Lifelong Learning, Abstraction and Generalization

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Lifelong Learning is the cutting edge of artificial intelligence - encompassing computational methods that allow systems to learn in runtime and incorporate learning for application in new, unanticipated situations. Until recently, this sort of computation has been found exclusively in nature; thus, Lifelong Learning looks to nature for its underlying principles and mechanisms and then transfer them to this new technology.

In this talk we will focus on the capability to abstract and generalize. We identified a property of the human connectome that leads to the capability of abstraction. The analytic results identified a previously unrecognized brain connectome hierarchy, shedding light on the role of brain structure and processing pathways in creating varying levels of cognition and leading ultimately to abstract thought [Scientific Reports 2015]. We will then translate the biological findings to mathematics and use this formulation as a measure of generalization in deep networks, proposing it as a tool to grade networks by their capability to generalize [ICML 2020].

We will also mention a recent result [Nature Communication 2020] that characterize brain's "rehearsal," a mechanism which reorganizes memories with new learning, and apply this new mechanism, "generative replay," to neural networks to enable generalization of information attained via continual learning.

The new science of thought imaging:
Using machine learning to break the brain's code for representing concepts

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Recent computational techniques, particularly machine learning, are being applied to fMRI brain imaging data, making it possible for the first time to relate patterns of brain activity to specific thoughts. Our early work focused on the identification of the neural signatures of individual concrete concepts, like the thought of an apple or a hammer. It progressed to identifying many other types of concepts, such as emotions, abstract concepts, and sentences.

One application of this approach is to instruction in science courses, and another is to neuropsychiatry, where it has been possible to identify suicidal ideation in terms of alterations of a normative pattern of concept representation.

Linking Dimensions of Psychopathology and Connectivity in Functional Brain Networks

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Neurobiological abnormalities associated with psychiatric disorders do not map well to existing diagnostic categories. High co-morbidity suggests dimensional circuit-level abnormalities that cross diagnoses. Here we seek to identify brain-based dimensions of psychopathology using sparse canonical correlation analysis in a large sample of youths. This analysis reveals correlated patterns of functional connectivity and psychiatric symptoms. We find that four dimensions of psychopathology – mood, psychosis, fear, and externalizing behavior – are associated with distinct patterns of connectivity. Loss of network segregation between the default mode network and executive networks emerges as a common feature across all dimensions. These results delineate connectivity-guided dimensions of psychopathology that cross clinical diagnostic categories, which could serve as a foundation for developing network-based biomarkers in psychiatry.

Neural representations of visually evoked emotional experience
感情体験の脳情報表現

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Our experiences are colored by a wide variety of emotions. Conventional emotion studies have characterized emotional experiences and neural responses based on a limited set of emotion categories (e.g., basic emotions) or affective dimensions (e.g., valence and arousal). Recent behavioral work by Cowen and Keltner (2017) analyzed reported emotional states (34 emotion categories and 14 affective dimensions) elicited by 2,185 short videos and identified 27 distinct varieties of experiences described in a high dimensional space. They also found that emotion categories rather than affective dimensions organize self-reports of subjective experience. In this talk, I will present the results of several analyses seeking to identify the neural substrates of the high-dimensional space of emotional experience using fMRI responses to all 2,185 videos. Our analyses demonstrated that (1) dozens of video-evoked emotions were accurately predicted from fMRI patterns in multiple brain regions with different regional configurations for individual emotions; (2) emotion categories better predicted cortical and subcortical responses than affective dimensions, outperforming visual and semantic covariates in transmodal regions; and (3) emotion-related fMRI responses had a cluster-like organization efficiently characterized by distinct categories. These results support an emerging theory of the high-dimensional emotion space, illustrating the feasibility and importance to characterize neural responses associated with our emotional experiences using richer and nuanced emotion categories.

Visualization of brain representation of diverse cognitive functions using encoding modeling
エンコーディングモデルによる多様な認知機能の脳内表現の可視化

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One of the central issues in cognitive neuroscience is to reveal how our daily cognitive processes are represented in the brain. Previous studies have revealed the cortical representation of perceptual experiences using encoding and decoding model approaches, while few attempts have been made to build a quantitative model for the cortical representation of active cognitive processes. We performed fMRI experiments with over 100 naturalistic tasks and examined cortical representations with two voxel-wise encoding models. A sparse task-type model revealed a hierarchical organization and cortical mapping of over 100 tasks. A metadata-based cognitive factor model predicts brain activity and decodes tasks, even under novel conditions. Our framework provides a powerful step toward the comprehensive modeling of the representations underlying human cognition.

Neuroscience revealing latent relationships among cognitive functions
神経科学的方法によって認知機能同士の隠れた関係性を明らかにする

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To look closer at each cognitive function and to consider the brain as a network of these functions, it is vital to uncover relationships among dozens of these functions. In this talk, I show several approaches to reveal latent relationships among cognitive functions and characteristics of each function using methods in functional brain mapping and network science. First, I provide a map of diverse cognitive functions (e.g. "emotion", "attention", "episodic memory") where the functions whose neural substrates are closely related are located closely. Then, I show the results from a neuroscience-based conceptual analysis where a concept of each cognitive function is divided into several sub-concepts. Moreover, I propose a novel way to construct the brain parcellation where each parcel is originally associated with some cognitive functions. Using those parcels as network nodes in the brain network analysis, I show several relationships between the cognitive functions and features of the subnetwork in the brain that plays a role in the function. Those results are informative not only for basic neuroscientific research but also for clinical applications and developments of brain-inspired artificial intelligence.