How We Image, Measure, and Understand the Brain: A Computational Perspective

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Understanding how the brain works in healthy and pathological conditions is considered as one of the major challenges for the 21st century. After the first electroencephalography (EEG) measurements in 1929, the 90's was the birth of modern functional brain imaging with the first functional MRI (fMRI) and full head magnetoencephalography (MEG) system. By offering noninvasively unique insights into the living brain, imaging has revolutionized in the last twenty years both clinical and cognitive neuroscience. While such devices do not reside inside the brain, it is now common practice in a clinical context to directly record the electric signals produced by neural assemblies. Probably the most common clinical motivation for invasive electrophysiological recordings is epilepsy presurgical mapping.

After pioneering breakthroughs in physics and engineering, the field of neuroscience has to face new major computational and statistical challenges. The size of the datasets produced by publicly funded populations studies (Human Connectome Project in the USA, UK Biobank or Cam-CAN in the UK etc.) keeps increasing with now hundreds of terabytes of data made available for basic and translational research. The new high density neural electrode grids record signals over hundred of sensors at thousands of Hz which represent also large datasets of time-series which are overly complex to model and analyze: non-stationarity, high noise levels, heterogeneity of sensors, strong variability between individuals, lack of accurate models for the signals.

In this talk I will review how functional MRI and electrophysiological data are acquired going briefly over the underlying physics as well as the different recording devices available today. I will then illustrate with many examples how machine learning, statistics and advanced signal processing are used today to get the best of such challenging, and sometimes massive, data.