What is the most efficient way to sense, or sample signals to we want to observe? Once data have been acquired, how do we retrieve the sought signal from these acquired data? These questions are core to Data Science. This module approaches them in the context of applications to imaging, in a variety of domains ranging from astronomy to medicine. This specific problematic is the realm of the what is called "Computational imaging". The course will aim to introduce the student to the field of computational imaging, from theory to application.

Itemised list:

- Introduce the interconnected problematics of data acquisition and image recovery in computational imaging.
- Study the theory of compressive sampling proposing nonconventional sub-Nyquist sampling approaches and related approaches for accurate signal recovery from partial data.
- Study the theory of convex optimisation offering algorithmic structures for reconstruction of signals an images from partial data.
- Study computational imaging applications with scientific and industrial relevance.

LEARNING OUTCOMES – SUBJECT MASTERY

- Critical understanding of the theory of compressive sensing and its application in computational imaging

- Critical understanding of the theory of convex optimisation and its use for computational imaging

- Practical knowledge of optimisation algorithms

- Practical knowledge of recent advances in signal processing theory and their applications for development of computational imaging algorithms, e.g. for medical imaging applications

- Understanding of hot topics in computational imaging research
B31XO Sampling and Computational imaging

- Ability to design efficient sampling/sensing strategies in imaging applications (e.g. medical imaging)

- Ability to design efficient algorithms to solve inverse problems in imaging applications (e.g. medical imaging)

- Practical experience of a computational imaging project

- Practical experience of teamwork under strict deadlines

- Practical experience of project and people management

- Practical experience of oral communication

SYLLABUS

General course content description:

A first part of the module will be dedicated to ‘Compressive sensing and imaging’. In many applications signals are firstly acquired (sampled) at Nyquist rate (full sampling) before being adaptively compressed for storage or transmission. Our ability to merge acquisition and compression into a non-adaptive methodology where signals would be sensed in a compressive form opens the door to applications where full data acquisition is not accessible in the first place, because it is too costly, too slow or requires too much bandwidth. But is it possible to sense/sample signals compressively? From a mathematical standpoint an ill-posed inverse problem arises in the perspective of signal recovery from the acquired data. The recent theory of compressive sensing demonstrates that a large class of signals may in fact be accurately recovered from sub-Nyquist sampling (incomplete sampling). The sampling strategy must follow specific randomness and incoherence conditions. The signals of interest must be sparse in some linear transform domain. The theory also provides tractable algorithms to solve the associated linear inverse problem, designed in the context of the theory of convex optimisation, and more specifically relying on \( l_1 \) minimisation. This part of the module will study the **basic theory of compressive sensing**. It also introduces the **basic theory of convex optimisation** and modern convex optimisation algorithms. Laboratories are dedicated to algorithm implementation in a quite generic application setting, with a strong bias towards imaging applications (image formation from randomly acquired data; image restoration, image denoising, etc.)

A second part of the module will take the form of a project providing more ‘hands on’ experience on sampling and optimisation for computational imaging applications. Taking a more pragmatic approach, the project will enable the students to investigate more general sampling procedures than those specifically prescribed by the theory of compressive sampling, and more general algorithms for image recovery than those proposed by the theory of convex optimisation. Problematics beyond image estimation will be investigated, such as calibration and uncertainty quantification, etc., with applications ranging from astronomy to medicine. When suitable, students will be offered some additional short courses on selected topics in computational imaging.
Itemised list of subjects covered:

- Compressive sensing: Motivation for compressive sensing in the context of imaging applications in medicine and astronomy; concepts of sparsity, incoherence, and randomness; theorems for $l_1$ recovery

- Convex optimisation: convex problem and optimality conditions; proximal operators; Forward backward algorithm; Alternating Direction Method of Multipliers (ADMM algorithm)

- Computational imaging project: Nonconvex optimisation algorithms; applications such as image estimation, joint calibration and imaging, uncertainty quantification, source separation, etc., mainly for real imaging problems, for example in astronomy or medicine.

- Short courses will be organised in support to the project when suitable: sampling and computational imaging on non-Euclidean manifolds (e.g. graphs); Bayesian inference for imaging inverse problems, etc.

COURSE RELATIONSHIPS

N/A

LOCATION AND ASSESSMENT METHODS

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