PhD Thesis Title: Towards a Smarter Healthcare: The Role of Deep Learning Supporting Biomedical Analysis

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ABSTRACT:

Medical imaging has been increasingly relevant in modern healthcare and has tremendously progressed in the last few decades. In addition, the latest years also witnessed the incredibly fast rise of Artificial Intelligence (AI) and its application in a wide range of application domains. Interestingly, AI techniques proved to be quite effective at tackling tasks in the healthcare sector and considered crucial. For instance, when AI is applied to medical imaging, it renders more precise diagnoses and more effective treatments. Among all AI techniques: industry, academia and popular culture have all recently taken a particular interest in Machine Learning (ML), largely due to very effective developments like the breakthroughs in Deep Learning (DL), that allow one to locate patterns in vast amounts of data by applying a proper set of algorithms and methodologies. Several image analysis techniques are subject to constant attention by the scientific community, including image synthesis, segmentation, disease diagnosis and computerized surgeries. In this thesis, we present the findings of our studies in the field along with our research activities, which have been mainly focused on two important topics: Image synthesis for MR-only radiotherapy and lesion segmentation.

Our first topic is related to image synthesis. In image synthesis, images are artificially generated that contain a specific content. An analogy would be generating an image containing the visual content associated with any given label as the inverse of the classification problem. Medical images can be produced using diverse imaging protocols, each with unique characteristics. A medical image synthesis method has been extensively explored for clinical applications owing to the high costs associated with scanning high-quality single modalities of images or homogeneous multiple modalities of images. For medical image synthesis, deep learning approaches, particularly convolutional neural networks (CNNs) and generative adversarial networks (GANs), have become increasingly popular over the past few years. MR-based CT synthesis is the objective of this thesis as it pertains to MR-only radiotherapy. Using clinically relevant quality measures, we evaluated different categories of CT synthesis methods. For the brain images specifically, we have implemented a Deep Convolutional Neural Network (DCNN) based method and provided a variety of loss functions, which compare favorably to state-of-the-art methods. Next, we review recent methods of image synthesis through systematic

literature reviews. In our next effort, we substantially improved our model by using the attention mechanism to improve the quality of images not only in terms of intensities but also based on structural similarity. Since the scientific community is more focused on the intensities of the images. But the structure and borders of the image are also important for synthetic image accuracy.

The second topic of this thesis explores how to segment lesion patterns in Computed Tomography (CT) scans. Segmentation is an important operation in Computer Vision. By segmenting images, we group objects that belong to the same class in an image. It is also referred to as pixel-level classification. Another way to describe this, it is splitting an image (or video frame) into multiple segments or objects. In medicine, image segmentation is often used to estimate tissue volumes or extract tumor boundaries. For example, image databases can be created that can be used to analyze pandemics and fast-spreading diseases. Medical imaging data for emerging infectious diseases is constrained by a limited size of publicly available datasets, which requires large-scale annotations for better performance. Using convolutional neural networks (CNN), the thesis proposes an unsupervised method that combines Generative Adversarial Network (GAN) with a Convolutional Neural Network (CNN) ensemble to overcome data constraints and effective lesion segmentation. By using the Cycle-GAN, we developed an unsupervised method for converting infected images into healthy ones. In our proposed adversarial network, an attention-based mask generator is used to improve this method. Data infected with COVID-19 was used to demonstrate this. Comparatively to state-of-the-art approaches, this method gives us a more accurate representation of lesions. Lesion segmentation can be done efficiently with this approach since it does not require annotated data and it is completely unsupervised. This manuscript is presented in two parts: the first one illustrates some background theoretical concepts and reports about our studies of the state-of-the-art in medical imaging and DL, while the second one presents the results of our works on biomedical image analysis via DL techniques. In this thesis, we have provided all the contributions to the scientific community using DL techniques in detail.

References to author publications that relate specifically to the dissertation: https://scholar.google.it/citations?user=uDlA1JgAAAAJ&hl=en