THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Convolutional Neural Networks: Automating CT Image Segmentation

Ashwath Kapilavai
Dr. Jianping Lu

Background - CT Imaging

- Computed tomography (CT) is an imaging technique that allows for a 3D reconstruction of human anatomy
- While a standard 2D X-Ray involves a stationary source and detector, CT employs a moving source + detector to take multiple scans at extremely high speeds
- Scans are taken with a full 360˚ range
- Image slices are generated → reconstructed to create 3D models
  - Iterative reconstruction
  - Filtered-back projection
- Applications:
  - Identifying tumors
  - Diagnosing muscular/bone deformities
  - Surgery preparation and planning

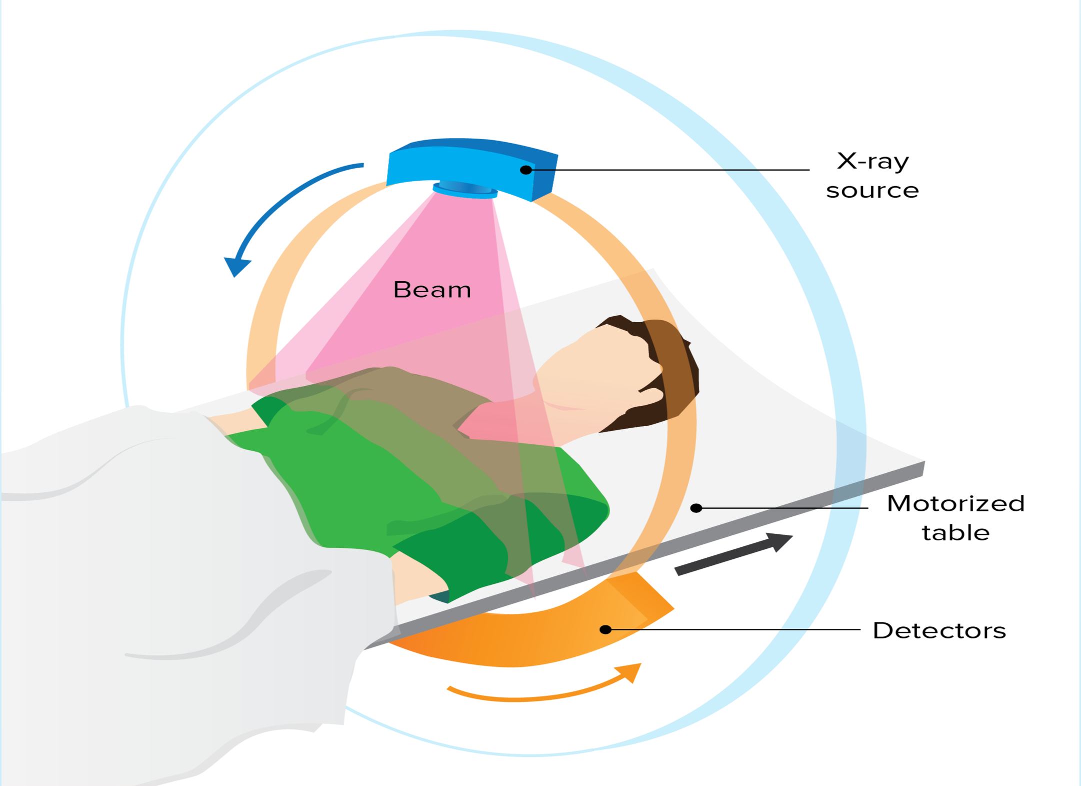


Fig. 1: Mechanism of Computed Tomography

Image Segmentation

- Image segmentation: process of identifying different anatomical parts of a CT image model
- Helpful for planning orthopedic surgeries
- Traditionally performed manually by radiologists or specialized clinicians
- Automatic segmentation can save time, money, and could be far more accurate
- Current methods: convolutional neural networks, transformer networks

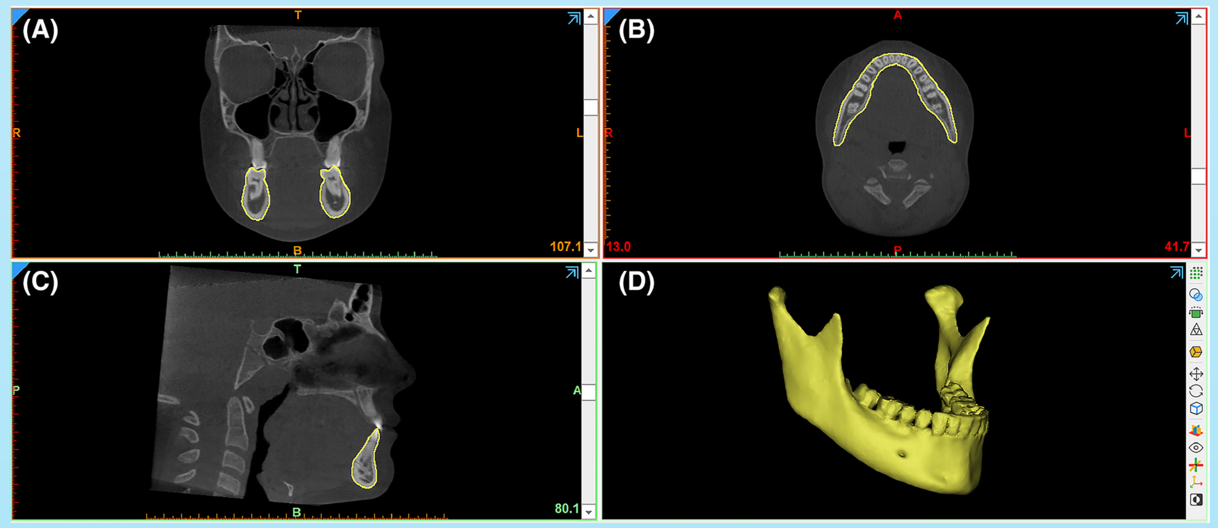


Fig. 2: Automatic segmentation of the mandible. (A) shows the coronal plane, (B) the axial plane, and (C) the sagittal plane. (D) shows the 3D model of the segmented bone.

Convolutional Neural Networks (CNNs)

- CNNs are a type of "deep learning" architecture that have become very popular for pattern recognition in images
- The general architecture was inspired by that of the visual cortex, hence the "neural network" name
- Due to their heavy adaptability, CNNs have become very popular in the field of medical imaging for the purpose of image segmentation. Their ability to recognize patterns, detect edges, and carry parameters through multiple image sets have proven them a useful candidate for automatic segmentation

CNN Architecture

- **Convolution** – function that takes an input image and applies a set of parameters across the image. It applies a **kernel**, or a **filter** onto the input image such that the kernel extracts the desired qualities from the image, such as the edges
- This is the function that CNNs are based off. They are used in conjunction with many other functions to produce a deeply layered network that mirrors neural patterns

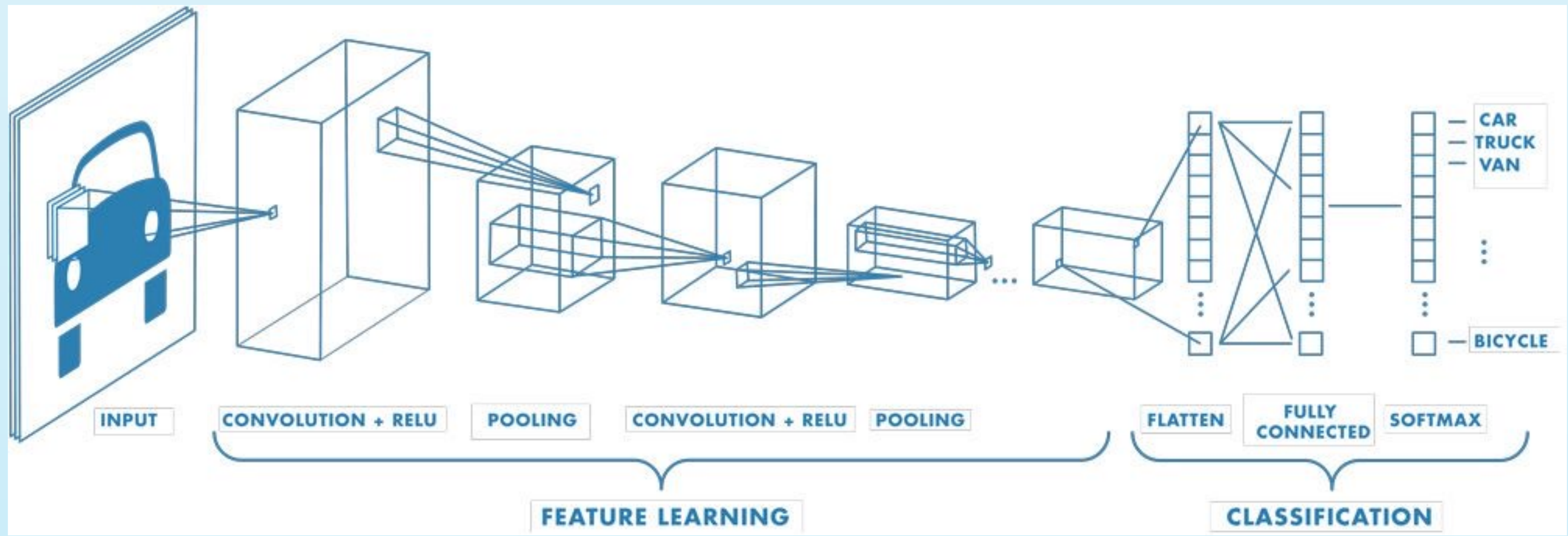
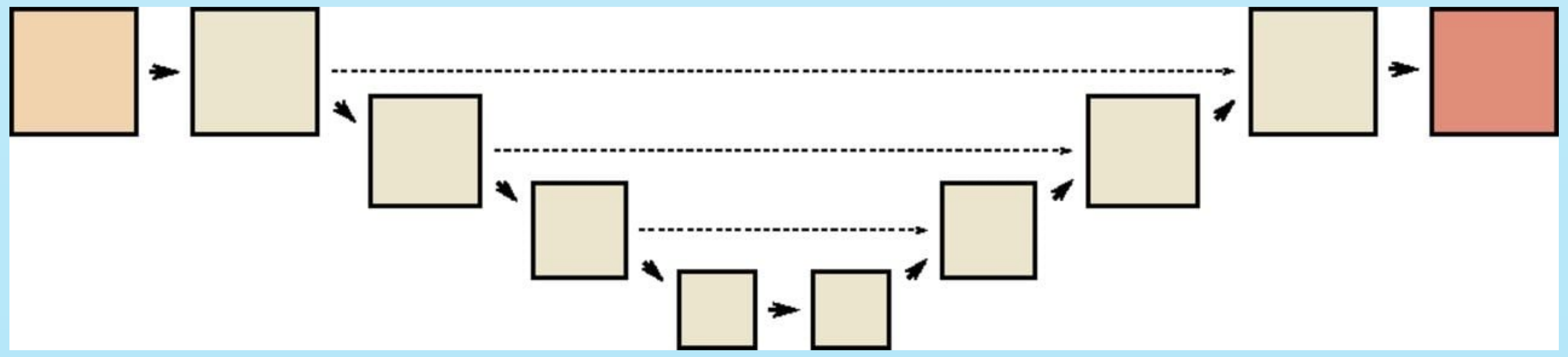


Fig. 3 (above): A flow map of how a CNN is built. As an input image is parsed through the many layers, feature maps are created such that the image is both downscaled and then upscaled back to its original size. These feature maps allow the network to identify and extract the needed features (fed to the network as its **trainable parameters**). A trained network can then be used to identify, or segment, the necessary features from an inputted image.

Fig. 4 (below): An example of how a traditional Deep CNN (DCNN) downscales and upscales images. The block on the left denotes the input image while the block on the far right denotes its output.



- Common CNNs (or DCNNs) in use for medical image segmentation include:
  - U-Net
  - ResNet
  - Inception Net (currently on V4)
- Some algorithms have been made to help with **semi-automatic** segmentation
- This means that manual steps are required alongside
- Examples: Magic Wand and Graph-Cuts algorithms

MS-D Net

- "Mixed-scale dense" convolutional neural network
- Developed by Daniel Pelt & James Sethian (2017)
- **Mixed-Scaling**: uses "dilated convolutions" instead of normal downscaling + upscaling done by typical CNNs
- Benefits:
  - Captures more features
  - Larger scale information becomes clearer in earlier layers, removing the need for additional convolutions in deeper layers
- Has regression capabilities
  - Reduces noise in images
  - Trained in similar fashion as for segmentation

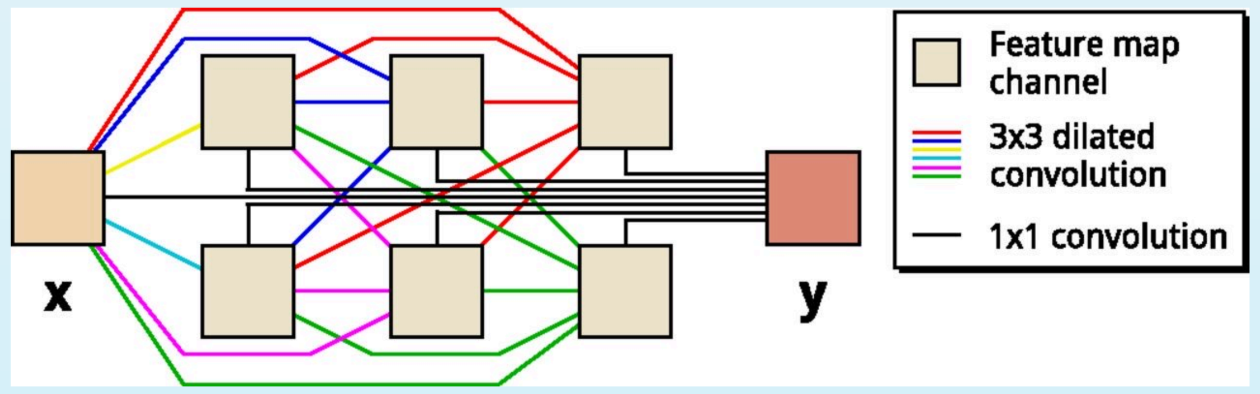
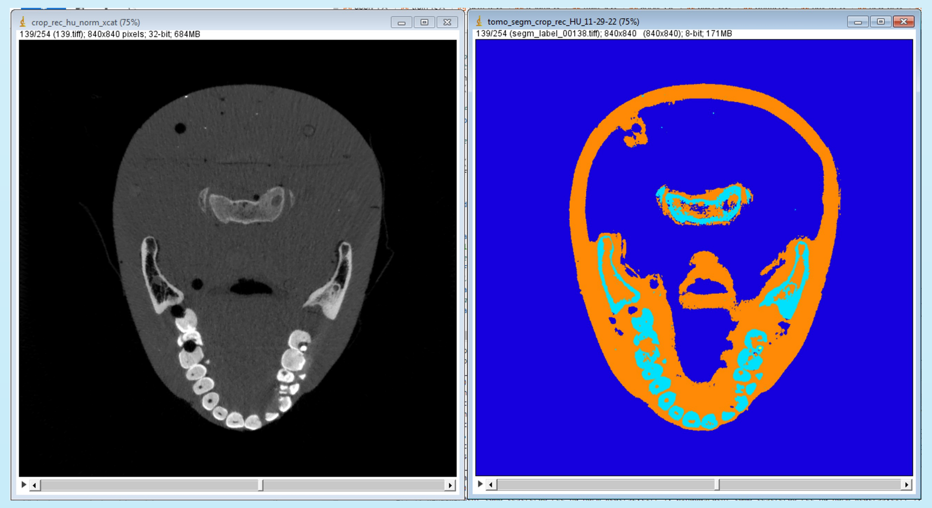


Fig. 6 (above): An overview of the architecture for MS-D Net. Dilated convolutions are used to create the mixed-scaling effect, thus reducing the need for repeated down and up-scaling.

Fig. 7 (right): MS-D Net segmentation results on simulated head phantoms (generated by XCAT). The segmentation consists of 4 labels: background, tissue, bone, and metal (yellow).



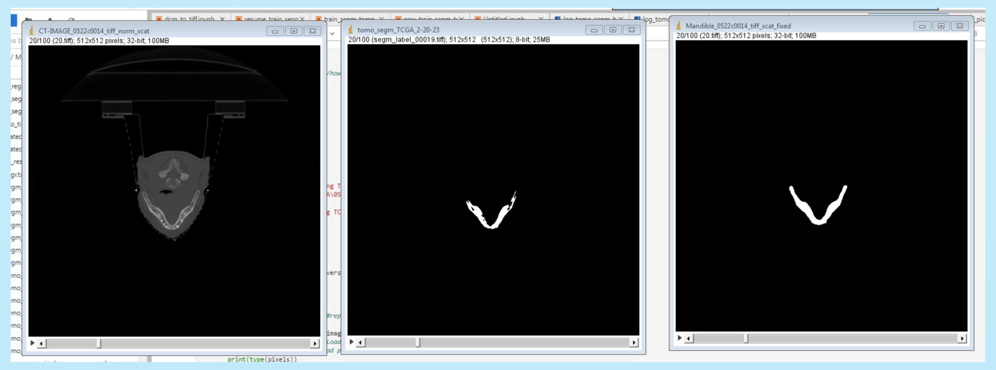


Fig. 8 (left): MS-D Net segmentation results on a clinical CT head scan. The middle image shows the segmentation of the mandible, while the far right is the label file.

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