2018-00761 - Computational developments for integrative structural biology: small-angle scattering using polynomial expansions

A propos du centre ou de la direction fonctionnelle

Inria, the French national institute for research in computer science and control, is dedicated to fundamental and applied research in information and communication science and technology (ICST). Inria has a workforce of 3,800 people working throughout its eight research centers established in seven regions of France.

Grenoble is the capital of the French Alps. Combining the urban life-style of southern France with a unique mountain setting, it is ideally situated for outdoor activities. The Grenoble area is today an important centre of industry and science (second largest in France). Dedicated to an ambitious policy in the arts, the city is host to numerous cultural institutions. With 60,000 students (including 6,000 foreign students), Grenoble is the third largest student area in France.

Contexte et atouts du poste

Within the framework of a partnership

- collaboration between the NANO-D team of Inria and several teams form international research facilities ILL, EMBL, ESRF, supported by the "Initiatives de Recherche Stratégiques" programme of the Grenoble Alpes University,
- public with academic partners

Mission confiée

Introduction:

While crystallography has been providing atomic-resolution structures of biomolecules for over half a century, the real challenge of today's biophysicists is to correlate molecules' structure and dynamics in solution with their function. Small-angle scattering (SAXS) is the fundamental techniques for structural studies of biological systems in solution. Thanks to advances in instrumentation and data analysis software, Small-angle X-ray scattering (SAXS), complemented by other methods, is becoming very popular in structural biology. Over the years, a number of computational tools have been developed for the analysis of SAXS curves, calculation of theoretical profiles and low-resolution reconstruction of model shapes. Many efforts have been spent to reduce the running time of these tools without degrading the quality of their approximations, most prominently the ATSAS package developed at EMBL Hamburg. Particularly the Crysol program calculates a model SAXS profile to test a structural hypothesis of a SAXS experiment. The number of Bio-SAXS publications exploded as a result of this effort. Comparatively, the lack of user-friendly analysis tools has hindered the development of Small Angle Neutron Scattering (SANS), more complex but providing more information.

Very recently, we developed a computational tool called Pepsi-SAXS that outperforms all the competitors for atomic modelling in both speed (5 ~ 50 times faster on average) and accuracy. However, Pepsi-SAXS developments were very much restricted by the lack of human resources and, more importantly, by the lack of support and expertise from experimental teams. Also, SANS experiments are somehow more complex and bring different information than SAXS experiments because they offer the possibility to tune the scattering of the solvent to match the scattering of some compounds included in a particle to determine the structure of the compounds that remain visible. The current project is devoted to the novel computational developments for SAXS and SANS with applications to integrative structural biology.

Challenges and tasks:

The overall research topic of the current project is to extend the state-of-the-art computational methods for small-angle (both SAXS and SANS) scattering experiments and to provide the algorithmic foundation to the upcoming single-molecule experimental techniques. In particular, the practical aim of the project is the development of software tools with intuitive user-interaction feedback.

Mathematically, the project will rely on the very efficient representation of the scattering profiles based on polynomial expansions of the scattering amplitudes using spherical harmonics. Structural optimization will be performed using the fast Fourier transform—accelerated techniques and the polynomial translation theorems and large collective structural motions using Normal Mode Analysis.

Three main axes of the proposed project are:

- (i) Molecular flexibility and the ways of modelling it;
- (ii) Algorithmic developments for new experimental setups, particularly combining SAXS and SANS data, and 2D scattering;
- (iii) Practical software development with intuitive user interfaces. Below we detail the main research axes of the project.

More precisely, the planned developments include the following:

- Modelling thermal fluctuations (see review by Hub, 2018) using an analytical model of the scattering profile resulting from thermal molecular vibrations. This will be possible thanks to the (i) expression of normal modes in spherical coordinates expanded in the Spherical Harmonics basis, and (ii) computing molecular fluctuations in this basis analytically using the algebra for triple and quadruple overlap integrals of spherical harmonics.

Informations générales

- Thème/Domaine: Schémas et simulations numériques
- Ville: Grenoble
- Centre Inria: CRI Grenoble - Rhône-Alpes
- Date de prise de fonction souhaitée: 2018-10-01
- Durée de contrat: 3 ans
- Date limite pour postuler: 2018-08-15

Contacts

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A propos d'Inria

Inria, institut de recherche dédié au numérique, promeut « l'excellence scientifique au service du transfert technologique et de la société ». Inria emploie 2700 collaborateurs issus des meilleures universités mondiales, qui relèvent des défis des sciences informatiques et mathématiques. Inria répond ainsi efficacement aux enjeux pluridisciplinaires et applicatifs de la transition numérique. Inria est à l'origine de nombreuses innovations créatrices de valeur et d'emplois.

L'essentiel pour réussir

We are looking for a motivated person willing to advance the state of the art in the field of integrative structural biology. The essential skills of the candidate include algorithm development and validation, C++ coding and proficiency in computational physics and math.

Conditions pour postuler

Sécurité défense: Ce poste est susceptible d'être affecté dans une zone à régime restrictif (ZRR), telle que définie dans le décret n°2011-1425 relatif à la protection du potentiel scientifique et technique de la nation (PPST). L'autorisation d'accès à une zone est délivrée par le chef d'établissement, après avis ministériel favorable, tel que défini dans l'arrêté du 03 juillet 2012, relatif à la PPST. Un avis ministériel défavorable pour un poste affecté dans une ZRR aurait pour conséquence l'annulation du recrutement.

Politique de recrutement: Dans le cadre de sa politique diversité, tous les postes Inria sont accessibles aux personnes en situation de handicap.

Attention: Les candidatures doivent être déposées en ligne sur le site Inria. Le traitement des candidatures adressées par d'autres canaux n'est pas garanti.
Flexible fitting of atomistic structures into small-angle scattering profiles. This includes combination the Pepsi-SAXS / Pepsi-SANS engines with the NOLB NMA method for the large-scale flexible structure optimization along the lowest-frequency normal modes. A working prototype exists, however, a proper analytical optimization technique with respect to the goodness of fit should be added. Also, the method needs to be extended to SANS data. Finally, the method needs to be made more robust and user-friendly, possibly, with a GUI inside the SAMSON modelling platform.

Application of motion planning to adapt the sampling techniques for flexible unstructured regions of the molecule.

In some cases it is impossible to represent the molecular structural heterogeneity continuously. This situation will require fitting the experimental SAS curves with an ensemble of structures. Therefore, we plan to extend the Pepsi-SAXS / Pepsi-SANS methods for the cases of multiple models, whose contributions will be adjusted with stochastic optimization techniques.

We will consider the case when the molecular system can be represented with a set of rigid domains. Here we can compute scattering profiles for supra-molecular assemblies based on the precomputed scattering amplitudes of individual rigid bodies with subsequent rigid-body transforms applied to the amplitudes in the Fourier space.

Fitting of atomic-resolution structures into multiple profiles obtained in different experimental configurations from the same sample. Indeed, the current modelling pipelines merge different experimental measurements into a single scattering profile. This approach has a significant drawback since the scaling factors for individual scattering components are generally unknown and can be erroneously guessed upon merging. A much more general, and also more computationally elegant approach would be to adjust the scaling factors of individual scattering profiles upon fitting atomistic models into multiple scattering curves. This approach would also have an obvious advantage of mixing different experimental information, e.g. SAXS and SANS experiments.

Novel developments for 2D scattering based on the spherical harmonics and cylindrical harmonics representation. Many elongated or polymeric molecules can be aligned in space along the magnetic field. Thanks to this spatial alignment, their scattering profiles wouldn't be axially symmetric any longer and will contain much more information compared to profiles from spherically averaged particles. We plan to extend the current method for analytical cylindrical averaging of spherical harmonics with multiple advantages over the standard approaches.

References:

Collaboration:
The recruited person will be in connection with
1. computational expert Sergei Grudinin from Inria / CNRS Grenoble
2. bioSAXS experts Anne Martel and Sylvain Prevost from ILL Grenoble
3. 2D fiber diffraction experts Trevor Forsyth, and Estelle Massou From ILL Grenoble
4. an instrument scientist at BioSAXS Martha Brennich from EMBL Grenoble

Principales activités
This is a very challenging project whose aim is to change the modelling paradigm in the small-angle community. It has many ambitious goals both on the algorithmic side and also considering software applications. The main activities of the candidate will be algorithms and code developments including the following:

- Combination of the existing software tools that model molecular flexibility (deformations along the slowest normal modes, rigid-body perturbations of rigid domains, modeler of flexible loops using robotics techniques) into a unified library and link it with the Pepsi-SAXS library. Then, multiple tests should be performed, and probably novel benchmarks should be created.
- Adaptation of the developed methods for SAXS scattering and flexible fitting of molecular models into scattering profiles for SANS experiments. Computationally, it is an easy and straightforward task, however, numerous tests should be performed and very convenient software released.
- Formulation of the local refinement problem in the basis of Spherical Harmonics (SH). This is a challenging task, since no scattering methods that use analytical gradients in the SH basis have been developed.
- Developments for scattering of aligned objects and single-particle experiments
- Creation of practical interactive GUI interfaces with force feedback computed from the experimental scattering profiles. This is a challenging task, however, we have already done attempts for the integration of the NOLB NMA and Pepsi-SAXS methods inside the SAMSON modular simulation platform (see https://www.samson-connect.net) Again, the most difficult part will be to create convenient and interactive software tools.

Compétences
Technical skills and level required: the candidate must be proficient in computer science, computational physics and applied math. Excellent knowledge of C++ and linear algebra are strictly required.

Languages: excellent oral, written and interpersonal communication skills are essential (working language will be English – knowledge of French is a plus).

Relational skills: the candidate will have to communicate with the software developers at the side of the Inria partner, instrument scientists at the side of EMBL-ILL partners, and also with numerous users of the small-angle instruments at ILL and ESRF facilities.

Other valued appreciated: we are looking for creative, passionate and hard-working individuals with exceptional talent for computer science and mathematics.
Avantages sociaux

- Subsidised catering service
- Partially-reimbursed public transport
- Social security
- Paid leave
- Flexible working hours
- Sports facilities

Rémunération

Salary: 1768.55 € gross/month paid by university