Self-learning of Neuroimaging Theory

—based on the book: ***Adaptive Spatial Filters for Electromagnetic Brain Imaging***

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A journey of a thousand miles begins with a single step. — Lao Tzu

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Chapter 1 Introduction

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1.1 Functional brain mapping

What is functional brain mapping? According to Wikipedia, ***Brain mapping*** *is a set of neuroscience techniques predicated on the mapping of (biological) quantities or properties onto spatial representations of the (human or non-human) brain resulting in maps.*

What can it be used to do?

- study the neural mechanisms underlying human behavior
- brain clinical diagnosis

Techniques for functional brain mapping

- positron emission tomography (PET, 正电子发射计算机断层显像)
- functional magnetic resonance imaging (fMRI, 功能磁共振成像)

The disadvantage : do not directly measure neuronal activities. Electrophysiological activity of neurons can generate both **electric potentials** as well as **magnetic fields**. At sub-millisecond time scale, the neurons' activities can be measured by

- magnetoencephalography (MEG, 脑磁图), 300 channels
- electroencephalography (EEG, 脑电图), 512 electrodes

MEG/EEG is very important because:

1. provide spatio-temporal brain activation profiles
2. algorithms that enable high-fidelity reconstruction of neuronal activities from MEG and EEG data.

1.2 Electromagetic brain imaging

The synaptic and intracellular currents in cortical is the major generators of MEG and EEG signals.

There are two main algorithms for electromagnetic brain imaging: **forward modeling** and **inverse modeling**.

1. Forward modeling: If the three-dimensional distribution of conductivity in a brain, referred to as the **volume conductor**, is known. One can use Quasi-static approximations of Maxwell's equations to compute the sensor outputs.

Forward modeling is embodied in the idea of the sensor lead eld, which represents the sensitivity prole of a sensor array and describes a linear relationship between sources and measurements.

2. Inverse modeling: In briefly, it is an algorithm or procedure based on the sensor lead field to find the soucres (spatio-temporal distributions) in human brain. Typically, there are two categories:

- **Parameter-estimation**.
  - **Assumption:** a small number of sources can adequately account for the observed sensor data, i.e., consisting of a small number of point sources.
  - **Parameters:** the locations, orientations, and strengths of these point sources.
  - Terminologies: **equivalent current dipole (ECD)** for multiple sources; **single-dipole search** for a single source.
  - **Method:** nonlinear least-squares fit to the measured data

  - **Disadvantage:** (1) the number of sources a Q must be known in advance. (2) requiring a $3Q$-dimensional nonlinear search. (3) as Q increases, the search dimension becomes very high, no numerical method can effectively solve the issue nowadays.
- **Imaging methods**
  - **Advantage:** do not require prior knowledge of the number of sources
  - two algorithms: the **tomographic reconstruction** methods and **spatial filters**
  - **tomographic reconstruction**: voxel discretization, a xed source at each voxel, estimate the amplitudes of the sources, least-squares fit,
  - Because the number of voxels is much larger than the number of sensors, require some criterion other than the least-squares criterion to find the source distribution.
  - Various algorithms including the well-known minimum-norm method have been proposed, and many tomographic reconstruction methods can be regarded as non-adaptive spatial filters.
  - Adaptive spatial filters is introduced in next setcion.

1.3 Spatial filters

The spatial filte is a linear operator applied to the measured data and is used to estimate the strength of activity at a particular spatial location. We refer to this spatial location as the **filter-pointing location** in this book.

Quite often, the spatial filter is called the **beamformer** in the field of signal processing.

Definition 1.1 (non-adaptive spatial filters.)

If spatial filters only depend on the geometry of the measurements, they are referred to as non-adaptive spatial filters. ♣

Adaptive spatial filter (also known as adaptive beamformer) depend on:

- the measurement geometry
- the measurement covariance matrix

See more history of adaptive beamformer in Wikipedia. The aim of this book is to describe the technical advances of adaptive spatial filters in the context of electromagnetic brain imaging.