Convolutional Neural Network: Analysis and its significance in Image Segmentation

CNN is the most widely used deep learning Neural Network for image processing. **Convolutional Neural Networks** are a category of **Neural Networks** that have proven very effective in areas such as image recognition, image segmentation, classification, computer vision and natural language processing. We must have heard lot about the applications of CNN in different scenarios, but not from the general perspective. Here, I aim to provide some novel ideas which are proposed recently about CNN and its significance in image segmentation.

So, where do we start!!!. First, let's talk history for a bit and how it evolved so fast over the past few years and then we dig into analyzing it and talk more about applications and prospects of CNN in this fast-growing field. Second, we will continue to explore about its implementation in image segmentation process.

Introduction: Computer Vision is an interdisciplinary field of science that aims to make computers process, analyze images and videos and extract details in the same way a human mind does. Convolutional Neural Network in computer vision has enabled people to accomplish what had been considered impossible in the past few centuries, such as face recognition, autonomous vehicles, self-service supermarket, and intelligent medical treatment. CNN in general is emerged from Artificial Neural Network (ANN). Artificial neural networks were great for the task which wasn't possible for Conventional Machine learning algorithms.

History: In 1943, a mathematician named McCulloh and pitts proposed the first mathematical model of neurons called as MP (Multi-layer perceptron) model. The concept of CNN was not a new one. It all started from the discovery of Hubel and Wiesel which explained that there are simple and complex neurons in the primary visual cortex and the visual processing always starts with simple structures such as oriented edges. The term '*Convolution*' was first used by LeCun et al, he constructed a convolutional neural network for a handwritten zip code recognition which is the original version of LeNet. In 2012, Alex et al achieved the best classification result using deep CNN in the ImageNet Large Scale Visual Recognition

Challenge (LSVRC). Some of the classic CNN-based models are LeNet-5, AlexNet to MobileNet v3 and GhostNet.

Convolutional neural network is a kind of feedforward neural network that can extract features from image data with convolution structures. The architecture of CNN is inspired by visual perception. We also have activation functions in CNN which are used to simulate the neurons when electrical signals exceeding a certain threshold is transmitted. Loss functions and optimizers are quite a thing people invented to teach the whole CNN system to learn.

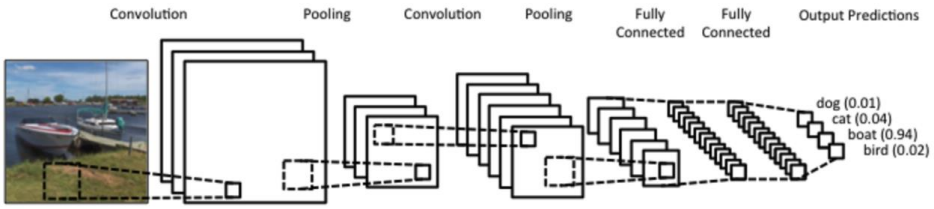

Fig. CNN Architecture

Differences in CNN from ANN:

- Each neuron is no longer connected to all neurons of the previous layer.
- Reduces the number of parameters and speed up convergence.
- A group of connections can share the same weights.
- Down-sampling dimensionality reduction.

In order to build a CNN model, four components are typically needed.

Padding: When setting a convolution kernel with a certain size, we will lose information in the border. Hence, padding is required to enlarge the input size with zeros.

Stride: To control the density of convolving, stride is employed. Larger the stride, lower the density.

Feature maps: Convolution is a pivotal step for feature extraction. The outputs of the convolution layer are called as feature maps. This map consists of large number

of features which is prone to cause overfitting. So, to solve this we will use a technique called pooling.

Pooling: It is used to eliminate redundancy. We have two types one is max pooling and average pooling.

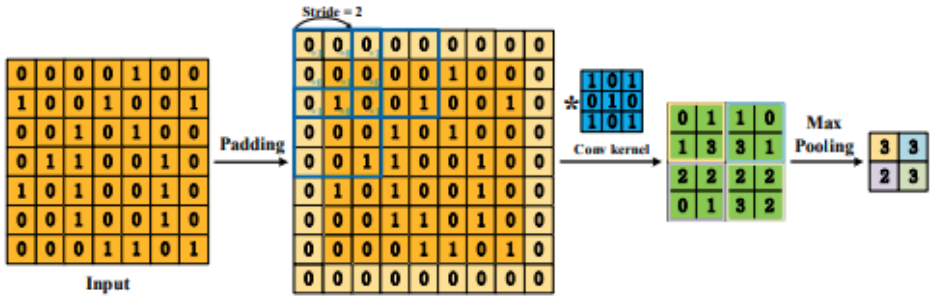

Fig. 1. Procedure of a two-dimensional CNN

There are some *pre-trained CNN models* that can be used for processing image data, instead of building our own model from scratch which are time consuming. AlexNet is a pre trained model which was proposed in 2012, after that researchers have invented a variety of CNN models — deeper, wider, and lighter which gives amazing results. Below is an image for evolution of CNN models and these are called as state-of-the-art models,

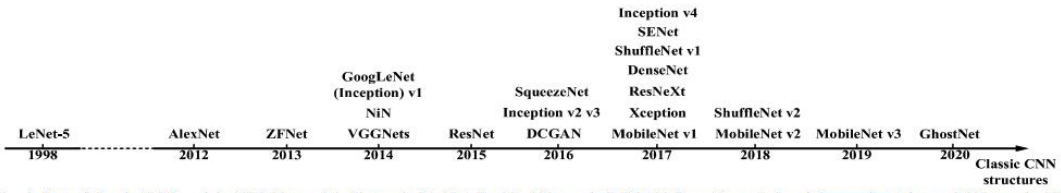

Fig. 4. Part of classic CNN models. NiN: Network in Network; ResNet: Residual Netwrok; DCGAN: Deep Convolutional Generative Adversarial Network; SENet: Squeeze-and-Excitation Network

CNN can harness a massive amount of data to achieve a promising result. Hence, there are lots of applications that come up. It can be used not only in the processing of two-dimensional images but also in one-dimensional and multi-dimensional scenarios. Some of the widely used applications are

- Image classification

- Object detection
- Image segmentation
- Face recognition

Now let's investigate one of the most fast-growing application of CNN.

Image Segmentation: As humans, if given a picture of any object we will be able to identify it. For instance, when we want to cross the road at intersection, we typically look left and right and make our decision. It's because our brain can analyze a kind of vehicle that comes, or it could be any object in each scenario. The question is, can machines do that??? The answer was 'no' till few years back. But with the advancements in computer vision, things have changed too fast and too soon. Below is an example of segmented image versus natural image.

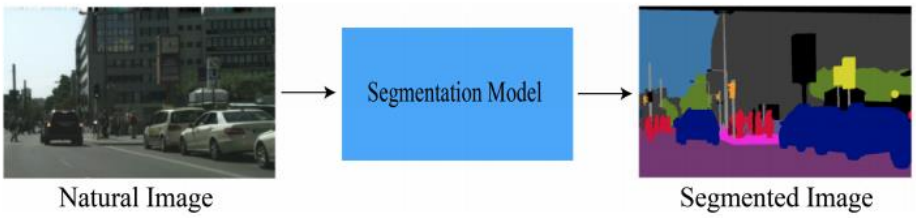

Fig. The process of Semantic Segmentation

Image segmentation is basically the ability of computer vision model to detect objects and be able to determine its shapes and can also predict the direction the objects that can move. It builds upon the idea of object detection. Unlike classification and object detection, segmenting an image is typically a low-level or pixel level vision task as the spatial information of an image is very important for segmenting different regions semantically. Image segmentation is of two types: semantic segmentation, instance segmentation and the combination of these two can be known as panoptic segmentation.

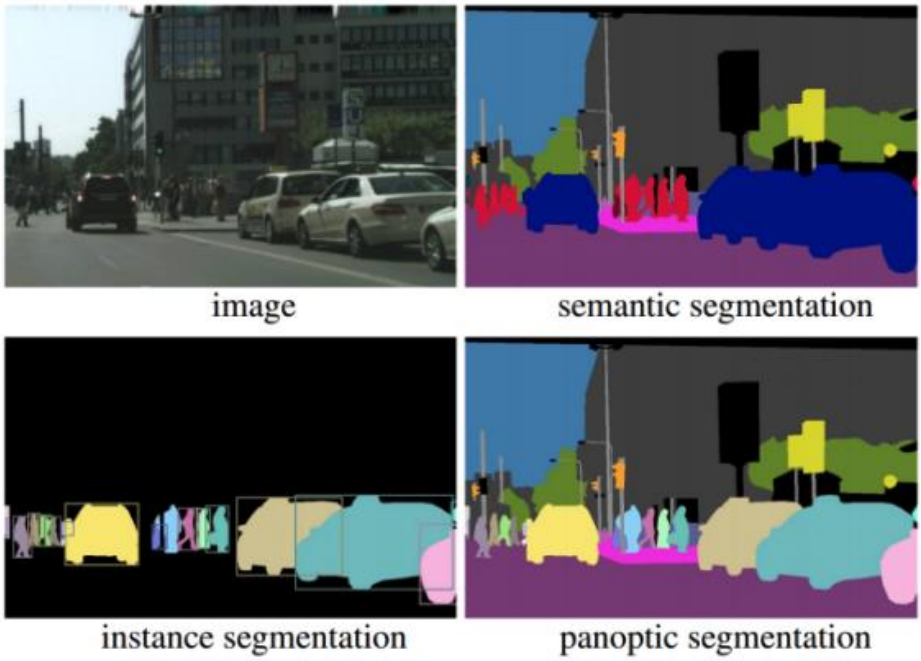

Fig. An example of different types of image segmentation

Ok, so why we need CNN to do image segmentation and why not traditional machine learning algorithm?

Image segmentation task is not a new field in computer vision. There have been many researches on addressing this task using traditional machine learning algorithms. First, feature engineering needs domain expertise and Deep learning does not need traditional handcrafted feature engineering techniques. On the other hand, deep learning has that capability to adapt itself according to the predicted result which cannot be achieved using traditional machine learning algorithm.

There are different ways to extract segmented images,

- **R-CNN** used selective search algorithm to extract region proposals first and then applied upon each proposal.
- **Multi-scale CNN** have been used for scene labeling and achieve state-of-the-art results.
- R-CNN used second order pooling to achieve record, which was a leading hand-engineered semantic segmentation system.

Semantic segmentation is a challenging task in computer vision systems. A lot of methods have been developed to tackle this problem ranging from autonomous vehicles, human-computer interaction, to robotics, medical research, agriculture and so on. Many of these methods have been built using the deep learning paradigm that has shown a salient performance.

Fully Convolutional Network (FCN) has gained the maximum attention and an FCN based semantic segmentation model is kind of new trend that emerged among different semantic segmentation models. The base model which achieved state of the art result is VGG16. FCN used only local connections which results in ambiguity and so contextual features are used to enhance the model. They used VGG16, GoogleNet and pre-trained data on ILSVRC data as base model and transferred these to dense FCN. This process produces FCN-AlexNet, FCN-VGG16, FCN-GoogleNet and achieved highest mean on validation dataset. Below is the image of architecture of FCN32, FCN-16, FCN-8

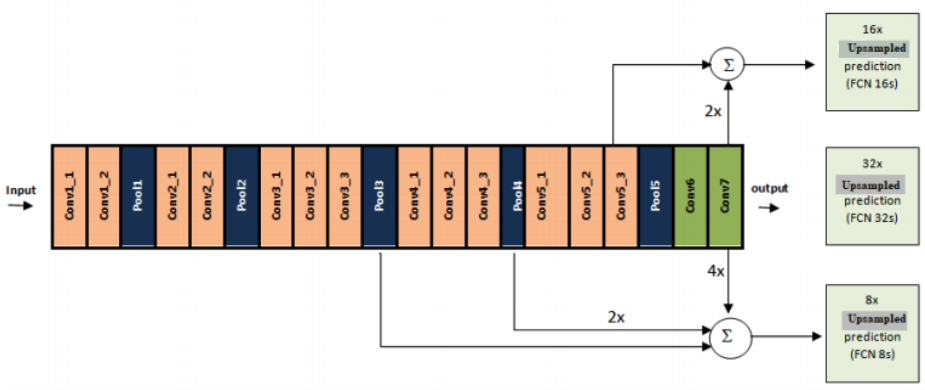

Fig. Architecture of FCN32s, FCN16s, FCN8s

Unlike semantic segmentation, ***instance segmentation*** masks each instance of an object contained in an image independently. It includes identification of boundaries of the objects at the detailed pixel level. In case of ***object detection*****,** it can provide not only the class labels but also indicate the spatial location of those labels. It considers the overlapping of objects. Instance segmentation can do more than the object detection by providing a segmentation mask over each instance. It basically solves of problem of object detection.

In the ***panoptic segmentation*** task, we need to classify all the pixels in the image as belonging to a class label, yet also identify what instance of that class they belong to. The goal in panoptic segmentation is to perform a unified segmentation task. The panoptic segmentation combines semantic and instance segmentation such that all pixels are assigned a class label and all object instances are uniquely segmented. The image segmentation task completed by CNN is shown below,

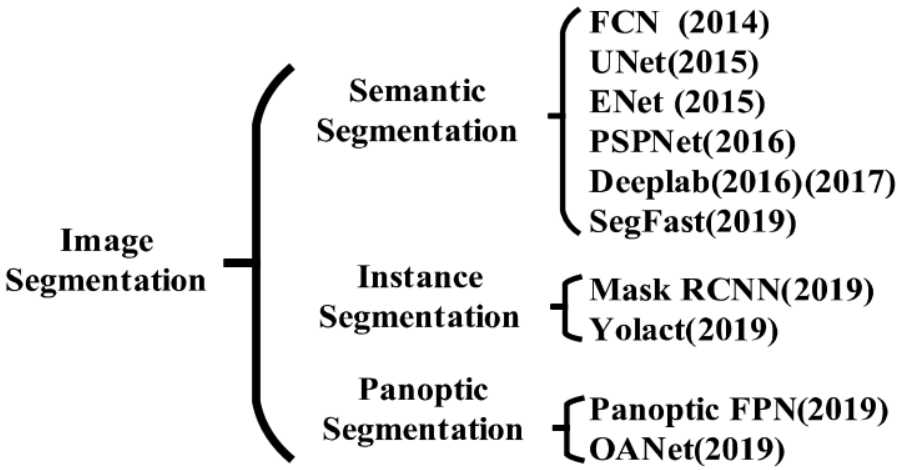

Fig. Applications of CNN in image segmentation

On the other hand, fine-tuning of hyper-parameters, data pre-processing methods, choice of the loss function and optimization function, etc. are also play an important role in the success of a model that we choose.

Conclusion:

In this article we have discussed about an overall view of convolutional neural network, its history, analysis, applications and prospects. We have also talked about image segmentation using CNN. The advantages of convolutional neural networks, such as local connection, weight sharing, and down-sampling dimensionality reduction, have been widely deployed in both research and industry projects. I have found CNN based image segmentation has been so useful in deep learning. It always amazes us like how much details we can extract in a image using these techniques.

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