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How neural circuits orchestrate the magic of human cognition

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The magic of cognition arises from the complex interactions of dynamical ensembles of neural circuits in neocortex. Deficits in these cortical networks lead to debilitating conditions and brain disorders have proven to be particularly resilient to treatment. In collaboration with neurosurgeons, we have developed neurotechnologies to enhance our ability to directly and invasively listen to and stimulate human cortex. These tools have enabled us to interrogate the dynamics of neural responses orchestrating cognitive functions including visual recognition, learning and decision making at unprecedented spatiotemporal resolution.

As a paradigmatic example of cognition, we will discuss our ability to rapidly and robustly recognize faces and objects, which is essential for navigation, reading, socialization and pattern recognition in general. Visual recognition happens in a small fraction of a second, even when the stimuli have undergone transformations in position, size, color, illumination and rotation. Using machine-learning algorithms, we demonstrated that we could read out in single trials responses along the human ventral visual stream at millisecond resolution. These signals are selective for faces and objects and show tolerance to scale and viewpoint changes and even to small amounts of clutter. The dynamics of these responses arise within 100 to 200 ms of image onset and are consistent with behavioral constraints for recognition. Natural vision often involves recognizing objects from partial information. The ability to extrapolate and make inferences from partial information is central to intelligence and constitutes a significant frontier for engineering systems that aim to emulate human thinking. Responses along the ventral visual stream retain selectivity despite presenting only a small fraction of information and provide evidence for holistic face and object processing. The delayed dynamics observed in the responses suggest that inference and pattern completion rely on recurrent and feedback signals that form attractors in the representational space. Taken together, the neurophysiological signals and computational models are beginning to shed light on how neural circuits can lead to cognition, on the physical basis for the mind. The high-resolution scrutiny of human cortical circuits provides a path to the inner workings of the brain and a way to read out biological codes, which can be translated into computational algorithms to make machines smarter. Additionally, furthering our understanding of where, when and how cognitive functions are instantiated opens the door to developing brain machine interfaces to alleviate brain disorders.