MR-based Synthetic CT Generation across Different Regions of the Entire Body with Deep Learning Methods

Team: TBD

Supervisor: Mariia Lapaeva, Prof. Dr. Manuel Günther

Intended Start: February 2025 **or earlier**

1 Introduction

Cancer is still one of the leading causes of death worldwide and half of the patients receive radiotherapy in the course of treatment. At present, both Magnetic Resonance (MR) and Computed Tomography (CT) images are used for the irradiation planning. MR images are used for delineating tumors and organs at risk due to their excellent soft tissue contrast. However, MR images do not provide a direct estimate of the tissue's electron density, which is required for radiation dose calculations. That is why CT images still play a fundamental role, although among their disadvantages is the increased radiation exposure of the patient. Eliminating CT images from the workflow can help to reduce radiation exposure and introduce a more cost-efficient workflow.

Deep Learning (DL) methods have emerged as an effective method for synthetic CT (sCT) generation. Similar to how image translation algorithms convert a photo to resemble Van Gogh's art, DL models are capable to translate MR images into sCT, offering faster inference times, making them more suitable for clinical settings. Our previous research [Lapaeva et al., 2022, Dal Bello et al., 2023, Saint-Esteven et al., 2023] showed that Generative Adversarial Networks (GANs) such as Pix2Pix [Isola et al., 2017] or CycleGAN [Zhu et al., 2017] can demonstrate clinically acceptable performance in the sCT generation task. However, most previous research has focused on specific body regions, with almost no work done to assess the clinical applicability of DL-based sCT generation methods across the entire body.

This master project is centered around the prestigious SynthRAD2025 Challenge,[1] the largest hackathon dedicated to synthetic CT (sCT) generation from MRI and from Cone-Beam CT (CBCT) data. One of the primary focus of the project is to develop and submit high-performing models to the competition. Our research group has already developed effective GAN-based models for the abdominal region [good basis to start with]. Your goal will be to fine-tune these existing approaches, explore alternative Deep Learning architectures, and extend the methods to achieve full-body sCT generation.

[1] `https://synthrad2025.grand-challenge.org/rules`

2 Research Objectives

This research will be conducted in collaboration with Mariia Lapaeva,[2] who is currently working in the Department of Radiation Oncology at the University Hospital Zurich (USZ). The objectives of this Master project are as follows:

1. Suggest and examine strategies for the utilization of Deep Learning (DL)-based methods for full body sCT generation (GANs, potential application of diffusion models [Pan et al., 2024], transfer learning techniques).
2. Assess the generalizability and clinical applicability of DL-based methods for sCT generation by analyzing their effectiveness across different regions of the entire body, ensuring consistent and accurate sCT generation in diverse anatomical areas.
3. Submit the best performing models to the SynthRAD2025[1] hackathon.

Since the aim is to submit a model to the SynthRAD2025[1] hackathon, there are a few Requirements:

- Curiosity and motivation for the topic
- Initial familiarity with deep learning methods (for example taught in my Deep Learning course) and Image Processing
- Solid command of Python and acquaintance of the PyTorch deep learning framework
- Availability: must be available during the SynthRAD 2025 Challenge period, specifically in the Spring semester of 2025 (March to June at a minimum)

This Master project provides several opportunities:

1. **Contribute to the Advancement of AI in Healthcare and cancer treatment:** By participating in this project, you will have the opportunity to contribute to the development of AI methods that can improve the quality of life and treatment outcomes for cancer patients.
2. **Prestigious Hackathon Experience:** Join the project centered around the SynthRAD 2025 Challenge, the largest hackathon dedicated to synthetic CT (sCT) generation from MRI data. Gain practical experience and compete for awards, all while contributing to advancements in medical imaging.
3. **Hands-On Experience with Deep Learning Methods:** Engage deeply with advanced Deep Learning techniques, focusing on DL NN designed for synthetic CT (sCT) generation. The USZ research group offers an established sCT generation workflow across multiple anatomical areas, providing you with a solid foundation to build on.
4. **Tailored Learning Experience:** Depending on your knowledge of medical image analysis (no prior knowledge is required, as it can be learned on the go), the project objectives can be adjusted to fit your current expertise. Whether you are looking for a gradual learning curve or a deeper dive into complex cases such as implant handling, the project can be customized to match your goals.
5. **Collaborative Environment:** Join the collaborative research group at USZ with the great team spirit.
6. **Potential for Publication:** Your contributions to this project may result in a co-authored publication, providing you with the opportunity to make an impact in the scientific community and enhance your academic profile.

If this project sounds appealing to you, write an email to: mariia.lapaeva@uzh.ch, manuel.guenther@uzh.ch briefly describing your interest and any relevant experience with programming projects. Do not hesitate to reach out with any questions.

[2] `https://www.usz.ch/team/mariia-lapaeva`

3 Schedule

Assuming 30 hours of work per week and a total of 15 ECTS with an average of 30 hours per ECTS, we arrive at a total workload of 15 weeks full-time. These could be distributed as follows:

Week 1-3 Get familiar with medical data processing, set up the work environment, install all required tools, and (partially) reproduce the results that are currently available at USZ.

⇒ Milestone 1: Existing work is replicated using existing pre-trained networks.

Week 4-5 Prepare a dataset containing various body regions from the data available at USZ. Train an image-to-image translation network (Pix2Pix, CycleGAN, or alike) under the guidance of existing code on the extended body region.

Week 6-8 Perform a guided literature review and search for available open-source implementations of image-to-image translation networks, including diffusion models. Try out these implementations on the data available at USZ and compare their performance with the results of the previous models.

⇒ Milestone 2: At least one new network type is trained on the USZ data and compared to previous models.

Week 9-12 Focus on training the networks for the challenge-specific MR-to-sCT translation task, by downloading the challenge dataset[1] (available from March 1, 2025) and implementing training and testing protocols.

⇒ Milestone 3: A first version of the new model for MR-to-sCT translation is trained and evaluated on the challenge dataset.

Week 13-15 Improve the performance of the new model by performing parameter optimization techniques. Submit the best performing models to the SynthRAD challenge (final deadline on August 15, 2025).

⇒ Milestone 4: At least one model is submitted to SynthRAD.

If time allows Train a model on the CBCT-to-sCT translation task provided in the challenge.[1]

The project is designed for two to four students. For two students, the focus should be on implementing and testing sCT generation tools for the full body, as provided in the challenge. When more students are present, more types of MR-to-sCT translation tools should be tested, and hyperparameter tuning should be performed to improve results.

Writing the project report is part of the Master project. As a template, the LaTeX thesis template from my webpage[3] should be used. I would recommend to start writing early and keep note of what was done when, and by whom. At the end of the project, there will be a joint presentation of the results in my research group.

4 Deliverables

There are three types of deliverables that are expected – additionally to the submission of the model to SynthRAD – which contribute to the grading process using the following criteria.

- Project Report (40 %): Describe the work that has been done. Include at least related work, methodology, experimental setup, results and conclusion. Make use of the AIML LaTeX template.[3]
- Project Presentation (30 %): Present the main findings of your project in 30 minutes to an internal audience containing people from USZ and the AIML group. Answer emerging questions from the audience.
- Implementation (30 %): Code should be implemented in a comprehensible, maintainable, reusable and extensible manner, including decent documentation. Open-sourcing the code is a surplus.

[3] https://www.ifi.uzh.ch/en/aiml/theses.html

5 References

[Dal Bello et al., 2023] Dal Bello, R., Lapaeva, M., La Greca Saint-Esteve, A., Wallimann, P., Günther, M., Konukoglu, E., Andratschke, N., Guckenberger, M., and Tanadini-Lang, S. (2023). Patient-specific quality assurance strategies for synthetic computed tomography in magnetic resonance-only radiotherapy of the abdomen. *Physics and Imaging in Radiation Oncology (phiRO)*, 27.

[Isola et al., 2017] Isola, P., Zhu, J.-Y., Zhou, T., and Efros, A. A. (2017). Image-to-image translation with conditional adversarial networks. In *Conference on Computer Vision and Pattern Recognition (CVPR).*

[Lapaeva et al., 2022] Lapaeva, M., La Greca Saint-Esteven, A., Wallimann, P., Günther, M., Konukoglu, E., Andratschke, N., Guckenberger, M., Tanadini-Lang, S., and Dal Bello, R. (2022). Synthetic computed tomography for low-field magnetic resonance-guided radiotherapy in the abdomen. *Physics and Imaging in Radiation Oncology (phiRO)*, 24.

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[Zhu et al., 2017] Zhu, J.-Y., Park, T., Isola, P., and Efros, A. A. (2017). Unpaired image-to-image translation using cycle-consistent adversarial networks. In *International Conference on Computer Vision.*