Shallow to Deep Machine Learning Algorithms for Anatomical Structure Segmentation in Clinical Ultrasound and Their Application to High Density Compression

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ULTRASOUND (US) imaging is widely used at primary health-care centers for preliminary investigation, as a low-cost alternative to infrastructure intensive clinical imaging modalities like computed tomography or magnetic resonance imaging. Since speckle intensity in US images is inherently stochastic, clinicians are often challenged in their ability to identify pathological regions while reading a 3D volume which is typically rendered as a large collection of 2D images. While clinicians aspire using image analysis solutions to identify suspicious regions of interest, they are challenged by the limits of data communication framework to transmit and archive for longer period of time such voluminous data.

This thesis presents two different approaches to segment anatomical structures in 2D images and 3D volumes of diagnostic US images. Subsequently these methods are employed to construct the compressor block for a high density US compression. The *first* approach employs mathematical modeling of tissue specific likelihood of speckles within well studied paradigm of US statistical mechanics, thereby employing classical machine learning (ML) techniques like random forests and random walkers to solve segmentation as a tissue posterior prediction problem. The *second* approach employs a data driven approach of associating stochastic US speckles to tissue types employing recent understanding of deep convolutional neural network (CNN) and its adversarial learning for semantic segmentation.

In the *third* contribution, these algorithms are demonstrated for their ability to segment lumen and external elastic luminae in intravascular ultrasound (IVUS) with clinical use demonstrated for inside-out imaging. The classical ML approach obtains a Dice score of 0.916 ± 0.030 assessed on 2D frames and 0.921 ± 0.023 assessed on 3D volume of a whole pullback. The CNN based segmentation approach on the other hand achieves a Dice score of 0.919 ± 0.011 in 2D frames and 0.930 ± 0.080 in 3D volumes.

In the *fourth* contribution, its use is demonstrated for outside-in imaging using the thyroid, to obtain a Dice score of 0.854 ± 0.066 in segmenting 2D frames and 0.889 ± 0.043 with 3D volume segmentation while processing each frame of size 372×252 in under 1.23 ± 0.27 s using classical ML approach. The CNN based approach achieves Dice score of 0.900 ± 0.034 in 2D frames and 0.920 ± 0.060 in 3D volumes, while processing each frame in under 0.035 s using a GPU. A moderate gain in performance measured for a CNN based approach is observed over classical ML, while both near the best case in segmentation. The data driven approach consuming significantly low processing time advocates its use.

In the *fifth* contribution, high density compression of US is presented using the developed segmentation methods. The decompressor is an adversarially learned CNN. Achieving a compression factor of $750\times$, the decompressed images retain pathologically realistic speckles rivaling standards like JPEG and JPEG2000 and recent developments like WebP and BPG. This is demonstrated by the 50% chance of experts to spot an original vs. its compressed version when presented as a pair in a visual Turing test.

Keywords: Adversarial learning, deep convolutional neural networks, gradient vector flow, iterative random walks, random forests, ultrasound segmentation.

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