Deep Convolutional Neural Networks have achieved remarkable performance on visual recognition problems, and have been extensively adopted in real-world applications. One major concern in the development of CNNs is that their computational complexity grows along with the increase in their accuracy. Therefore, there is a continuous demand to find the right balance between accuracy and complexity in the design of CNN models.

This dissertation focuses on designing various structures to enhance the performance and efficiency of CNNs. Our efforts fall into two categories. One is to explore the redundancy in convolutional neural networks so that comparable learning capability can be achieved with lower complexity. The second is to improve network performance with distinctive structures that can learn better feature representations, yielding negligible complexity by themselves.

To explore the redundancy in CNNs and reduce their complexity, we propose three exclusive designs: Single Intra-Channel Convolutional (SIC) Layer, topological sub-divisioning, and spatial "bottleneck" structure. The SIC layer reduces the redundancy from the disentanglement between spatial 2D convolution and linear projection. Topological sub-divisioning is introduced to reduce the density of connections between input and output channels. The Spatial "bottleneck" structure takes advantage of the correlation between adjacent pixels in the spatial dimension to reduce the complexity without reducing the spatial resolution of the subsequent layer.

Since the most straightforward approach for boosting network performance from the non-linearity perspective is to design more powerful activation functions, we design a unique Look-up Table Unit activation function that learns the shape of the activation function from the data and provides sufficient non-linearity to the network to learn more complex feature representations. We also propose a novel layer, referred to as a Wide Hidden Expansion (WHE) layer, to substantially increase the number of activation functions along with the implicit hidden-channel increase, enhancing the performance of different network architectures.