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Uncertainty-Aware Deep Learning for Image Classification in Pathology

1 Background

Sectra is a high-tech company that develops products in the areas of medical IT and secure communication. The company has customers in over 60 countries and more than 600 employees, with the headquarters located in Linköping, Sweden.

On the medical side they have a strong interest in automated diagnostic systems for radiology and pathology. Pathology is the medical specialty concerned with diagnostics based on microscopy images of tissue and cell smears. Pathology is a crucial component in a vast number of diagnostic processes, in particular those concerning cancer. However, diagnosis based on pathological images, which are often extremely high-resolution and need to be analyzed at different scales, is typically very time consuming. This has lead to an increased interest in developing automated methods for classification and decision support in pathology.

However, for such systems to be widely adopted a reliable quality assurance procedure is of utmost importance. Specifically, the algorithm needs to be able to warn the user of uncertain classifications and anomalies in the data. This is made particularly challenging by the large variations in the characteristics of pathological imagery. In addition to providing quality assurance, uncertainty quantification also enables a dynamic workflow: when the algorithm finds itself in uncharted territory a human expert can be alerted and manually adapt the algorithm parameters to the new scenario.

2 Project Description

The goal of this PhD project is to construct uncertainty-aware methods for quality assurance in pathological image classification. To this end we will make use of state-of-the-art machine learning methods—in particular following the *deep learning* paradigm—and develop new probabilistic models and computational methods for accurate uncertainty quantification.

Deep learning methods are among the current state-of-the-art for image analysis in pathology [7, 2], as well as for many other applications such as text analysis and audio processing. The multiple layers of a deep architecture result in an exponential reduction of the number of hidden units required by an artificial neural network for obtaining a certain level of expressivity, compared to a traditional (shallow) architecture [1]. However, deep neural networks do not readily provide any uncertainty quantification which is a significant drawback, not least when it comes to pathological image classification.

Some attempts have been made to alleviate this: Gal and Ghaharamani [3] exploit the connection between deep learning and Gaussian processes to interpret the deep network as an approximation of a probabilistic model; Renzende, Mohamed and Wierstra [6] use variational auto-encoders to construct *generative* probabilistic models incorporating deep neural networks; [5] propose to use an ensemble of deep networks for quantifying uncertainty. However, this development is still in its infancy and much work remains to be done to bring full-fledged uncertainty-awareness to deep learning.

A starting point for the proposed PhD project will be to investigate generative models, in the vein of variational auto-encoders. These models are likely to be very useful since they enable reasoning about uncertainties, or anomalies, in the input data (i.e., the pathological images). Thus, the algorithm can detect that it is operating in uncharted territory and alert the user. Generative adversarial networks [4] provide another interesting possibility in this direction. We will also investigate new computational methods (e.g. based on efficient Monte Carlo sampling procedures) capable of handling probabilistic extensions of deep networks.

The outcomes of this PhD project will have direct impact on the important problem of automated diagnosis in pathology, but also have far-reaching implications for a wide range of other machine learning applications.

3 Advisors

- Fredrik Lindsten, Department of Information Technology, Uppsala University, `fredrik.lindsten@it.uu.se`
- Erik Sjöblom, Sectra AB, `erik.sjoblom@sectra.com`
- Thomas Schön, Department of Information Technology, Uppsala University, `thomas.schon@it.uu.se`

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