End-to-end Training in Gabor Convolutional Networks

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Before the deep learning era, image processing was often performed with Gabor wavelets [Lee, 1996], mostly in terms of face recognition [Wiskott et al., 1997, Zhang et al., 2005, Günther et al., 2012, Serrano et al., 2010], because they are related with the functioning of the human brain. While much research was only treating Gabor wavelets as pre-processing for follow-up tasks [Zhang et al., 2005], we also have learned important understanding on how to make use of local texture features [Wiskott et al., 1997, Günther, 2012].

Most of the previous knowledge came out of favor when deep learning and convolutional neural networks revolutionized image processing. Instead of using a fixed set of kernels, as represented by Gabor wavelets, convolutional kernels are nowadays learned end-to-end [Krizhevsky et al., 2012] by adapting to the input data. Interestingly, it was shown that these filters automatically learn structures that represent Gabor filters [Krizhevsky et al., 2012], at least partially. Since Gabor filters are typically large (more than 100×100 pixels), for a long time, Gabor filters were not considered in image processing tasks. Only a few and very limited approaches have been made to replace or augment first convolutional filters with Gabor filters [Luan et al., 2018, Alekseev and Bobe, 2019, Rai and Rivas, 2020], but these approaches have not used the complete representational power of Gabor wavelets.

Interestingly, when applying the Gabor filters in frequency domain [Günther, 2012], processing time can be greatly reduced. Recently, a Master project [Duan and Wu, 2024] implemented Gabor wavelet processing in frequency domain using PyTorch [Paszke et al., 2019], which allows including Gabor filters just as a regular network layer – including backpropagation capabilities. The goal of this Master thesis is to make use of this implementation to exploit Gabor wavelet processing for image processing tasks, such as ImageNet classification [Russakovsky et al., 2015]. Gabor filters can be utilized in various different ways, which will be explored in this thesis. For a start, we will rely on gray scale images (a requirement for current Gabor filters), which can be extended to utilize color. Later, non-linearity that mimics brain processing can be applied [Günther, 2012], so that magnitudes and Gabor phases [Günther et al., 2012] can be exploited.

Standard convolutional networks are susceptible to adversarial attacks [Goodfellow et al., 2015], which typically induce high-frequency noise into images. Since Gabor wavelets are immune high-frequency noise by design, such attacks will likely not be successful for Gabor networks. If time permits, the adversarial stability of Gabor networks with respect to this and other types of gradient-based adversarial attacks [Carlini and Wagner, 2017] should be investigated.

Requirements:

- Successful participation in my Deep Learning course.
- A reasonable understanding of complex-valued math, deep neural networks and adversarial attacks.
- Programming experience in python and a deep learning framework, optimally, pytorch.

References

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