université de BORDEAUX

PhD thesis

Thesis topic:

Integration of morphological constraints in tomographic image reconstruction through deep learning: Application in Biology

Contract duration: **3 years**
Start date : September or October 2024
Location: **University of Bordeaux, France**

Host institution and work environment

The doctoral thesis will be supervised under the joint responsibility of Claire MICHELET, a physicist and Associate Professor at the **Laboratory of Physics of the Two Infinities Bordeaux (LP2IB)**, who specializes in micro-tomography techniques, and Pascal DESBARATS, a computer scientist and Professor at the **Bordeaux Laboratory for Computer Science Research (LaBRI)**, who specializes in inversion problems and image reconstruction techniques. Additionally, the candidate will benefit from the expertise of Jean-François GIOVANNELLI, a data scientist and Professor at the Laboratory for Integration from Material to System (IMS Bordeaux), who is also a specialist in these areas.

The candidate will be hosted at LP2IB, within the **multidisciplinary iRiBio team** "Interactions of Ionizing Radiations and Biology", which combines expertise in physics, computer science, chemistry, and biology to address issues related to the characterization of living organisms using microscopic biological models (cells, microorganisms). The candidate will also have access to a secondary office at LaBRI to facilitate access to computational servers. The candidate will benefit from the synergy and complementary skills of this multidisciplinary environment, including a postdoctoral researcher (Applied Mathematics) and several master's interns (Physics and Computer Science) directly involved in the project.

The candidate will also have the opportunity to expand their knowledge and research perspectives, particularly in synchrotron imaging and image reconstruction, through numerous **ongoing multidisciplinary collaborations at both national and international levels:** European Synchrotron Radiation Facility (ESRF) in Grenoble; Australian Synchrotron in Melbourne; Geant4 and Geant4-DNA collaborations, particularly within the "Advanced Examples" and "G4-Med" research groups, in partnership with the University of Wollongong, Australia.

Context and objectives of the PhD thesis

3D tomography is becoming an essential tool in the analysis of matter, particularly living matter, as it allows for direct imaging of preserved biological samples, very close to their native state, without the need for physical sectioning. This PhD thesis aims to explore a novel approach for **reconstructing three-dimensional (3D) tomographic images**, specifically for biological applications, by implementing deep learning methods.

The primary challenge addressed in this thesis is **the issue of incomplete data**. Data can be incomplete for various reasons: i) temporal constraints to limit the duration of the experiment or minimize radiation exposure, for instance; *ii) physical constraints* related to the geometry of the object, preventing access to certain measurement angles, resulting in a "missing wedge" in the data. These limitations introduce errors in the reconstructed images. The thesis proposes an innovative approach to minimize these effects. We propose leveraging the fact that structural information is often known for many types of objects, including the biological models specifically studied in this project. **We aim to integrate these morphological constraints into the reconstruction algorithm to promote a solution that is as accurate as possible.**

In medical tomography, incorporating morphological information interpreted through deep learning already helps guide image reconstruction, thereby minimizing the radiation dose delivered to the patient during the examination. The goal of this thesis is to extend this approach to micro-tomography, facilitating its use internationally for both fundamental research (biology, medicine, materials physico-chemistry) and the analytical needs of companies. **The project paves the way for a genuine microscopic-scale "3D imager"**, significantly improving time efficiency and ergonomics. These considerations are crucial in biology, as demonstrating a biological response often relies on comparing a large number of samples.

It's important to note that the issue of incomplete data is also **central in other imaging modalities** (aperture synthesis, interferometry, super-resolution, hyperspectral imaging) and various fields (medical imaging, non-destructive testing, astrophysics, materials science, mechanics, radar). Therefore, the developments made in this thesis will be applicable to these other disciplines as well.

Methodology

The thesis focuses on three main aspects:

- **Designing tomographic reconstruction methods** based on deep learning;
- **Testing these methods** and evaluating their accuracy quantitatively (calculated density values) using digital phantoms;
- **Applying these methods to experimental imaging data** of biological microorganisms using various techniques (micro-tomography with protonic X-ray emission and synchrotron radiation).

The approaches are based on constraints related to prior knowledge of the samples (microstructure, discontinuities, overall chemical composition - for example, organic matter containing C, H, O, N for biological samples - support, and positivity constraints) as well as on the acquisition process and measurements (acquisition geometry, missing wedge, presence of attenuations, statistical nature of the acquired data).

The development will concretely rely on the biological model of the nematode *Caenorhabditis elegans* (*C. elegans*), a multicellular microorganism approximately 1 mm long. This organism exhibits the anatomical and functional characteristics of a multicellular biological organism with consistent cell numbers, life cycle, and development patterns. Consequently, it has become a staple in international fundamental research for studying major biological functions (genetics, aging, neuroscience).

Candidate profile

The doctoral candidate should possess **strong skills in data processing and image reconstruction:**

- **Either a physicist** with experience and a career goal oriented towards imaging;
- **Or a computer scientist** with experience and a career goal oriented towards image processing and analysis, regardless of the field (physics, biology, mechanics, medical, etc.).

The Doctoral School will be chosen based on the candidate's profile.