C++ Parallel computing based implementation of a numerical simulator dedicated to 3D reconstruction in tomographic diffractive microscopy for the study of viral infections

Laboratoire Hubert Curien

Subject title : C++ Parallel computing based implementation of a numerical simulator dedicated to 3D reconstruction in tomographic diffractive microscopy for the study of viral infections.

Host laboratory : Laboratoire Hubert Curien (LaHC), 18 Rue Pr B. Lauras, 42000 SAINT-ÉTIENNE.

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Keywords : 3D (tomographic) image reconstruction, numerical simulation, CPU/GPU parallel computing in C++ (OpenMP, Cuda), scientific programming with Matlab®, tomographic diffractive microscopy, biological imaging (viruses).

Duration : 6 months.

Starting date : february/march 2022.

Salary : $\sim$ 600 €/month.

Housing : opportunity to house at the Résidence des Arts (in the town center of Saint-Étienne, 20 minutes far from the lab).

Context and problematics :
Current health issues show us how important biomedical research is to understand how viruses work. Optical microscopy techniques are among the preferred methods for biological studies, thanks to their unique capability of imaging living specimens in 3-D (cells, bacteria, viruses). Tomographic Diffractive Microscopy (TDM) is a new technique, which allows the imaging of transparent specimens in 3-D [1], using image acquisitions in "tomographic" mode (multi-angle views).

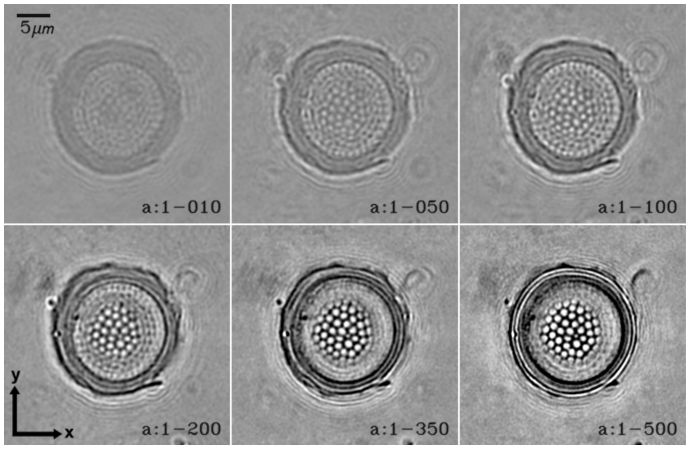

Figure 1: Reconstruction of a diatom frustule using TDM [Bailleul *et al.*, 2018].

The HORUS project, involving a collaboration between the IRIMAS laboratory (Mulhouse), the Hubert Curien laboratory (Saint-Étienne) and the IGBMC institute (Strasbourg), and funded by the Agence Nationale de la Recherche (ANR), aims at improving this imaging technique [2, 3] in terms of instrumentation and image processing for reconstruction.

Subject of the internship :

This internship is part of **the improvement task of 3D reconstruction algorithms** (cf. Fig. 2(a)). In this context, one of the main concerns is the **numerical modelization of the image formation process**, *i.e.* **the numerical simulation of the tomographic views from a digital 3D image**. An advanced model, called *Beam Propagation Method*, has already been implemented by the team in Matlab®, to use it in iterative reconstruction procedures [4]. It is based on a sequential application of numerical convolution steps (using fast Fourier transforms) and pixelwise products slice by slice, of the 3D "voxel" image, to simulate the light propagation through the 3D sample

(Fig. 2(b)). **However this model involves a high computational burden and requires to be optimized, for example by implementing it in a compiled programming language.**

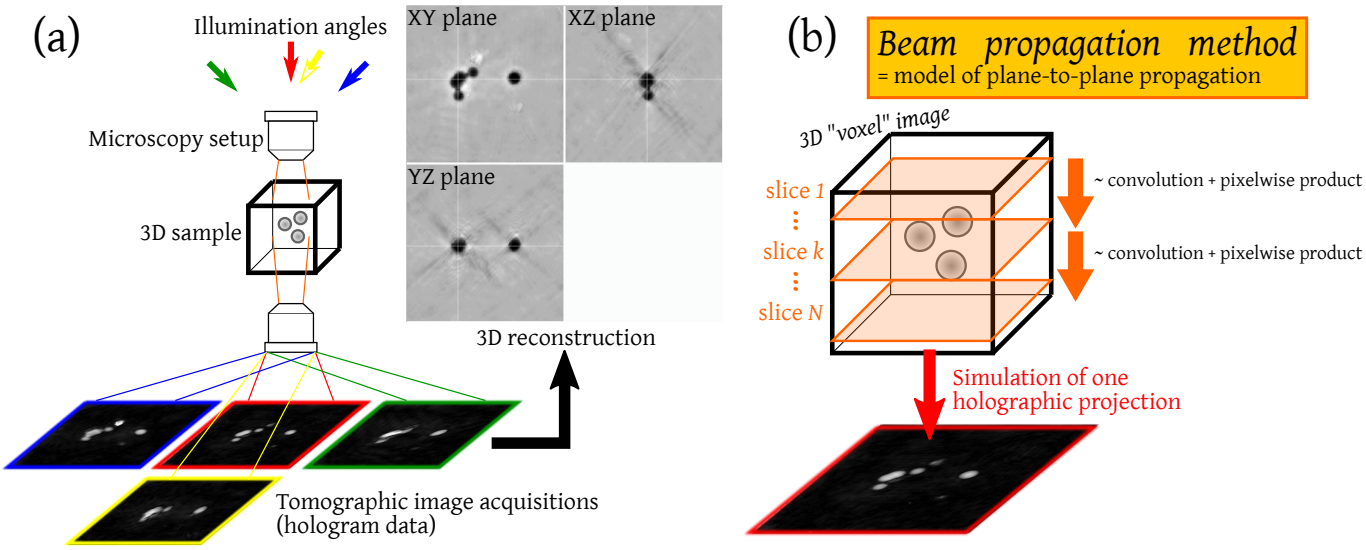

Figure 2: (a) Acquisition and reconstruction principles of TDM. (b) Numerical data formation model based on the *Beam Propagation Method*.

A preliminary implementation of the model in the C++ language has been realized and allows a better exploitation of relevant libraries such `FFTW` (for numerical convolutions). The recruited trainee will have to optimize this implementation studying the possibilities of parallelization of this code with appropriate CPU or GPU dedicated C++ parallel computing libraries (`OpemMP`, `Cuda`), and to test the proposed solutions before transferring them to the Matlab® code (implementing `MEX` functions). Tests will be performed on both simulated and experimental data (reconstruction tests with existing algorithms).

We are looking for a candidate in master 2 or in last year of an engineering school in computer science and/or signal and image processing, comfortable with programming in the targeted languages, and interested in imaging problems (reconstruction, simulation), particularly for biomedical applications in scientific research.

Required skills: C++ programming, CPU/GPU parallel computing, signal and image processing, Matlab® language.
Appreciated knowledge and interests: imaging, 2D/3D image reconstruction (tomography), *scientific research*.

References

[1] O. Haeberlé, K. Belkebir, H. Giovaninni, and A. Sentenac. Tomographic diffractive microscopy: basics, techniques and perspectives. *Journal of Modern Optics*, 57(9):686–699, May 2010.

[2] Matthieu Debailleul, Bertrand Simon, Vincent Georges, Olivier Haeberlé, and Vincent Lauer. Holographic microscopy and diffractive microtomography of transparent samples. *Measurement Science and Technology*, 19(7):074009, 2008.

[3] Matthieu DEBAILLEUL and Bruno COLICCHIO. Imagerie microscopique 3d de phase méthode d'imagerie sans marquage. *Techniques de l'Ingénieur*, ref. article : p955, 2018.

[4] U. S. Kamilov, I. N. Papadopoulos, M. H. Shoreh, A. Goy, C. Vonesch, M. Unser, and D. Psaltis. Optical Tomographic Image Reconstruction Based on Beam Propagation and Sparse Regularization. *IEEE Transactions on Computational Imaging*, 2(1):59–70, March 2016.