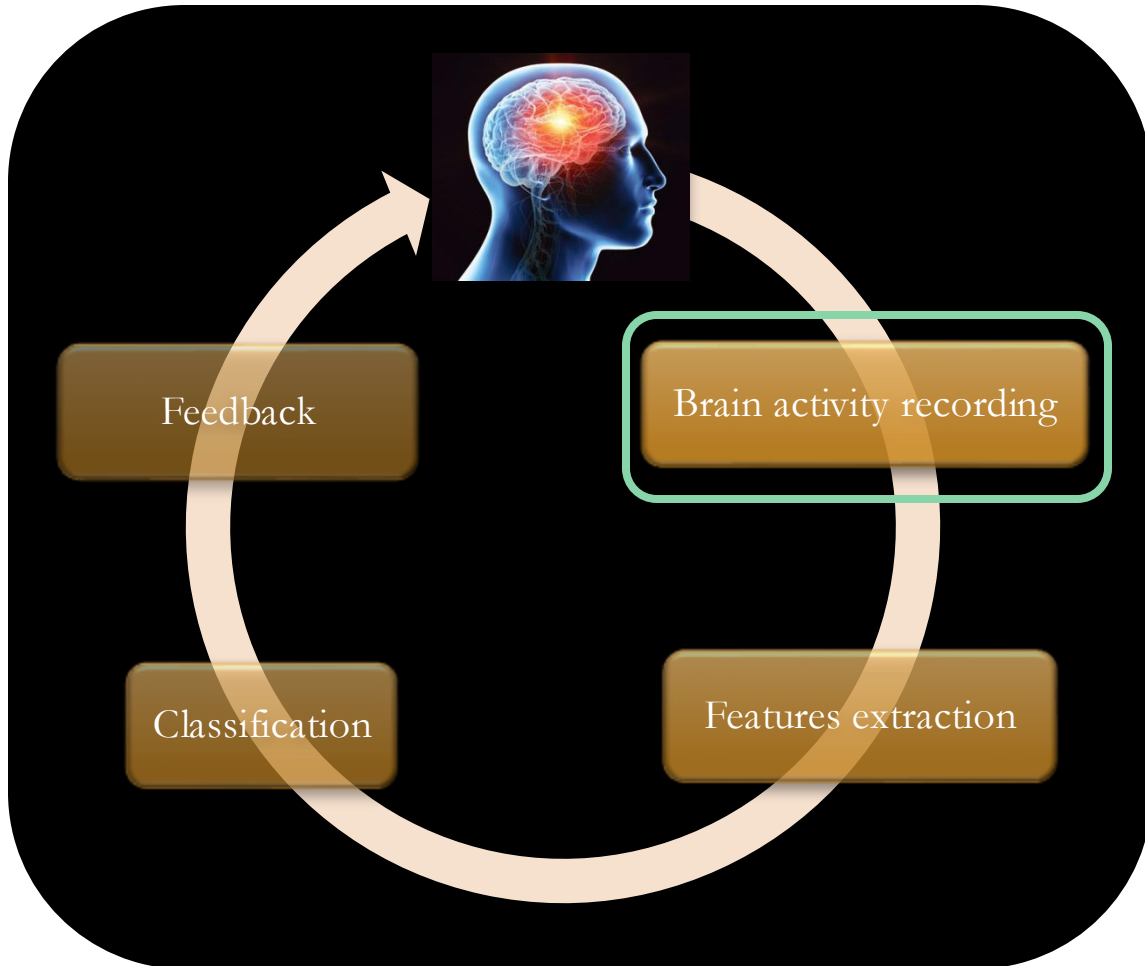
The neuronal avalanches could spread differently according to the task/populations & more!

What is a Brain-Computer Interface (BCI)?



Adapted from (Lotte et al, 2015)

Behind the magic...

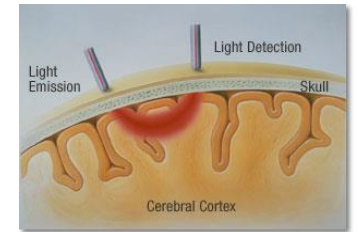


Non-invasive tools

EEG



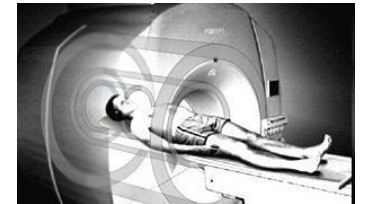
NIRS



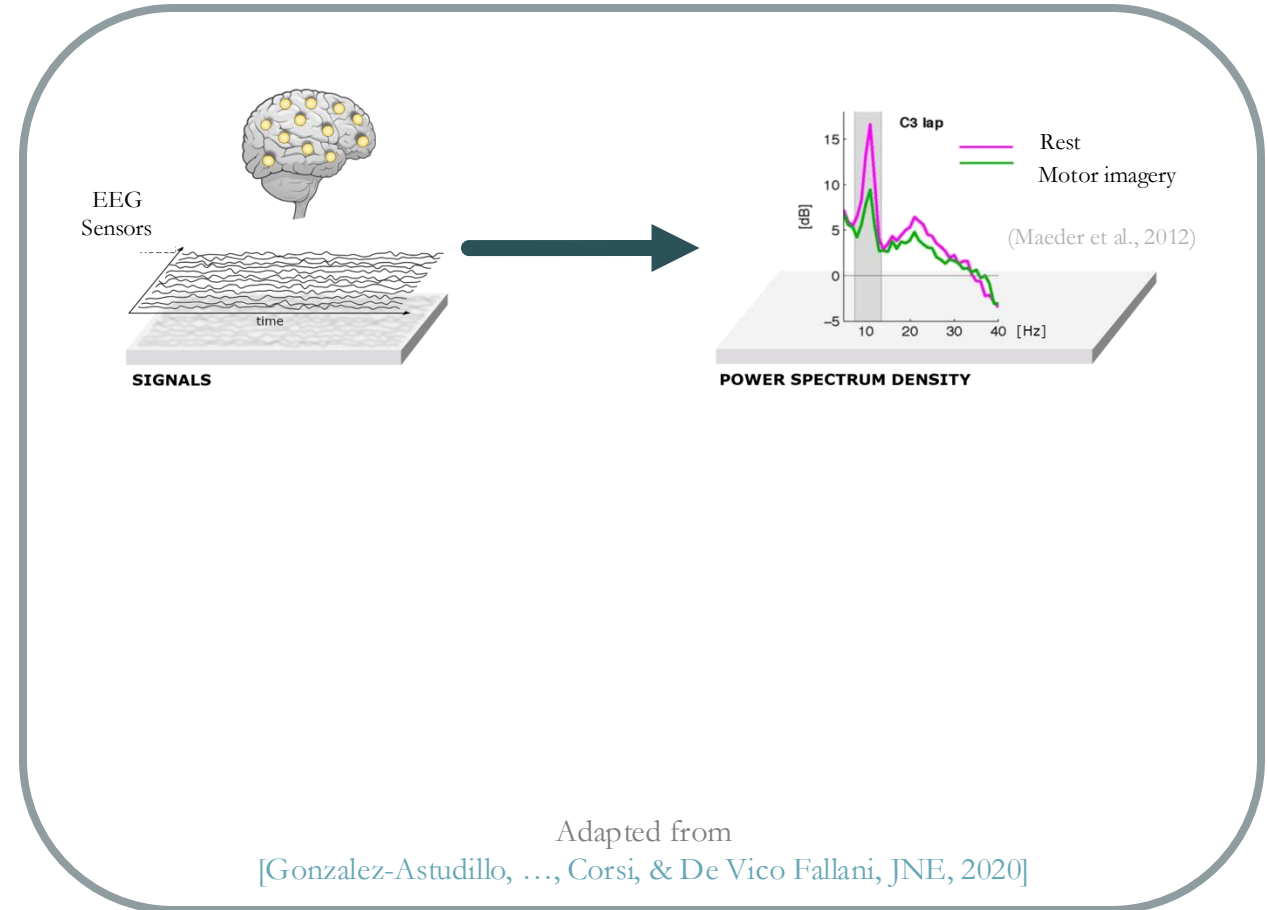
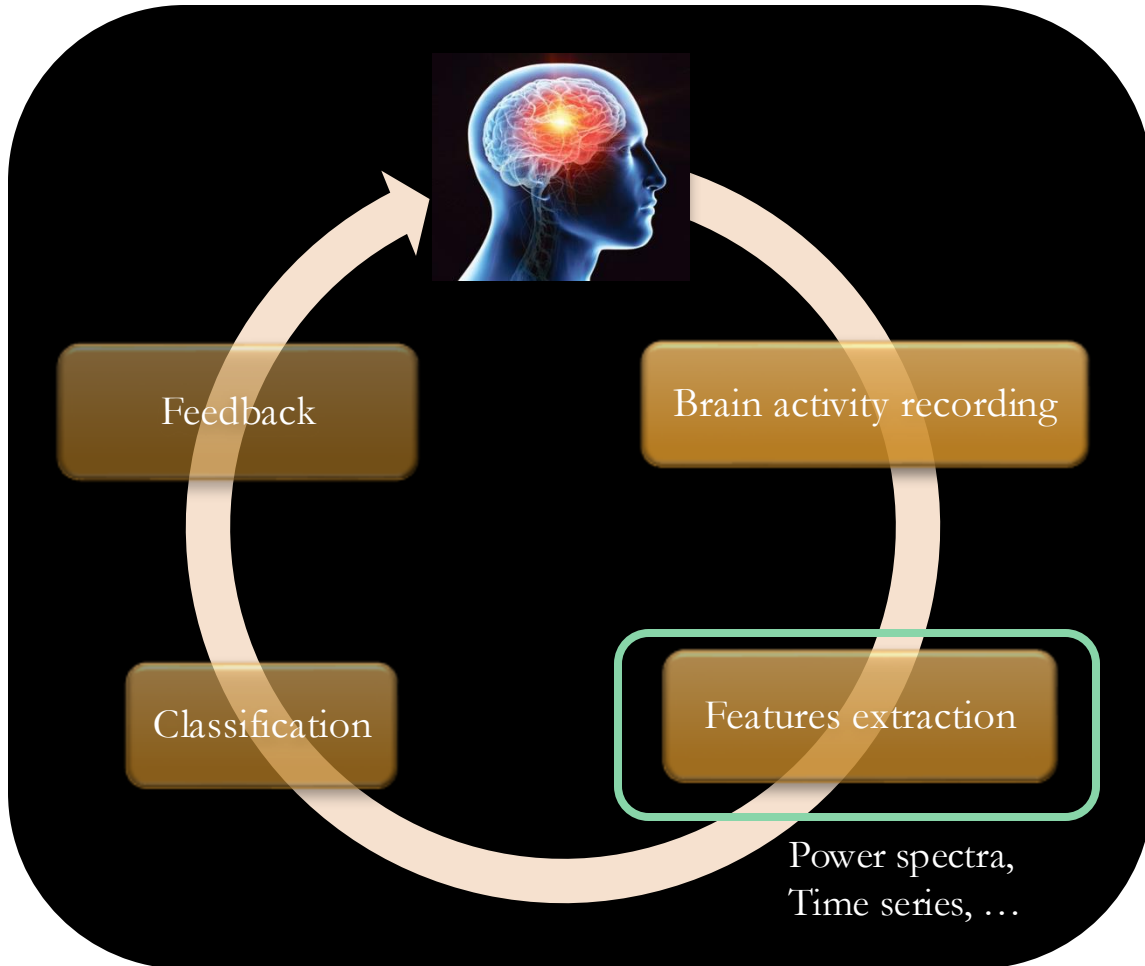
MEG



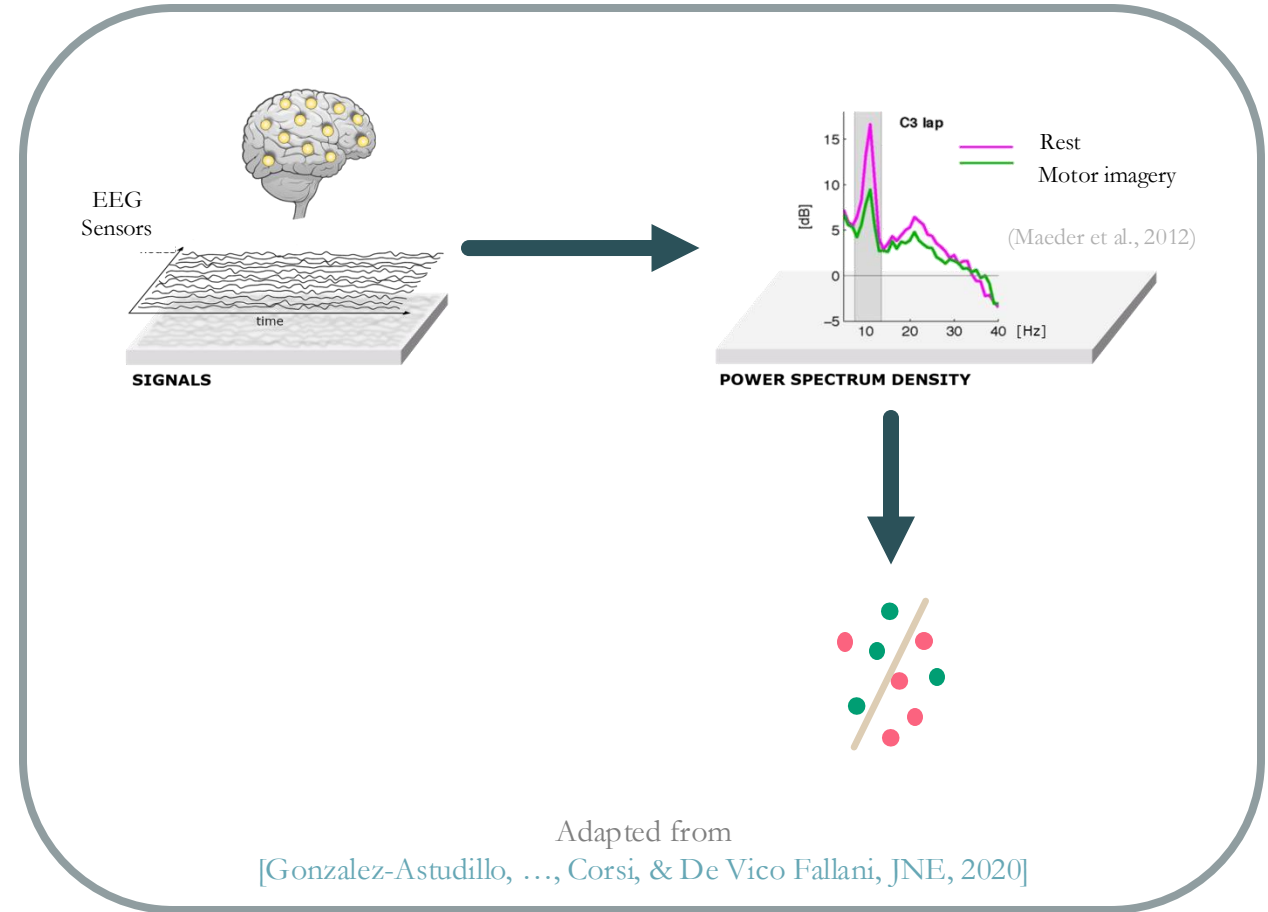
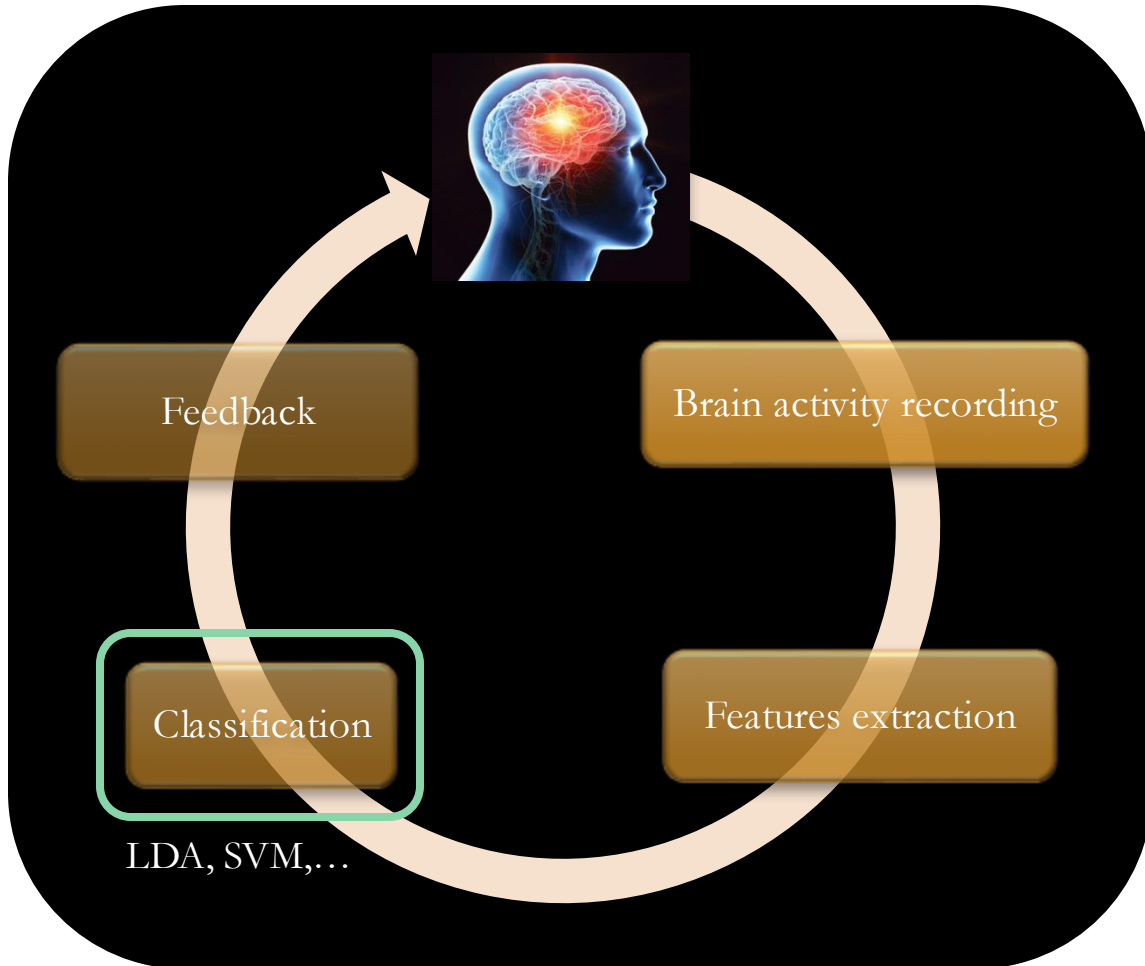
fMRI



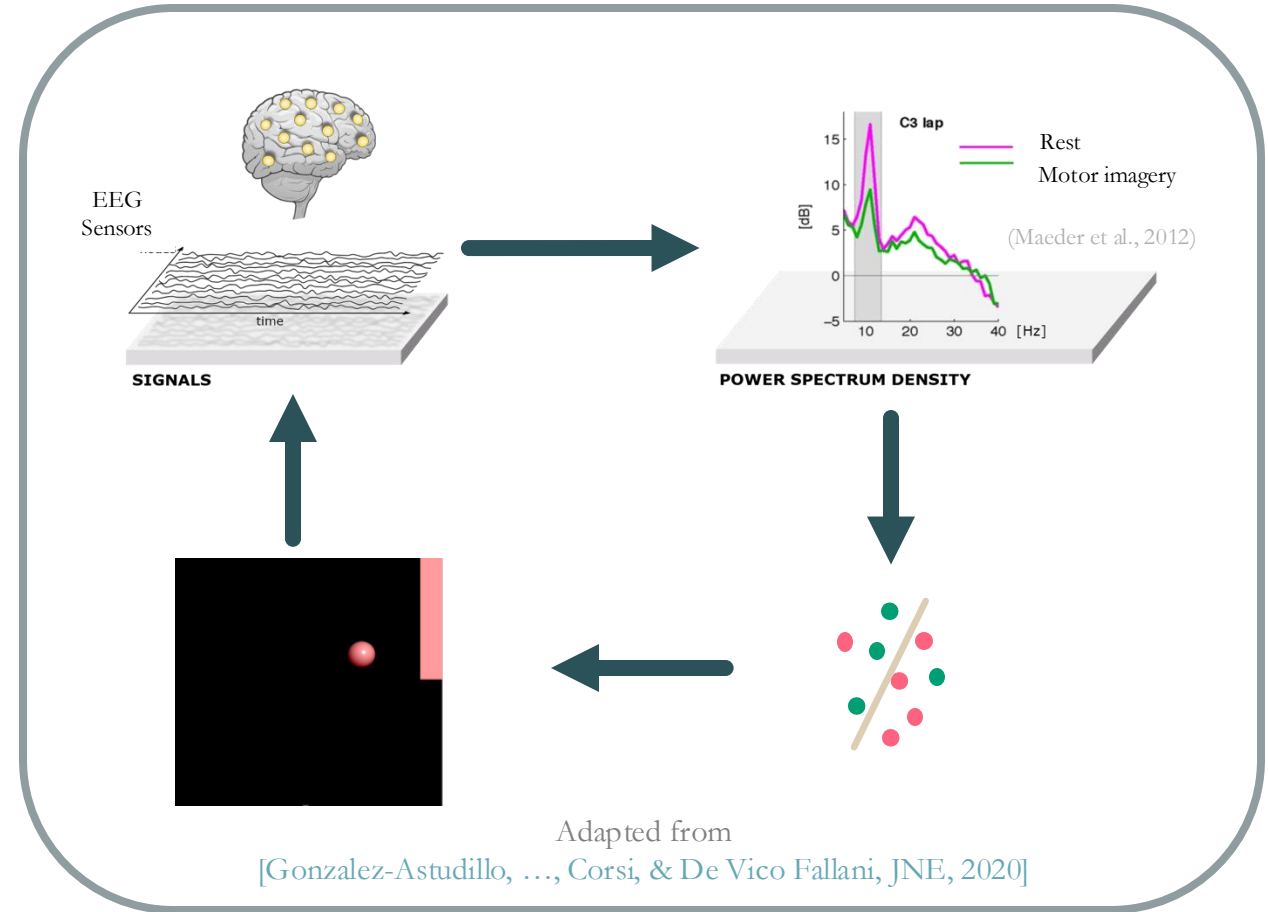
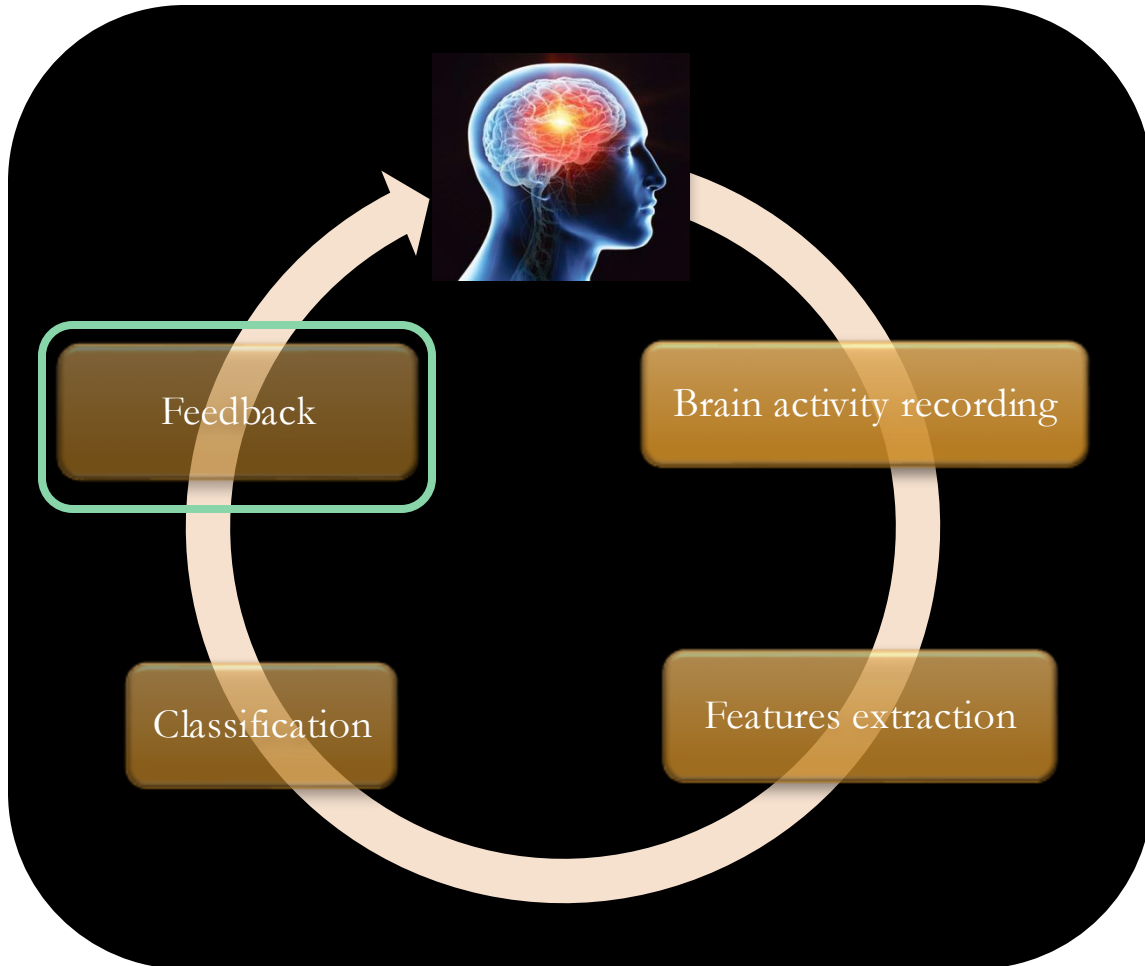
Behind the magic...

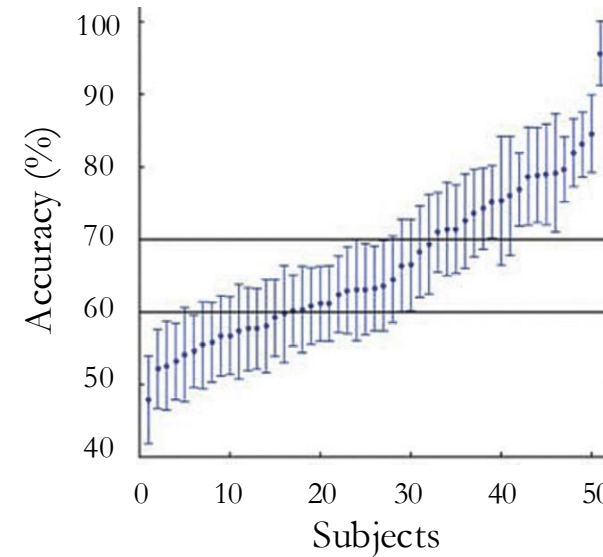
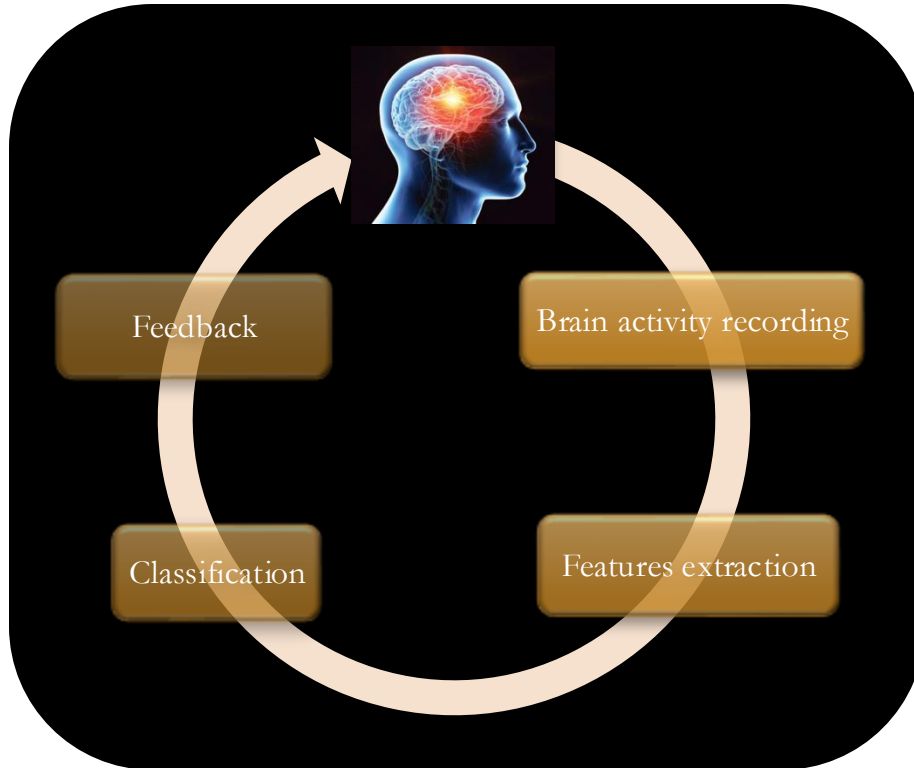


Behind the magic...



Behind the magic...





Adapted from (Ahn & Jun, 2015)

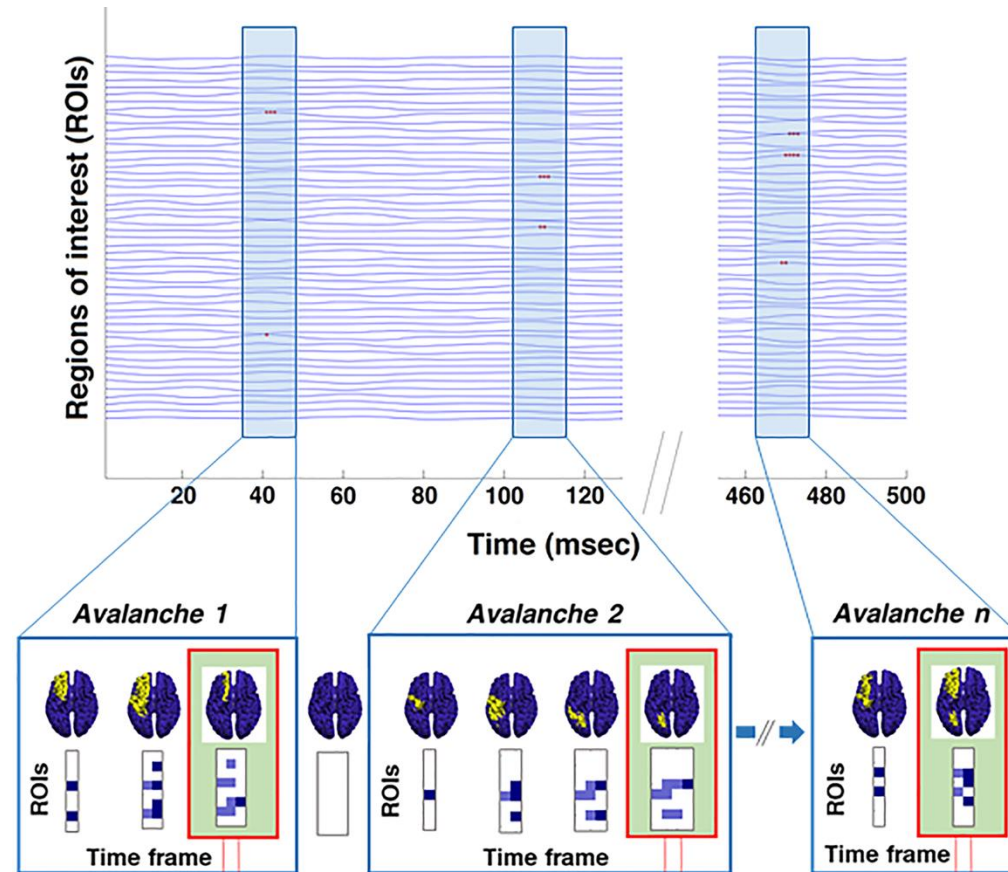
Problem:

Current BCIs fail to detect the mental intentions in ~30% of users – **BCI inefficiency** (Thompson, 2018)

⇒ Rely on local measurements of the brain activity

Capturing fast, non-linear brain dynamics

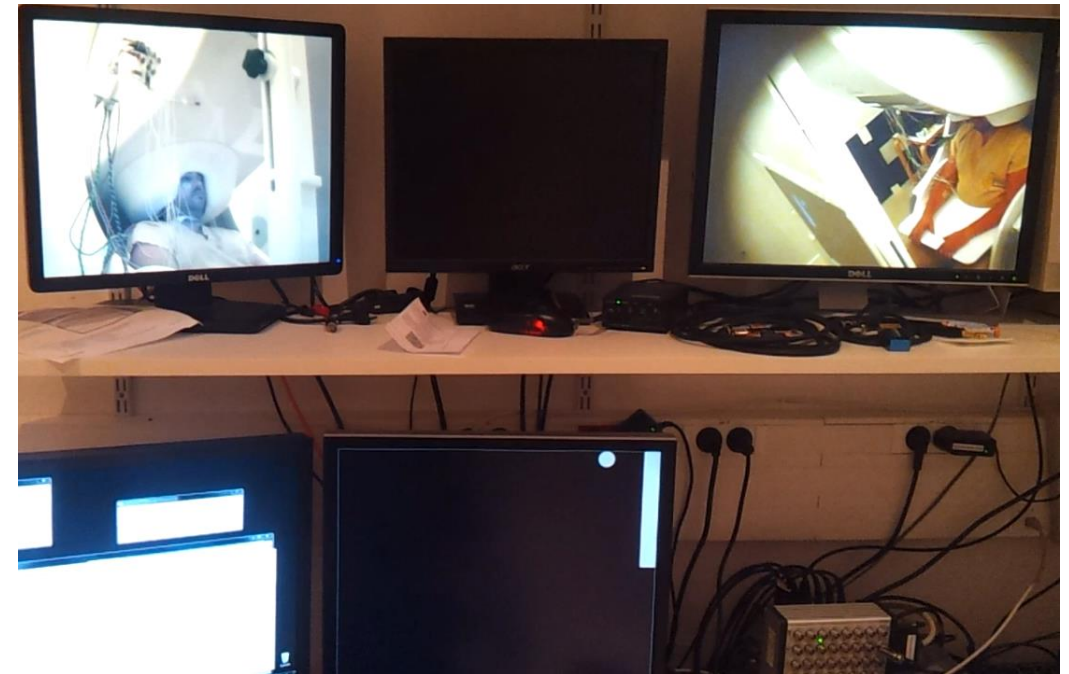
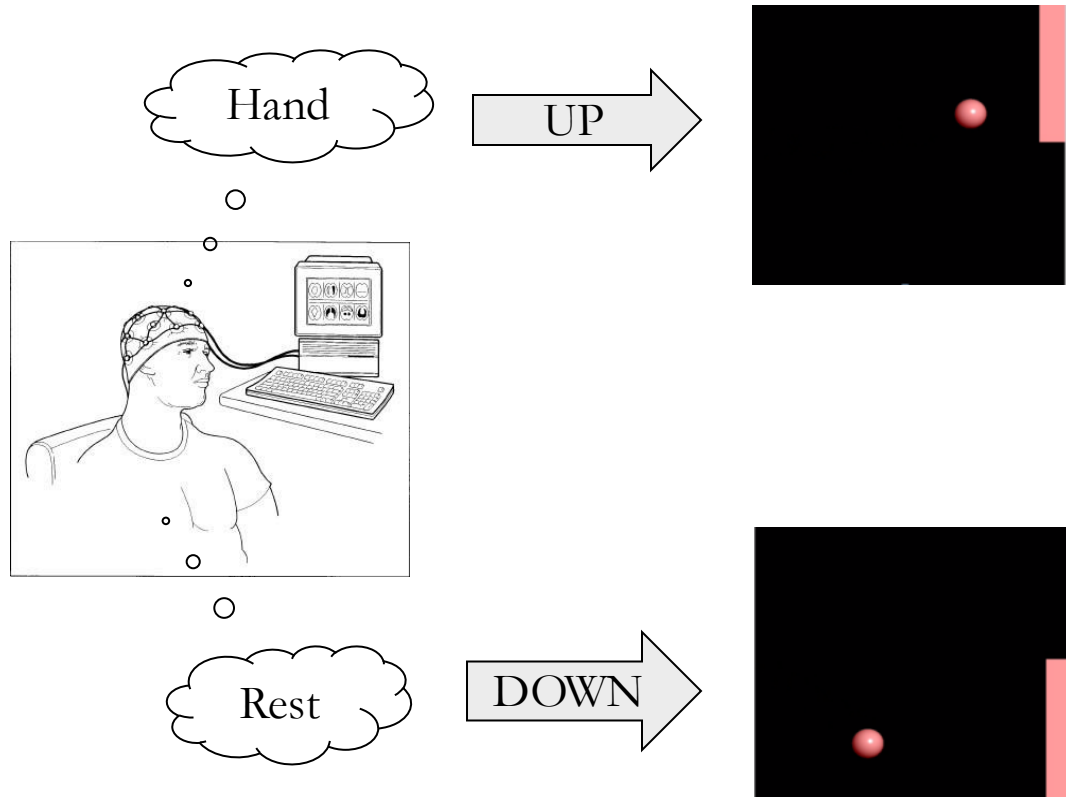
Neuronal avalanches: bursts of enhanced activity observed across neuroimaging modalities



Adapted from [Polverino et al, Neurology, 2022]

Hypothesis:

The neuronal avalanches could spread differently according to the task & provide original markers of BCI performance.

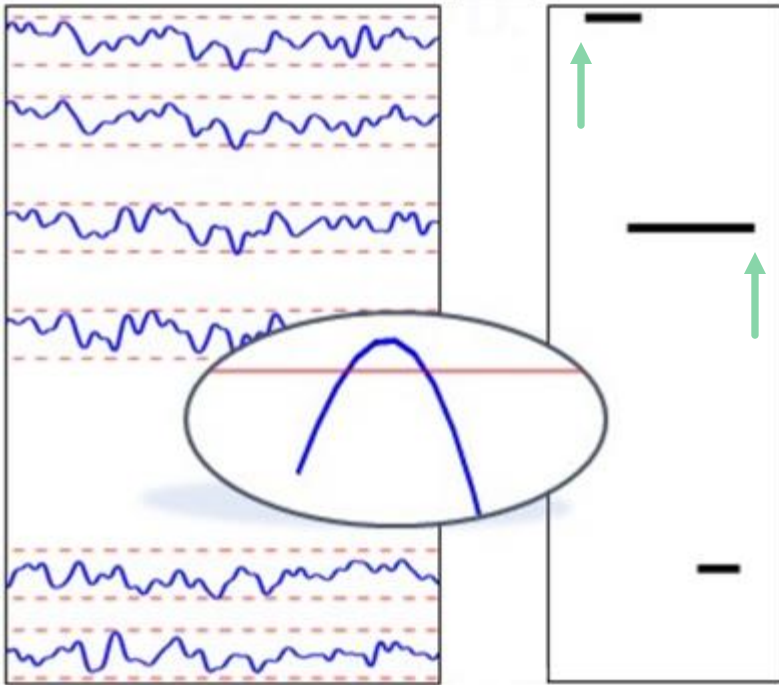


For a complete description of the protocol and the dataset, please refer to [Corsi et al, NeuroImage, 2020]

Objective:

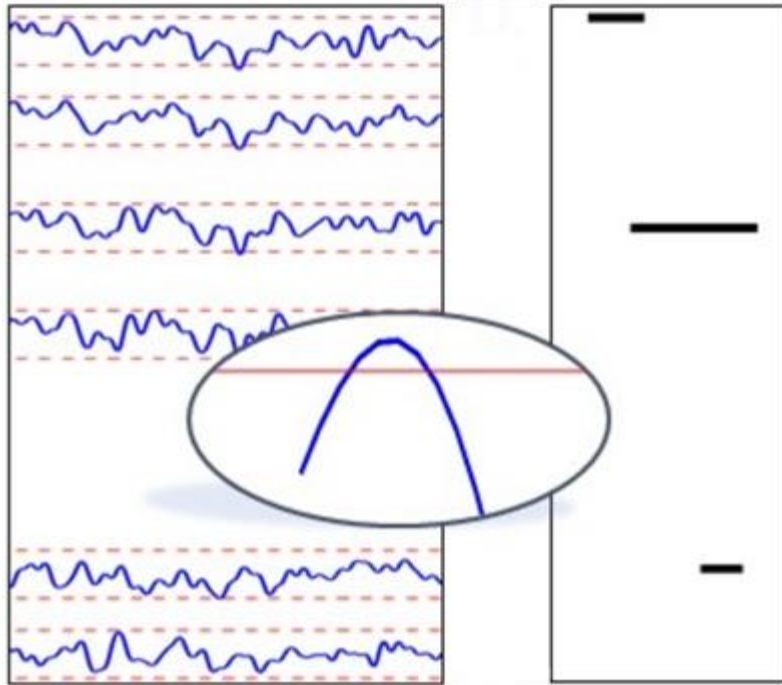
Tracking the dynamical features related to motor imagery as compared to rest

Differences in transition probabilities discriminate mental states

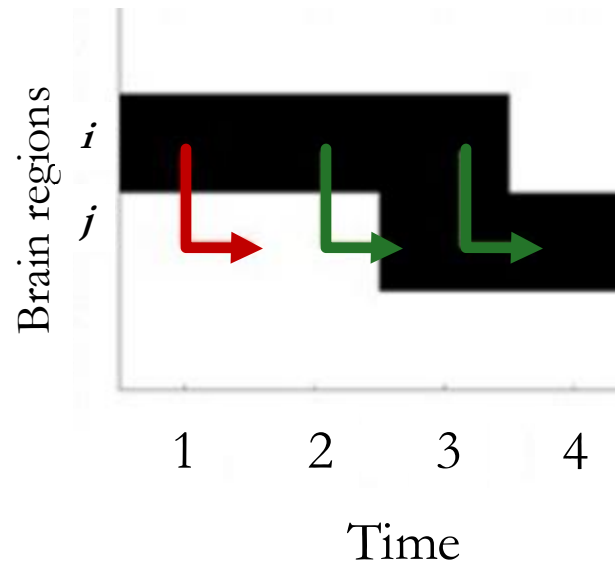


Adapted from [Sorrentino et al, eLife, 2021]

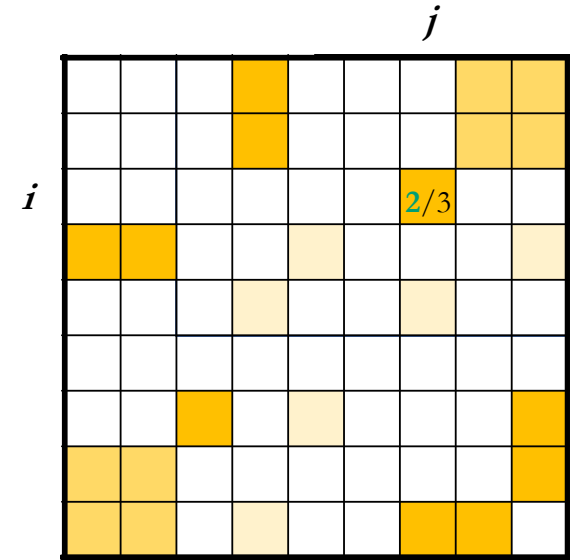




Neuronal avalanche



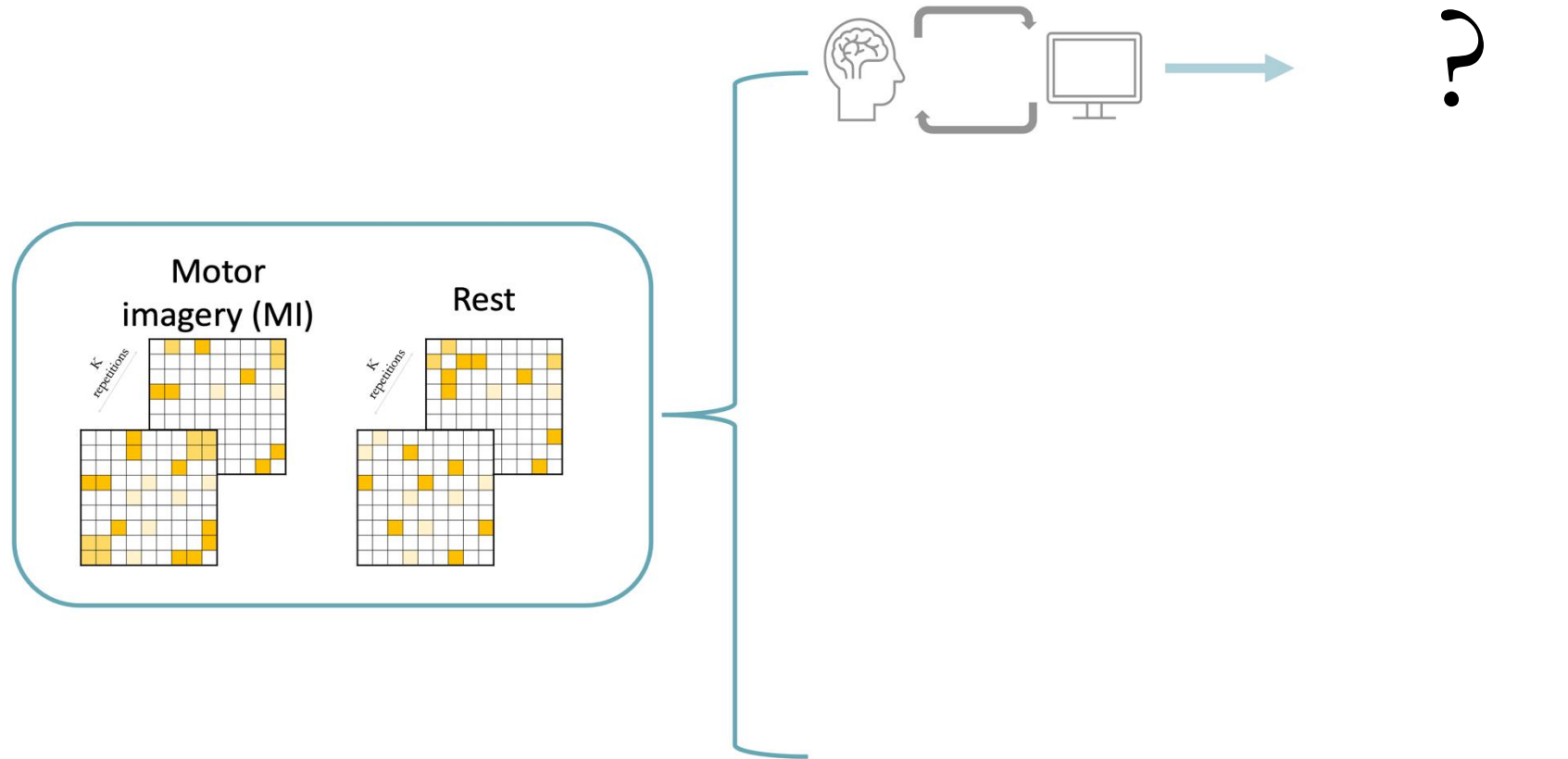
Avalanche Transition Matrix (ATM)



Adapted from [Sorrentino et al, eLife, 2021]



Differences in transition probabilities discriminate mental states

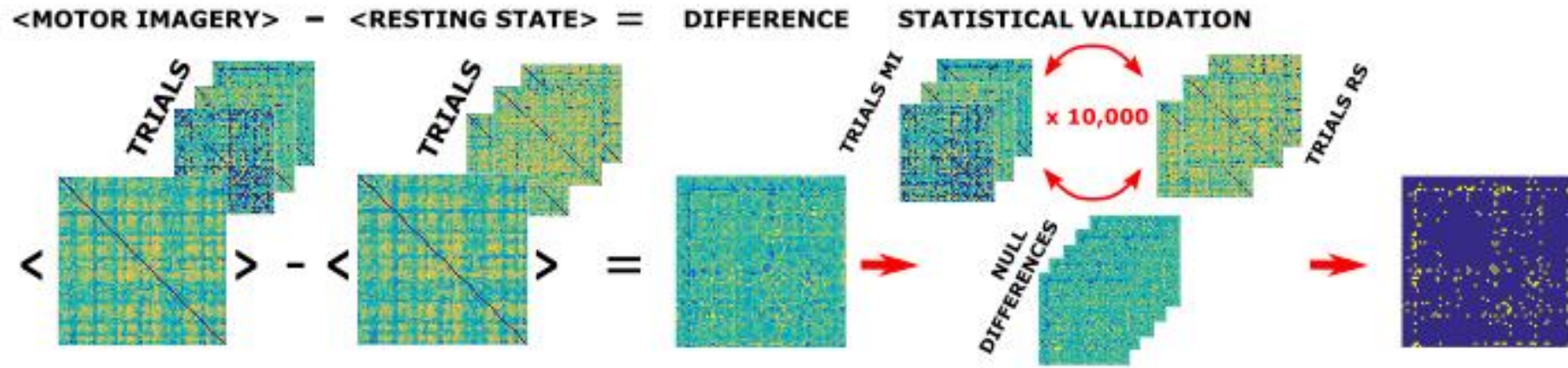


[Corsi*, Sorrentino* et al, iScience, 2024]

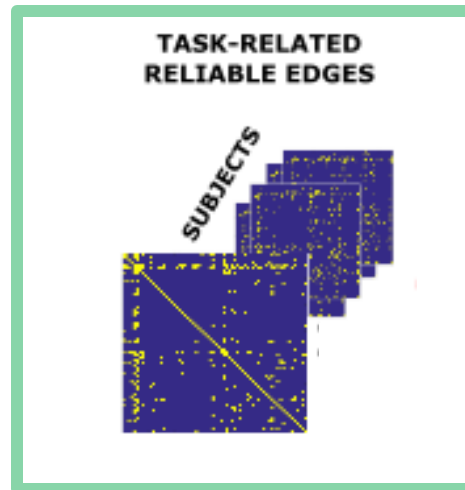


Differences in transition probabilities discriminate mental states

Subject-level



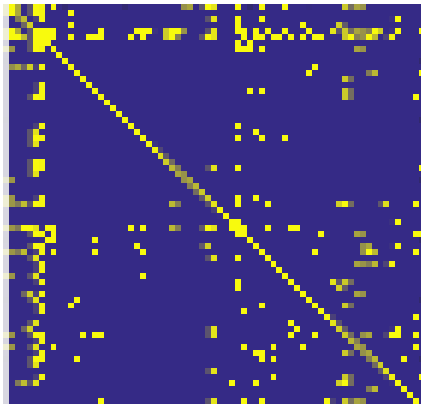
Group-level



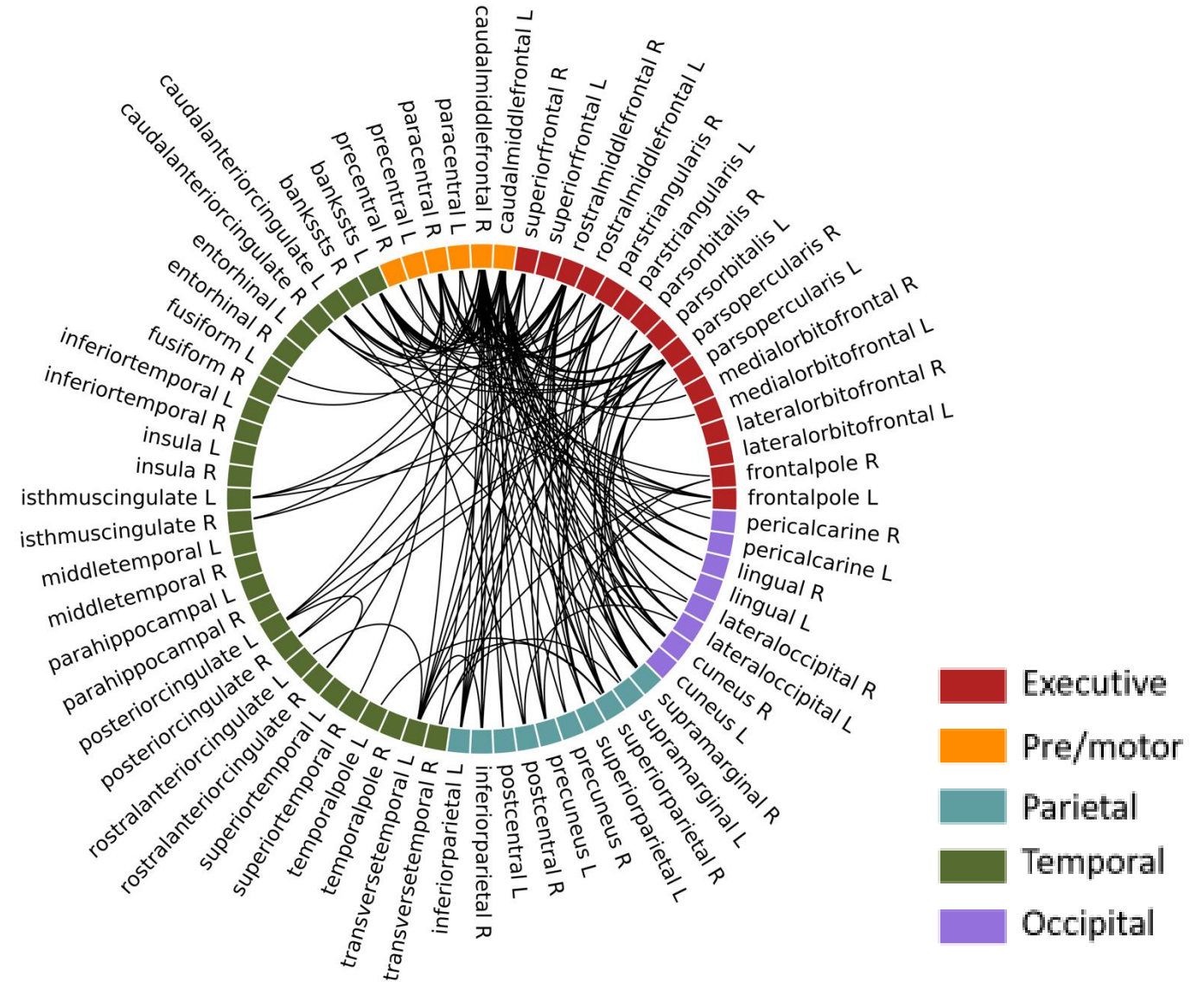
[Corsi*, Sorrentino* et al, iScience, 2024]



Differences in transition probabilities discriminate mental states

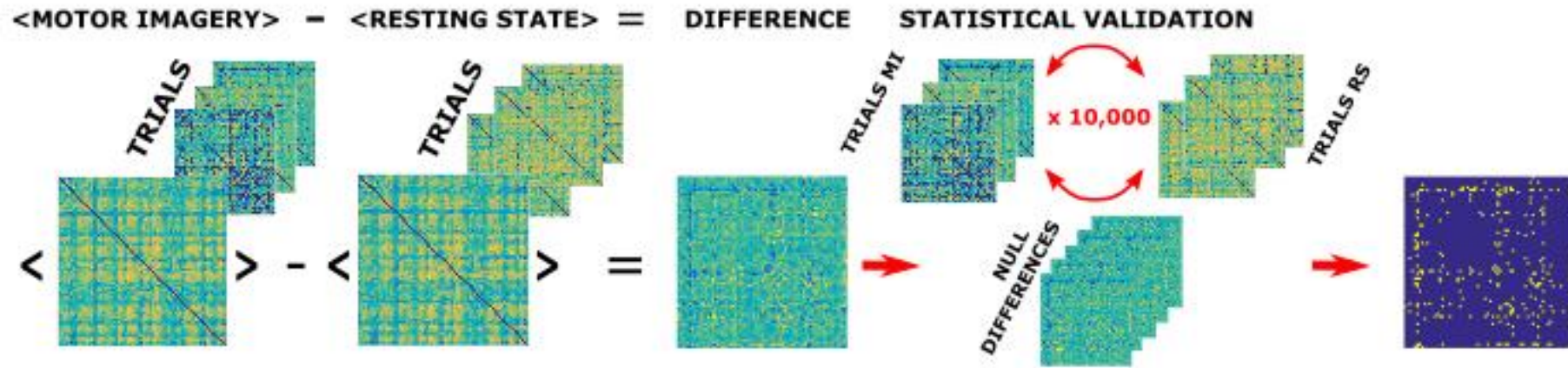


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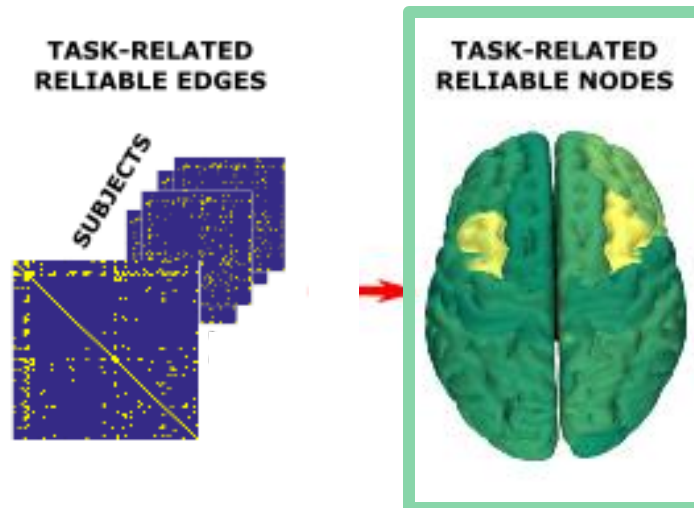


Task-related differences are in edges hinging on pre/motor areas (in most subjects)

Subject-level



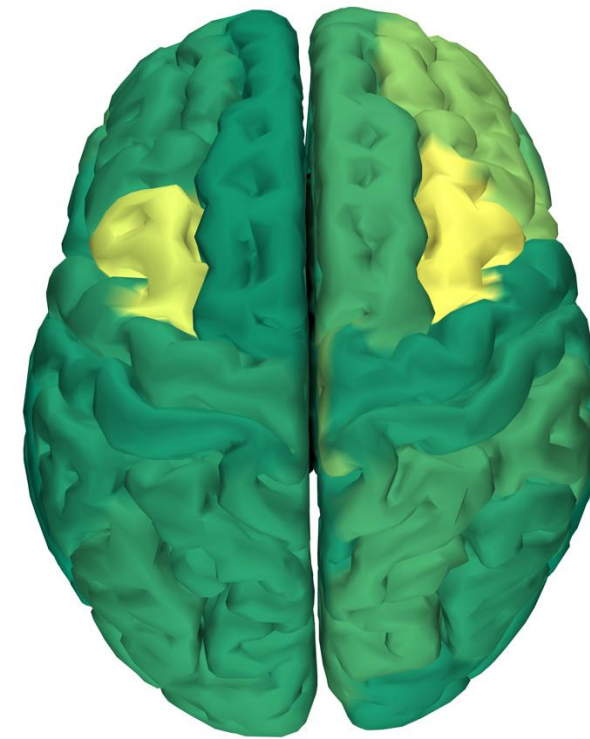
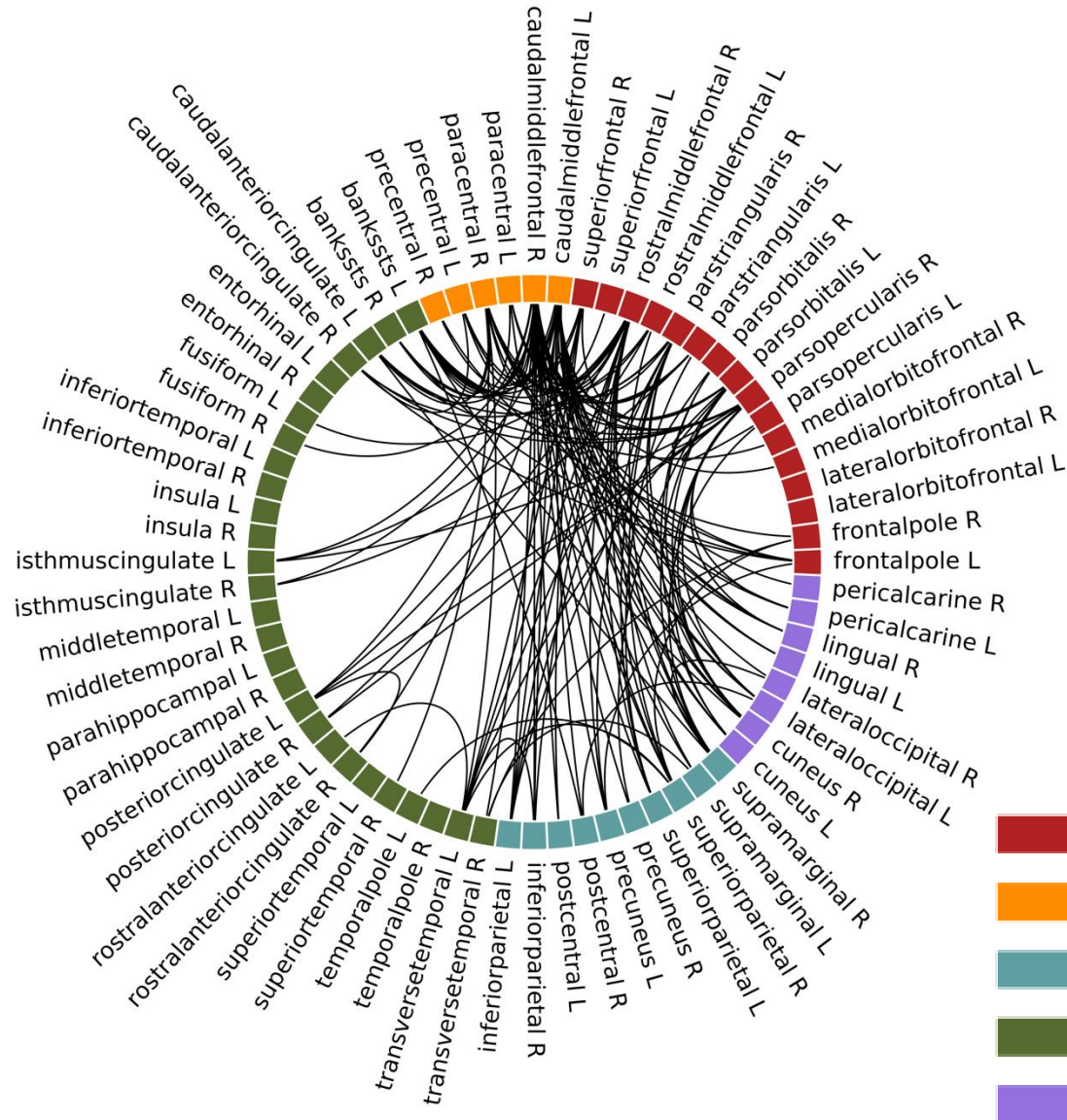
Group-level



[Corsi*, Sorrentino* et al, iScience, 2024]



Differences in transition probabilities discriminate mental states

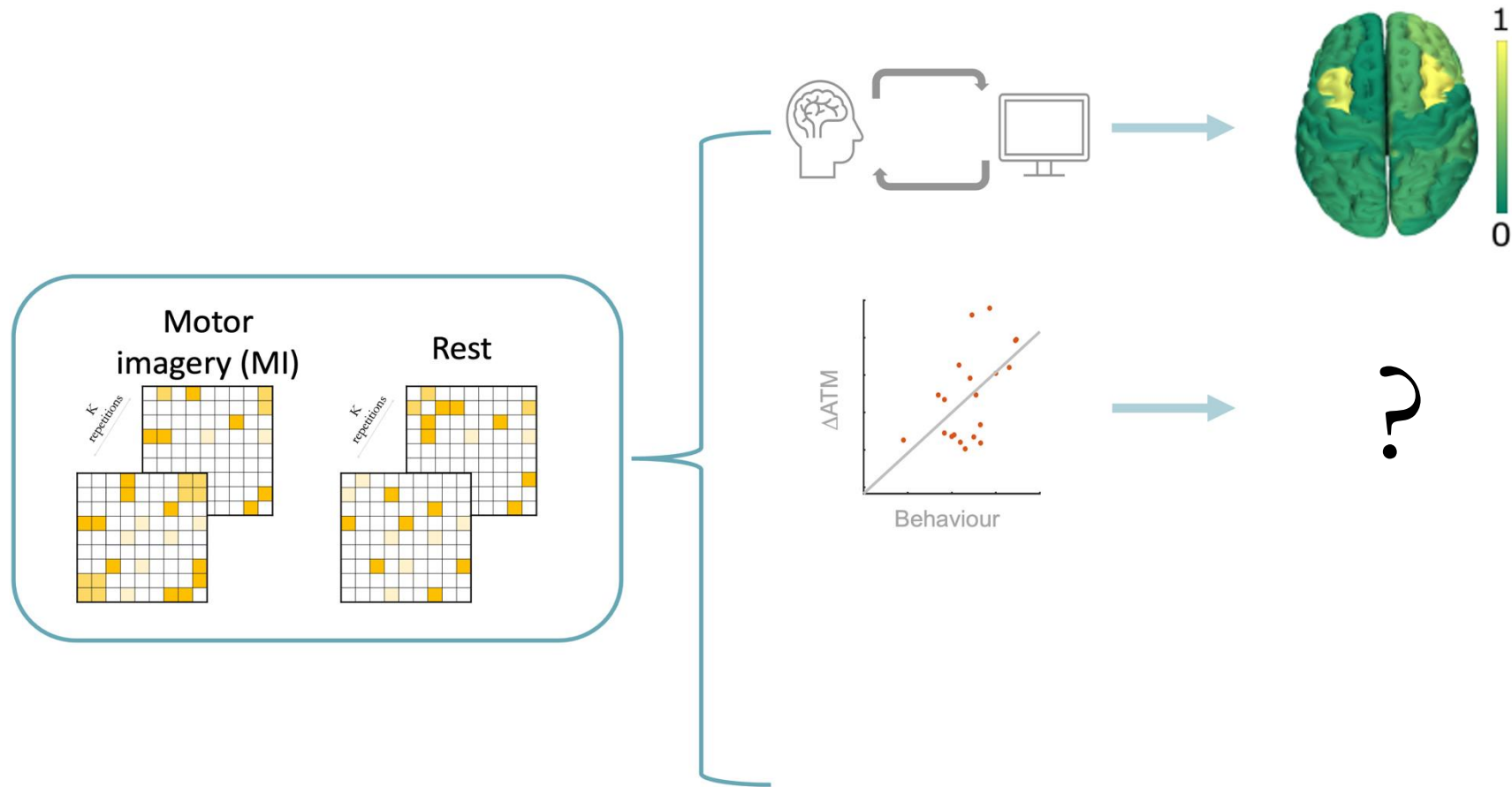


Reliable differences across subjects – Node-level

[Corsi*, Sorrentino* et al, iScience, 2024]



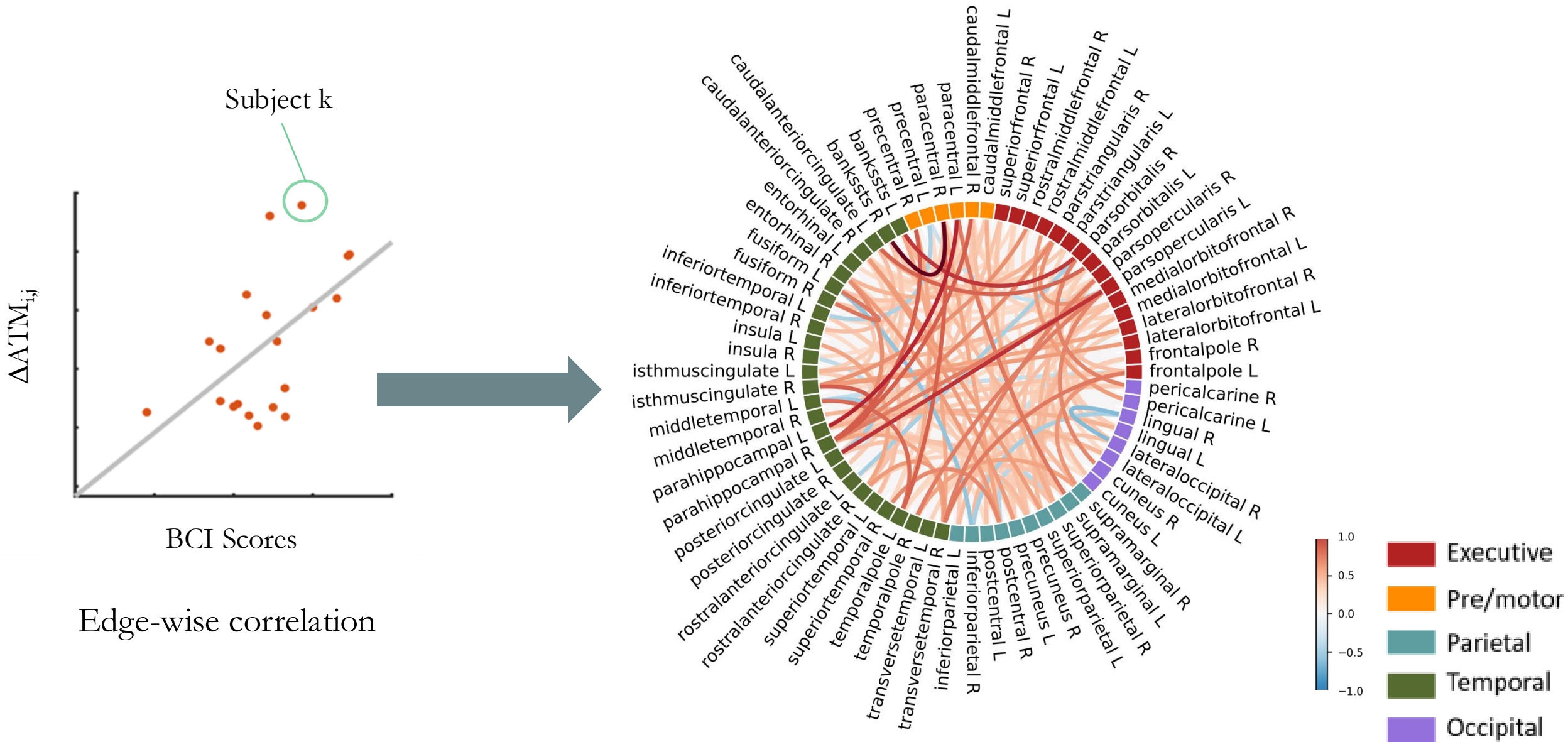
Differences in transition probabilities relate to BCI scores

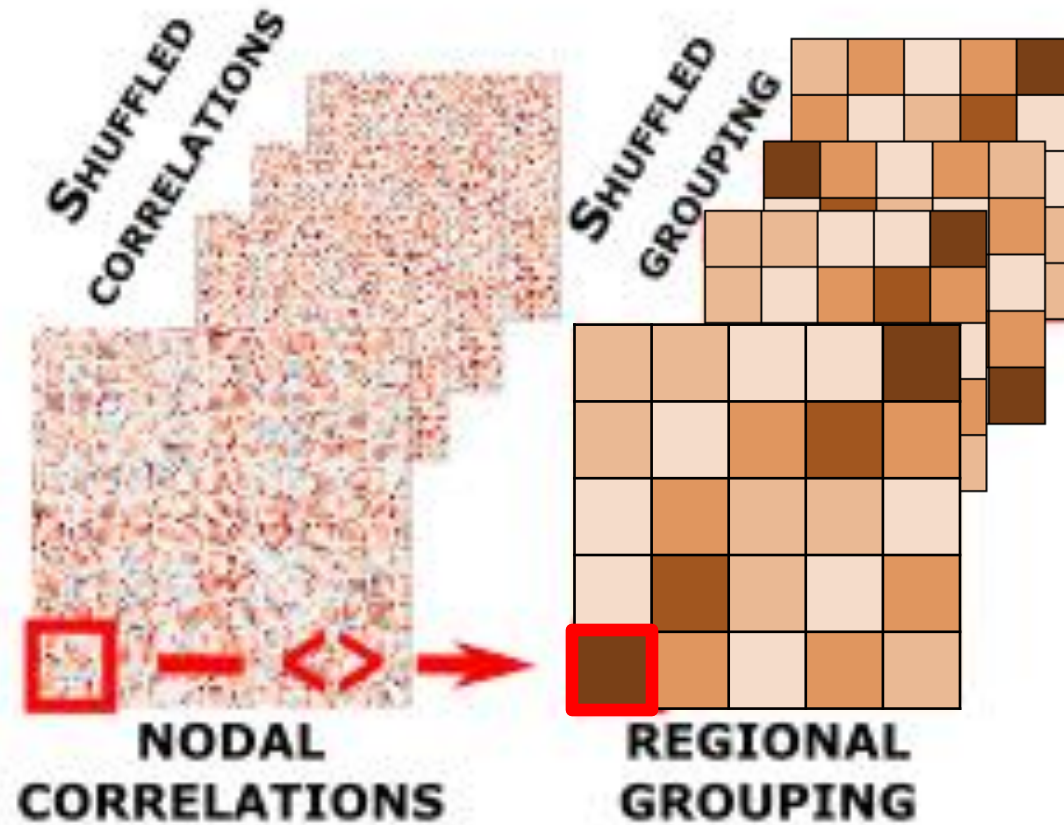


[Corsi*, Sorrentino* et al, iScience, 2024]



Differences in transition probabilities relate to BCI scores



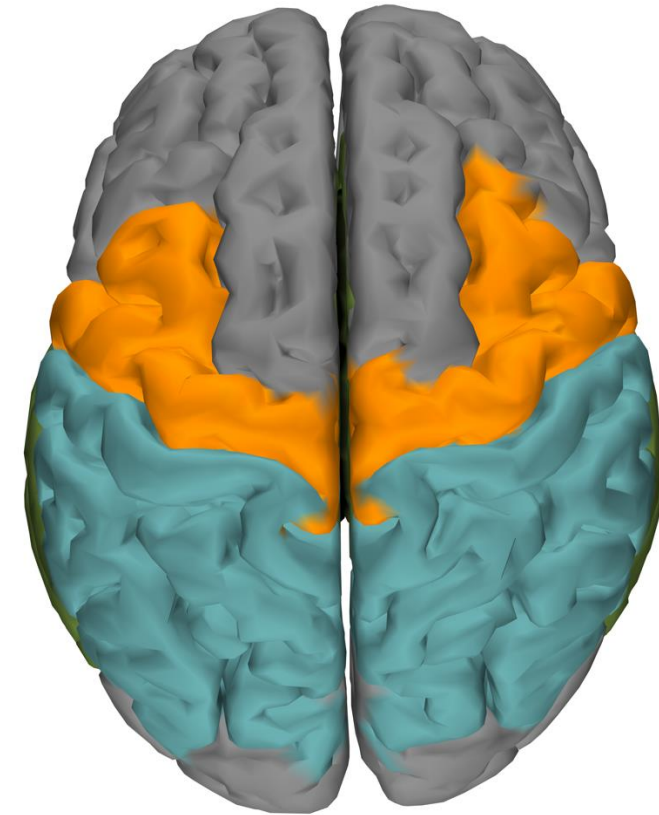
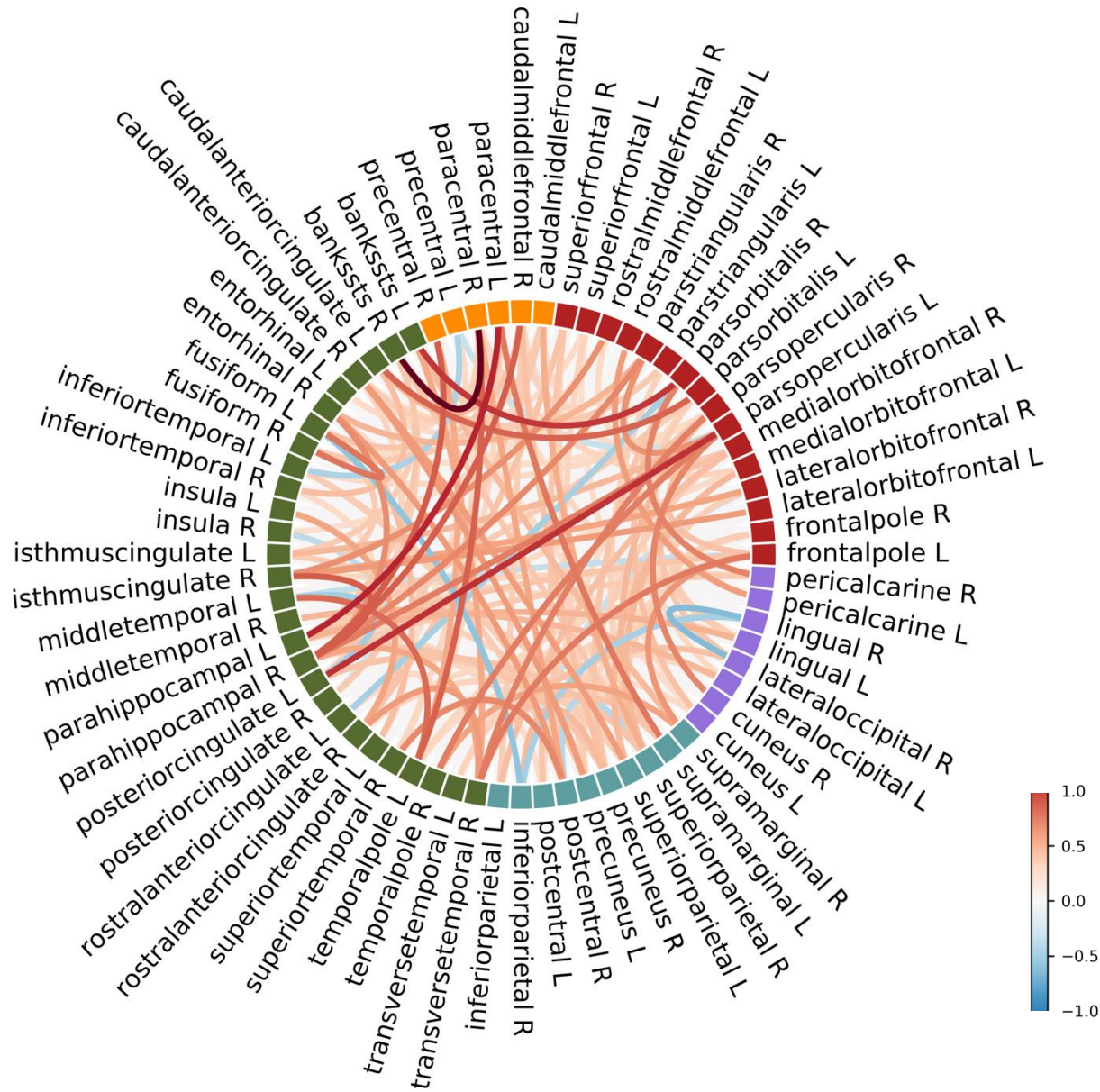


CORRELATED FUNCTIONAL GROUPS

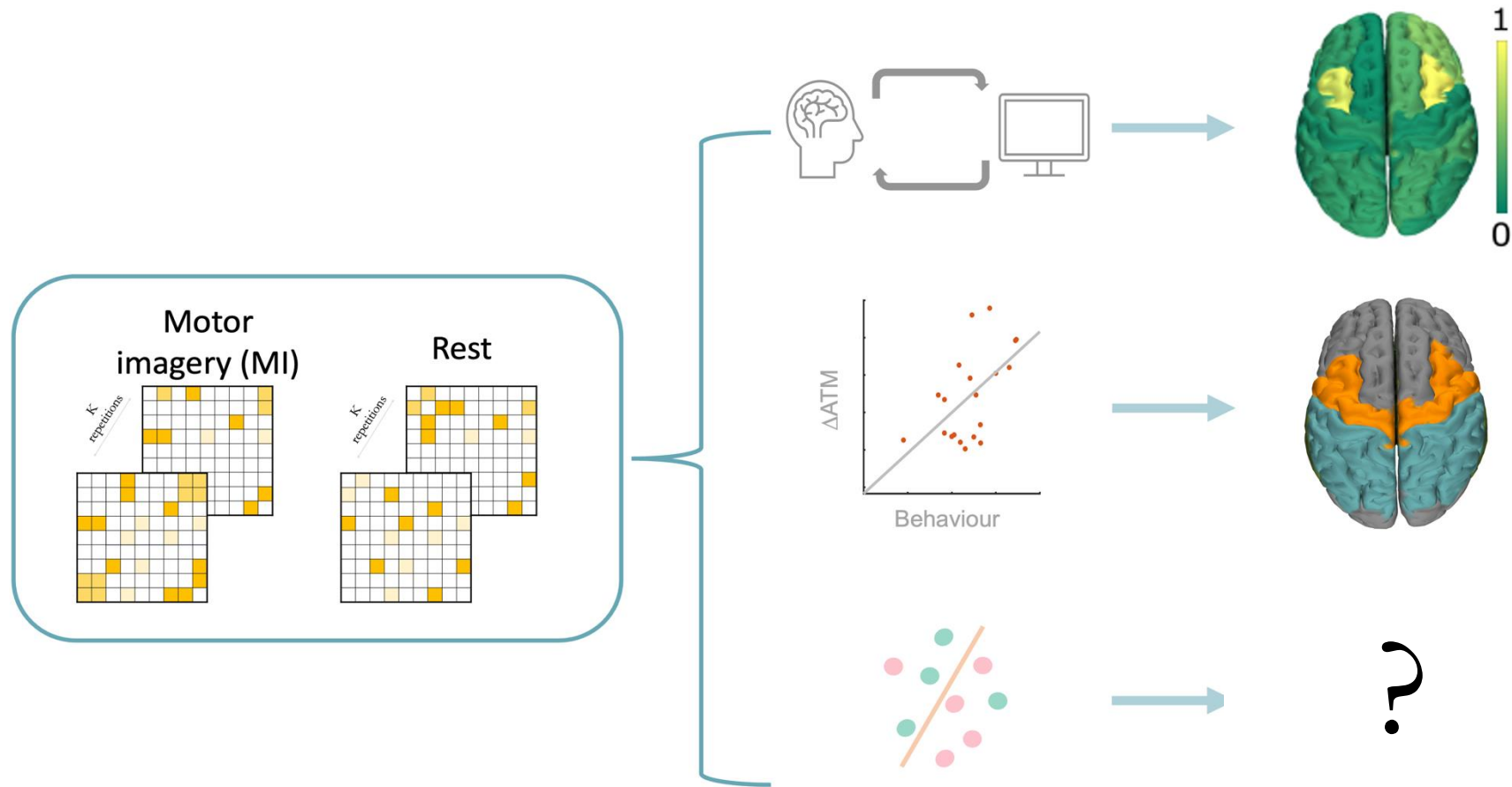


- Executive
- Pre/motor
- Parietal
- Temporal
- Occipital

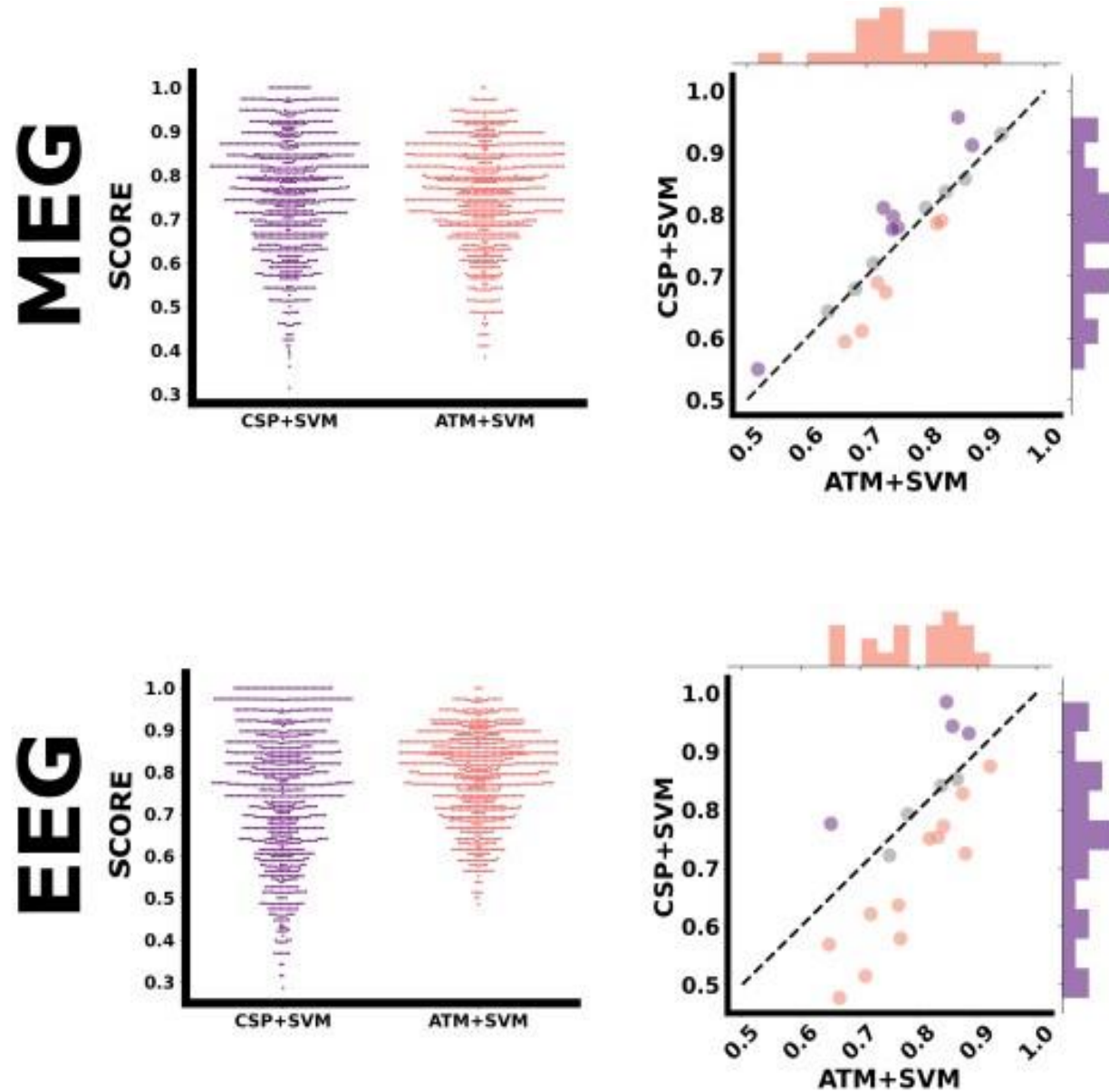
Differences in transition probabilities relate to BCI scores



- Executive
- Pre/motor
- Parietal
- Temporal
- Occipital



Transition probabilities as alternative features for BCI

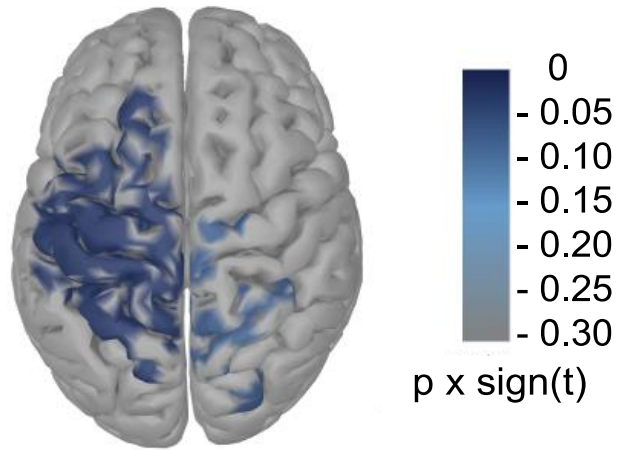


[Corsi*, Sorrentino* et al, iScience, 2024]

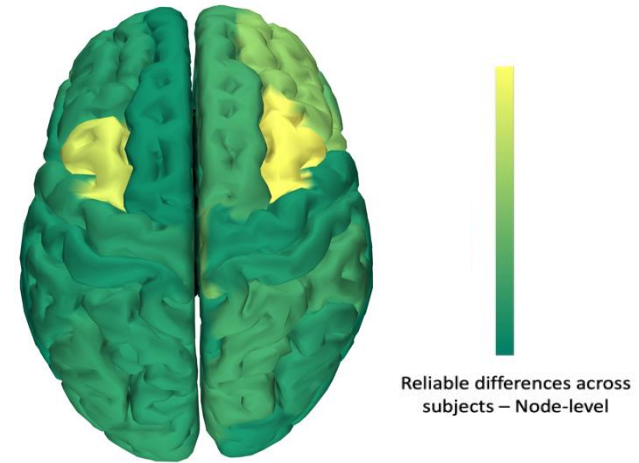


Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation



Power spectra
significant at **group** level

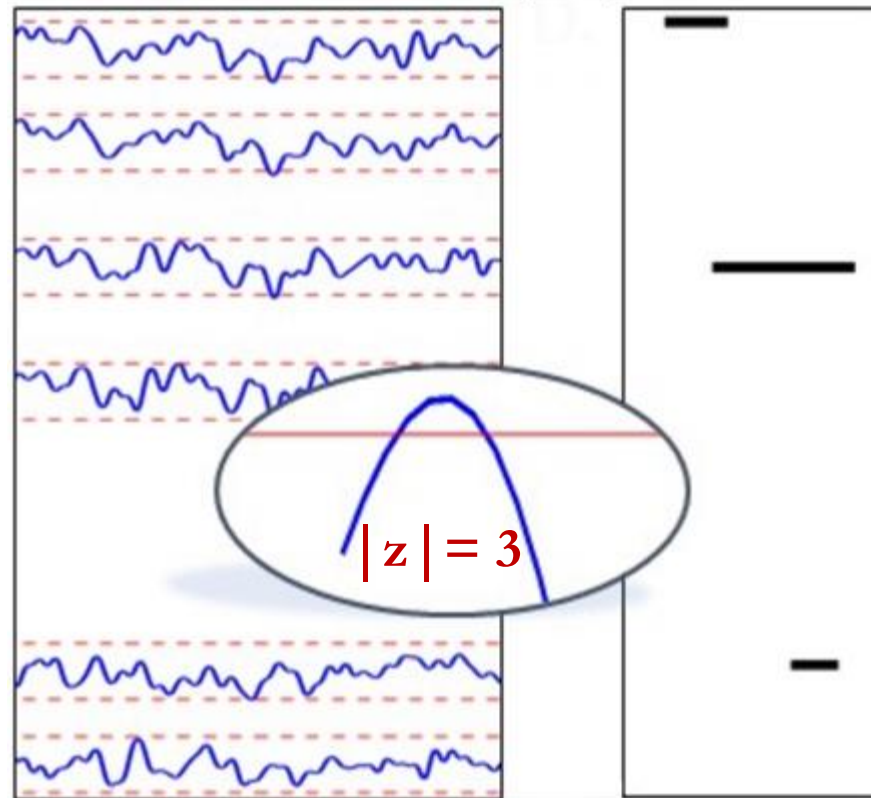


Neuronal avalanches
significant at **individual** level

⇒ Tracking changes in perturbation spreading while performing different tasks via the avalanches transition matrices

Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation

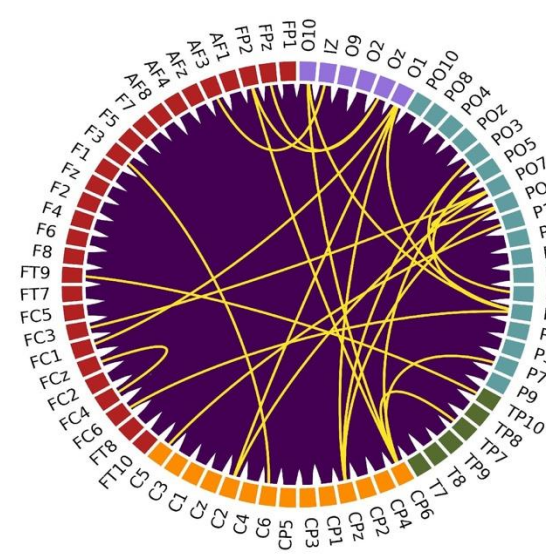
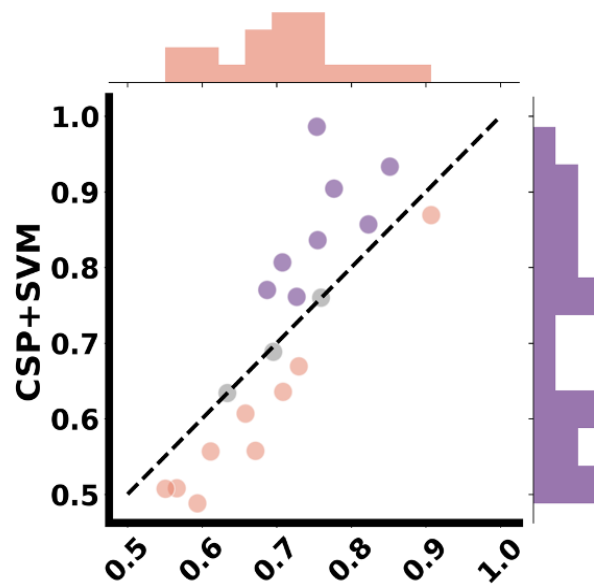


⇒ Focusing on higher-order perturbations to capture functionally-relevant processes & reliable information

Reliable functional information of task performance retrieval

Building innovative BCI protocols based on ATMs

- Outperforms the benchmark in EEG – gold standard in BCI → one step closer to the implementation
- Need to further investigate more suited classification methods



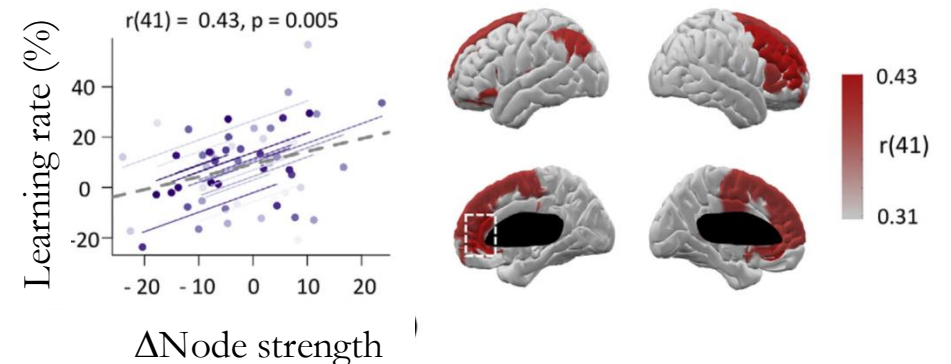
C. Mannino

Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation
- Building innovative BCI protocols
 - Tracking changes in perturbation spreading while performing different tasks
 - Focusing on higher-order perturbations to capture functionally-relevant processes & reliable information

Markers of BCI performance

- Current predictors of BCI
 - Local measurements – power spectra (Ahn et al, 2015) → replicability issues
 - Time-averaged brain interactions (Sugata et al, 2014) & Brain networks metrics [Gonzalez-Astudillo et al, JNE, 2020] → online implementation?
 - node strength & learning process [Corsi et al, NeuroImage 2020]
 - core-periphery properties & multimodal integration [Corsi et al, JNE 2021]
- Spreading of neuronal avalanches
 - Patterns behaviorally meaningful (Chialvo et al, 2010)
 - Computational fast marker



Paris Brain Institute



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Tristan Venot
Mario Chavez,
Denis Schwartz,
Nathalie George,
Laurent Hugueville,
Christophe Gitton
Sophie Dupont,
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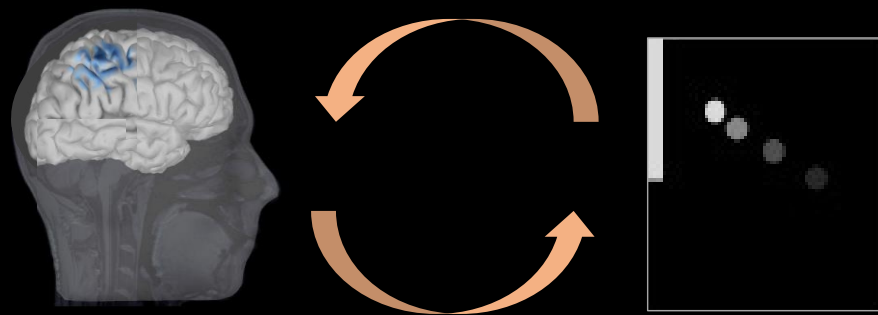
Pierpaolo Sorrentino,

Viktor Jirsa



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Thank you for your attention!



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[mccorsi](https://github.com/mccorsi)