Self-supervised Learning for Cardiac MRI: Fast Image Reconstruction and Prescription

Supervisors: Dr Mehrdad Yaghoobi (Engineering) m.yaghoobi-vaighan@ed.ac.uk,

Dr Lucy Kershaw (Edinburgh Imaging Facility QMRI) Lucy.Kershaw@ed.ac.uk

Abstract: Cardiac Magnetic Resonance Imaging (Cardiac MRI) has been used as a non-invasive method for medical diagnostics. It aims to incorporate the heart movements and deformations and reconstruct 3D, or 3D+time, images. However, there are challenges in imaging with fewer K-space samples, for fast imaging, and making the process self-driving to facilitate the widespread use of this approach.

This project wants to use recent deep learning methodologies in self-supervised learning to avoid labelling biases (due to ambiguities in labels), and to use a larger corpus of unlabelled data, through an underlying discovered structure, called representation space. Specifically, we aim to improve the robustness of image reconstructions and analyses, and make the solutions scanner-agnostic, eventually implementing this in an open reconstruction framework that allows user algorithms to reconstruct images on the scanner at run-time rather than requiring off-line reconstruction.

Introduction: Magnetic Resonance Imaging (MRI) is a non-invasive and radiation-free tool for clinical diagnostics. Despite its numerous applications in medical diagnostics, it suffers from a relatively slow acquisition, which needs patients to stay in the scanner for often more than half an hour. For cardiac imaging this is compounded by the need for breath-holding and ECG gating to compensate for respiratory and cardiac motion. Various methods have been proposed to accelerate the acquisition time, including multi-element and compressed sensing frameworks, but cardiac MRI is still less popular than conventional MRI, partly due to the complicated scanning protocols and image prescription [1].

Research Challenge:

The recent successes of deep learning in Cardiac MRI reconstruction and analysis are promising for self-driving scanners doing most scanner setting up automatically, which can make them widely available for precision cardiovascular imaging. There are still concerns about the approaches which need to be addressed, including:

I) Robustness: when small errors at scan time does not significantly change the outcomes.

II) Generalization: with respect to distribution shifts, i.e. changes from patient to patient.

III) Scanner agnostic: with respect to changing the scanner type, e.g. number of coil elements [2] and manufacturer specifications.

IV) Reliability on the manually labelled data: by avoiding human generated labels or robustness to the label errors

In the image reconstruction domain, labelled data means reconstructed images, which is needed for the supervised leaning. The images are not often particularly high-resolution due to longer per patient scan time, which can be practically problematic in large-scale data-collection trials. This can be a serious barrier in high-resolution reconstruction, using such datasets.

Data & Methodology:

Data: The aim of this project is to go beyond the current mainstream of research which uses fully labelled data, e.g. [3]. A few datasets are available with limited labels, such as CMRxRecon [4], UK Biobank [5] and Harvard Dataverse [6] (see supplementary material of [1] for a comprehensive list).

Moreover, we aim to use some existing datasets in the university for this task, from cardiac MRI studies conducted at Edinburgh Imaging in recent years. Imaging that captures heart wall motion during a breath-hold is collected as standard for cardiac MRI studies, resulting in many available datasets. As we need to validate the performance of algorithms on more realistic scenarios, we aim to collect validation data at Edinburgh Imaging Facility QMRI during this project.

Methodology:

The self-supervised learning (SSL) paradigm, see [7] for an overview, has numerous advantages when we apply the method in K-space, including, a) not being restricted to the provided image resolution, b) being robust to the patient's anatomical diversity by avoiding ambiguities in parameters during labelling, e.g. myocardial wall thickness, c) avoiding overfitting to the available labelled datasets, if larger (but unlabelled) datasets are available, i.e. generalisation, and d) updating during the life-time function, as it does not need model re-training in a supervised setting, which is helpful when we have distribution shift during the operation.

The SSL includes two distinct steps, a) generating labels for the data in some pretext tasks, and b) training for the down-stream tasks using generated labels. The first step is often done through representation learning [7], e.g. similarity and contrastive learning. The project aims to generate cardiac MRI pretext labels, e.g. high-resolution images through resolution enhancement methods and reconstructed image segmentation, then to train to do the reconstruction and analysis based on the pretext labels. The challenge to address, similar to other SSL methods, is how reliable the labels are. This project will derive metrics to quantify the accuracy of the pretext tasks.

RRI/Ethical Considerations:

The aim of this project is to enable use of the technology in a wider community, in terms of providing solutions for self-driving MRIs. The success of the project directly impacts society in terms of ease of accessibility to an effective medical diagnostic technology. Specifically, it provides faster scans with less reliance on breath holds and ECG gating for ill patients.

Most of the investigation will be done using publicly available datasets, which need to be checked in terms of ethical consideration during data collection. For in-house data collected as part of previous studies, the relevant Principal Investigator will be approached to request data re-use if this is permitted under the original study consent form. Any data used will already be pseudonymised, with no access to the key linking study ID to patient name. Should additional ethical opinion be required for data reuse, or if data are collected prospectively for this study, an application will be made via the Medical School research ethics committee.

Expected Outcome and Impact:

The outcome of this project is twofold, a) research impact, and b) training of a researcher. The developed ML models will facilitate the used of Cardiac MRI by reducing the complexity of the operation, and needing the prescription by a specialist, when the expertise can be used in the later stage in medical diagnosis. Besides making the developed code publicly available for impact generation, we aim to release the data which will be produced during the study (subject to favourable ethical opinion and complete anonymisation, i.e. removal of original study ID).

The PhD researcher will learn about the physics and clinical aspects of Cardiac MRI, signal acquisition and processing, and machine learning techniques during this project. The student will have the opportunity to engage with cardiologists, radiologists and radiographers to understand their requirements for patient comfort, straightforward acquisition and image quality.

References:

[1] Morales MA, Manning WJ, Nezafat R. "Present and Future Innovations in AI and Cardiac MRI. Radiology. 2024 Jan 9;310(1).

[2] Liu J, Qin C, Yaghoobi M. Coil-Agnostic Attention-Based Network for Parallel MRI Reconstruction. InProceedings of the Asian Conference on Computer Vision 2022 (pp. 2866-2883).

[3] J. Liu, C. Qin and M. Yaghoobi, "Deep Network Cascade for Dynamic Cardiac MRI Reconstruction with Motion Feature Incorporation and the Fourier Neural Attention," in IEEE Transactions on Computational Imaging, doi: 10.1109/TCI.2024.3402335.

[4] Wang C, Lyu J, Wang S, et al. CMRxRecon: An open cardiac MRI dataset for the competition of accelerated image reconstruction[J]. arXiv preprint arXiv:2309.10836, 2023

[5] https://www.ukbiobank.ac.uk/

[6] https://dataverse.harvard.edu/dataverse/cardiacmr

[7] Ericsson L, Gouk H, Loy CC, Hospedales TM. Self-supervised representation learning: Introduction, advances, and challenges. IEEE Signal Processing Magazine. 2022 May 6;39(3):42-62.