Decoding the Micro- and Macroscopic Dynamics of Neural Activity

Organizer: Eelke Spaak and Jean-Rémi King

Room: # 103

Date and Time: Wednesday, October5 / 16:00-18:10

How does the Structure of Neural Representations Unfold over Time?
Advances in the Decoding of Time-Resolved High-Dimensional Neural Data

The past few decades have seen significant advances in our understanding of which brain regions are involved in particular cognitive tasks and processes. Additionally, the fine temporal resolution offered by magneto- and electroencephalography, and invasive electrophysiology, is providing us with an ever more detailed picture of the temporal evolution of these cognitive processes. However, it is less clear exactly how the brain implements them: how are cognitive computations subserved by specific neural representations? How are these representations transformed over time? This symposium will present five lines of experimental research, showing how the decoding of micro- and macroscopic neural signals (from spikes to whole-brain MEG) allows us to dissociate and simultaneously track multiple, distributed neuronal computations. Specifically, we will demonstrate how the structure, modulation, and re-activation of neural representations can be identified with novel multivariate approaches in a variety of visual and cognitive tasks.

Speakers:

- **Eelke Spaak** (Univ. of Oxford, UK)
  "Multivariate analyses of primate prefrontal cortex activity reveal simultaneously stable and dynamic coding for working memory"

  Working memory (WM) provides the stability necessary for high-level cognition. Influential theories typically assume that WM depends on the persistence of stable neural representations, yet increasing evidence suggests that neural states are highly dynamic. Here we apply multivariate pattern analysis to explore the population dynamics in primate lateral prefrontal cortex (PFC) during three variants of the classic memory-guided saccade task (recorded in 4 animals), as well as a typical change detection task. We observed the hallmark of dynamic population coding even when the representational states remained stable. We identified two characteristics that could explain these dynamics: (1) time-varying changes in the subpopulation of neurons coding for task variables (i.e., dynamic subpopulations); and (2) time-varying selectivity within neurons (i.e., dynamic selectivity). Using a data-driven simulation, we formally demonstrate that both factors contribute to population-level dynamic coding for WM. These results indicate that even in very simple cognitive tasks, PFC neurons display complex dynamics, yet support stable representations for WM.

- **Jean-Remi King** (New York Univ., USA)
  "The selective maintenance of sensory features is dissociated from their visibility"

  Recent studies of “unconscious working memory” have challenged the notion that only visible stimuli can be actively maintained over time. In the present study, we investigated the neural dynamics of subliminal maintenance using multivariate pattern analyses of magnetoencephalography recordings (MEG). Subjects were presented with a masked Gabor patch whose angle had to be briefly memorized. We show that, while irrelevant sensory features of contrast, frequency and phase are only encoded transiently, the relevant feature of angle is encoded and maintained in a distributed and dynamically changing manner, throughout the brief retention period. Furthermore, although stimulus visibility is marked by an amplification of late neural codes, we show that unseen stimuli can be partially maintained by the corresponding neural assemblies. Together, these results invalidate several predictions of current neuronal theories of visual awareness and suggest that visual perception relies on a long sequence of neural assemblies that repeatedly recode and maintain task-relevant features at multiple levels of processing, even under unconscious conditions.

- **Anna Jafarpour** (Univ. of California-Berkeley, USA)
  "Decoding content of working memory using MVPA"

  We investigated how sequences of events are retained in working memory. In a magnetoencephalography (MEG) study, healthy human participants encoded sequences of three categorically distinct visual stimuli and maintained that information over a 5 second retention interval to answer questions about the sequence order and identity of stimuli. Multivariate pattern classifiers could discriminate the three categories at 170 ms post stimulus onset during encoding on the basis of broadband amplitude. Decoding of brain activity during retention with these classifiers revealed that one of the three stimuli dominated the content of working memory. Early (125 ms) event-related-field responses during encoding indicated that the dominating stimulus was the least attended one independent of its category and position in the encoding sequence. These findings suggest that replay in working memory benefits the retention of task-relevant but weakly attended events, possibly by reducing interference of other attended events.

- **Radoslaw Martin Cichy** (Free Univ. Berlin, Germany)
  "A spatio-temporally resolved and algorithmically explicit account combining MEG with fMRI and neural networks"

  Understanding visual cognition in the brain requires answering three questions: what is happening where and when in the human brain when we see? In this talk I will present recent work that addresses these questions in an integrated analysis framework combining human magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI) and deep neural networks (DNNs). The talk has three parts. In the first part, I will show how fMRI and MEG can be combined using multivariate analysis techniques (classification plus representational similarity analysis) to yield a spatio-temporally integrated view of human brain activity during object vision. In the second part I will show how DNNs can be used to understand the human visual system. In one study, we showed that DNNs predicted the spatial-temporal hierarchy of the human visual system. In another study, we showed that representations of abstract visual properties, such as scene size, find an analogue in DNNs. In the third, shorter part I will present research informing about the source of information present in MEG signals: representations encoding at the level of columnar columns may be accessible to multivariate pattern classification.

- **Nicholas Myers** (Univ. of Oxford, UK)
  "Testing sensory evidence against mnemonic templates"

  Most perceptual decisions require comparisons between current input and an internal template. Classic studies propose that templates are encoded in sustained activity of sensory neurons. However, stimulus encoding is itself dynamic, tracing a complex trajectory through neural activity space. Which part of this trajectory is pre-activated to reflect the template? We recorded magneto- and electroencephalography during a visual target-detection task, and used pattern analyses to decode template, stimulus, and decision-variable representations over time. Our findings ran counter to the dominant model of sustained pre-activation. Instead, template information emerged transiently around stimulus onset and quickly subsided. Cross-generalization between stimulus and template coding, indicating a shared neural representation, occurred only briefly and weakly. Our results are thus more compatible with the proposal that template representation relies on a matched filter, transforming sensory input into task-appropriate output. This proposal was consistent with a signed difference response at the perceptual decision stage, which can be explained by a simple neural model.