Inria

Job vacancy #2023-05954

Post-Doctoral Research Visit F/M MRF-zero: Magnetic Resonance Fingerprinting sequence optimization via optimal control

Contract type : Fixed-term contract

Level of qualifications required : PhD or equivalent

Fonction : Post-Doctoral Research Visit

Level of experience : Recently graduated

About the research centre or Inria department

The Centre Inria de l'Université de Grenoble groups together almost 600 people in 22 research teams and 7 research support departments.

Staff is present on three campuses in Grenoble, in close collaboration with other research and higher education institutions (Université Grenoble Alpes, CNRS, CEA, INRAE, ...), but also with key economic players in the area.

The Centre Inria de l'Université Grenoble Alpe is active in the fields of high-performance computing, verification and embedded systems, modeling of the environment at multiple levels, and data science and artificial intelligence. The center is a top-level scientific institute with an extensive network of international collaborations in Europe and the rest of the world.

Context

Collaboration between Inria team Statify & the neuroimaging team of Grenoble Institute of Neuroscience:

This project involves Statify and Grenoble Institute of Neuroscience (GIN). T. Christen (CR Inserm) will be the main contact at GIN. T. Christen has established national and international collaborations on the topic of MRF and has an ongoing partnership with Philips on clinical MRF developments. The additional expertise of P. Rodrigues (CR Inria) and F. Forbes (DR Inria), in particular in inverse problems in a MRI context (Rodrigues et al 2021, Jallais et al. 2021, Boux et al. 2021), will be provided as MRF requires better theoretical characterizations for practical use.

Assignment

Key words: Magnetic Resonance Fingerprinting, sequence optimization, simulation-based inference, POMDP, optimal control, reinforcement learning, sensitivity analysis, Bayesian optimal design.

Theme / Domain: The main topics of this proposal are in Bayesian inverse problems, optimal experimental design, stochastic approximation and reinforcement learning.

Context and motivation: Traditional Magnetic Resonance (MR) imaging is based on an analytical resolution of dynamical equations using conventional tuning of the MR hardware through sequences of pulses, each characterized by different values of parameters such as the flip angle and repetition time. In conventional MRI, sequences are relatively simple and give access to only qualitative information and for a limited number of tissue properties. The concept of Magnetic Resonance Fingerprinting (MRF), introduced in Nature (Ma et al 2013), has been a great step toward unleashing the full power of MRI by allowing single 'sequences' to randomly excite tissues and be sensitive to multiple parameters at the same time. This concept allows the simultaneous measurements of multiple quantitative maps with extremely undersampled raw images, thus saving considerable acquisition time (McGivney et al 2019). Thus, MRF could be a game changer for emergency patients (eg. stroke) who need complete exams in a few minutes. However, when more than 3 parameters are considered, the current acquisition (>20 min) and reconstruction times (hours to days) are too long. Although promising, MRF, introduced almost 10 years ago now, has not yet reached the hospital because theoretical problems remain to be solved.

Contact: florence.forbes@inria.fr, pedro.rodrigues@inria.fr , thomas.christen@univ-grenoble-alpes.fr

Main location: Inria Montbonnot, Statify team https://team.inria.fr/statify/

Main activities

Summary: Magnetic Resonance Fingerprinting (MRF) is a recent technology which has the potential to become a game changer in radiology and medicine. In contrast to conventional MRI, MRF opens up a design space of thousands of tunable parameters over which to search for optimal sequences. We propose to generate such optimal sequences by investigating optimal control and reinforcement learning techniques.

Approach: MRF involves complex inverse problems and a number of challenges that call for the development of innovative methods. First, (1) the direct MRF model is only available through complex simulations and these simulations are costly both in time and memory requirements. Then (2) observed MRF signals are high dimensional and cannot be handled with mainstream learning approaches. (3) The MRF goal is to produce parameter maps (images) so that the inference procedure has to be repeated a large number of times (eg for millions of voxels). (4) Parameters to be reconstructed are correlated and more or less informed by the MRF signals, the noise level and possible acquisition artifacts (eg motion). Their reconstruction has to be associated with a confidence index and calls for uncertainty quantification. (5) At last, MRF acquisition can also be ultimately optimized from manually designed sequences to automated ones. We propose to investigate this possibility through optimal control or reinforcement learning techniques. This is crucial when more than a few parameters are considered.

Goal: MRF sequence optimization via stochastic optimal control

In contrast to conventional MRI which uses limited human-design sequences, MRF extract quantitative tissue information from pseudo-random pulse sequences. However, the sequence's acquisition parameters must be carefully chosen for the tissue parameter quantification to be accurate. By allowing arbitrary pulse sequences, MRF opens up a design space of thousands of tunable parameters over which to search for pulse sequences achieving substantially improved performance.
The high dimensionality of the search space requires advanced optimization techniques. Some attempts can be found in the literature (Jordan et al 2021, Loktyushin et al 2020). They are formulated as supervised learning problems that need pairs of input-output examples. They focus on conventional MRI or MRF restricted to two parameters (T1 and T2 measurements). In this work, we target clinical applications which require to go beyond T1 and T2 reconstruction and traditional Bloch equations (Christen et al 2014). Another limitation of supervised methods is to require a comprehensive and large dataset of input sequences and output parameter maps which may be impossible to produce. To bypass this issue, we plan to investigate solutions that can generate optimal sequences solely governed by the target provided. We propose to formulate our MRF context as a sequential decision process and to investigate reinforcement learning (RL).

References:

[Boux et al 2021] F. Boux, F. Forbes, J. Arbel, B. Lemasson, E. Barbier. Bayesian inverse regression for vascular magnetic resonance fingerprinting. IEEE Trans. on Medical Imaging 2021.
[Brossard et al 2020] C. Brossard, O. Montigon, F. Boux, A. Delphin, T. Christen, E. L. Barbier, and B. Lemasson, MP3: Medical Software for Processing Multi-Parametric Images Pipelines, Frontiers in Neuroinformatics, vol. 14, p. 53, 2020.}
[Christen et al 2014] T. Christen, N. A. Pannetier, W. W. Ni, D. Qiu, M. E. Moseley, N. Schuff, and G. Zaharchuk, MR vascular fingerprinting: A new approach to compute cerebral blood volume, mean vessel radius, and oxygenation maps in the human brain, NeuroImage, vol. 89, pp. 262–270, 2014.

[Jallais et al. 2022] M. Jallais, P. Rodrigues, A. Gramfort, D. Wassermann. Inverting brain grey matter models with likelihood-free inference: a tool for trustable cytoarchitecture measurements. J. of Machine Learning for Biomedical Imaging.

[Jordan et al 2021] S. P. Jordan, S. Hu, I. Rozada, D. F. McGivney, R. Boya- cioglu, D. C. Jacob, S. Huang, M. Beverland, H. G. Katzgraber, M. Troyer, M. A. Griswold, D. Ma. Automated design of pulse sequences for magnetic resonance fingerprinting using physics-inspired optimization. PNAS, 118(40),2021.

[Loktyushin et al 2020] Loktyushin, A., Herz, K., Dang, N., Glang, F., Desh- mane, A., Weinmuller, F., et al. Fully automated invertion of MRI sequences using supervised learning. arXiv preprint.

[Ma et al 2013] D. Ma, V. Gulani, N. Seiberlich, K. Liu, J. L. Sunshine, J. L. Duerk, and M. A. Griswold, Magnetic resonance fingerprinting, Nature, vol. 495, no. 7440, pp. 187–192, 2013.

[McGivney et al. 2019] Magnetic resonance fingerprinting review part 2 : Technique and directions. J. Magn. Reson. Imaging (2019).

[Rodrigues et al 2021] P. Rodrigues, Thomas Moreau, Gilles Louppe, A Gramfort. Leveraging global parameters for flow-based neural posterior estimation. NeurIPS, 2021.
[Walker-Samuel 2019] Using deep reinforcement learning to actively, adaptively and autonomously control a simulated MRI scanner. Proc. of ISMRM 2019.
[Zhu et al 2018] B. Zhu, J. Liu, N. Koonjoo, B. R. Rosen, M. S. Rosen, AUTOmated pulse SEQuence (AUTOSEQ) generation using Bayesian reinforcement learning in an MRI physics simulation environment. Proc. ISMRM 2018.

Skills

Technical skills and level required :

Languages : good English skills both written and spoken

Relational skills : good team working skills

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Remuneration

- 2746 euros gross salary/month

General Information

- **Theme/Domain :** Optimization, machine learning and statistical methods
  Statistics (Big data) (BAP E)
- **Town/city :** Montbonnot
- **Inria Center :** Centre Inria de l'Université Grenoble Alpes
- **Starting date :** 2023-10-01
- **Duration of contract :** 2 years
- **Deadline to apply :** 2023-12-31

Contacts

- **Inria Team :** STATIFY
- **Recruiter :**
  Forbes Florence / florence.forbes@inria.fr

About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

The keys to success

Skills required: computer science, applied mathematics, interest for statistics and machine learning applied to medical data

We look for candidates strongly motivated by challenging research topics. The applicant must have an excellent background in statistics and machine learning, and good programming skills. A knowledge of the following methods will be helpful: simulation-based inference, reinforcement learning, POMDP, Bayesian statistics, Bayesian optimal experimental design.

Good skills in at least R or python is required.

Warning : you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

Instruction to apply

Defence Security :
This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST).Authorisation to enter an area is

granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

Recruitment Policy :
As part of its diversity policy, all Inria positions are accessible to people with disabilities.