Deep Learning and Applications in Medical Imaging

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Deep learning: Principles, achievements and future potential in medical imaging

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What is Deep Learning?

- A sub-field within machine learning
- Learning multiple levels of representation in order to model complex relationships among data
  - Higher-level concepts defined in terms of lower-level ones, the hierarchy of such features is called a deep architecture
- The hierarchy of concepts allows the computer to learn complicated concepts by building them out of simpler ones
- Typically implemented using artificial neural networks (ANNs)

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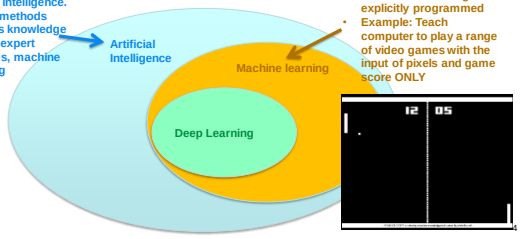
Where does deep learning fall within the field of artificial intelligence?

- Imitate or surpass human intelligence.
- Varied methods such as knowledge bases, expert systems, machine learning



- Learn without being explicitly programmed
- Example: Teach computer to play a range of video games with the input of pixels and game score ONLY

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What has deep learning achieved so far?

- Record-breaking performance in
  - Speech recognition
  - Image recognition
  - Natural language processing
  - Recommendation systems

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Example: Image Recognition

- ImageNet Challenge:
  - A benchmark in object category classification and detection
- ImageNet classification task
  - 1000 categories
  - Training: 1.28M images with ground truth
  - Test: 100k images, predict 5 (out of 1000) classes
    - Correct if at least one of the predictions is the ground truth.

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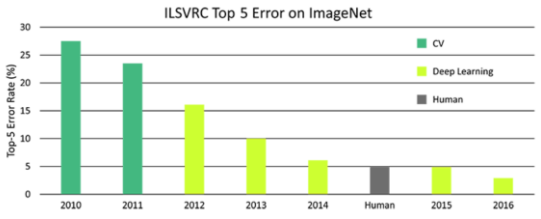
ImageNet Challenge



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Deep Neural Networks

- The best-performing methods in ImageNet Challenge, as well as many other tasks have been deep artificial neural networks (ANNs)
- The best-performing deep ANNs in imaging tasks have been a special type of ANNs called deep convolutional neural networks (CNNs)

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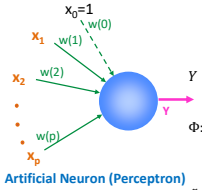
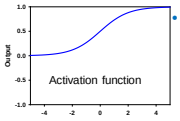
Artificial Neuron



$$Y = \Phi\left(\sum_{i=0}^{p} x_i\, w(i)\right)$$

Φ: Activation function



x_1, …x_p: Predictor variables, or features

- Perceptrons were first described in 1960's
- Used for classification
- Fell into disfavor because they cannot form non-linear combination of inputs

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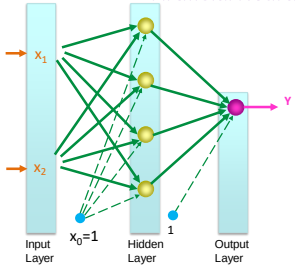
Artificial Neural Networks



- ANNs were first introduced in 1980's
- Have been very popular for a variety of tasks
- Provided conceptual and practical framework for deep neural networks

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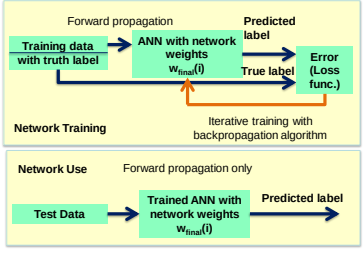
Supervised Artificial Neural Networks



- For many problems, a large training data set size (compared to the number of weights to train) is needed for proper training

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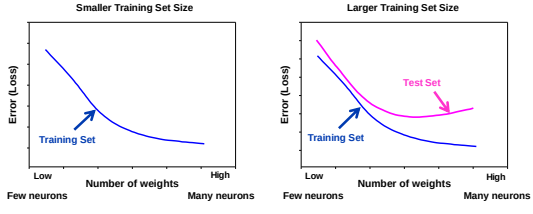
Generalization



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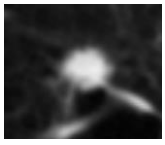
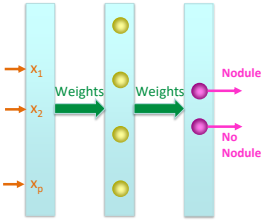
Feature Engineering Approach for Imaging Applications



- Does this patch from a CT image contain a lung nodule?

- Extract features
  - Gray-scale
  - Segmentation
    - Shape, size, etc.
  - Texture
  - Others



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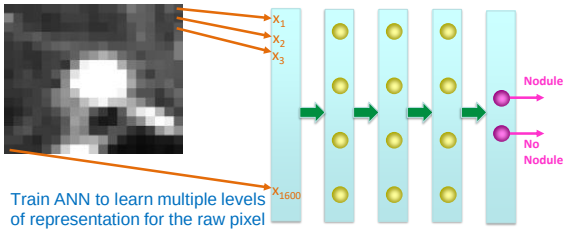
Deep Learning in Imaging Applications, Naive Approach



- Train ANN to learn multiple levels of representation for the raw pixel data

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Deep Learning Approach

- Using every pixel as a feature has disadvantages:
  - The number of weights in the network becomes extremely large, necessitating a very large training data set
  - What the network learns is not translation invariant
    - If I translate the image by one pixel, network inputs completely change

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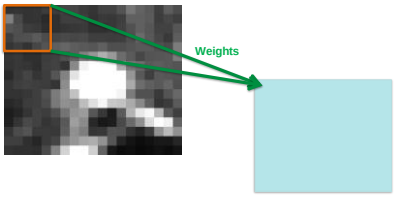
Deep Convolutional Neural Networks



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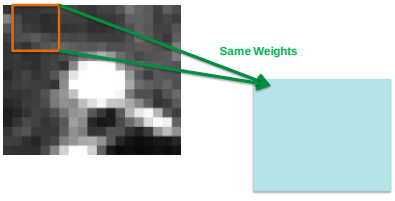
Deep Convolutional Neural Networks



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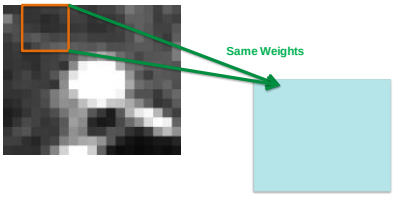
Deep Convolutional Neural Networks



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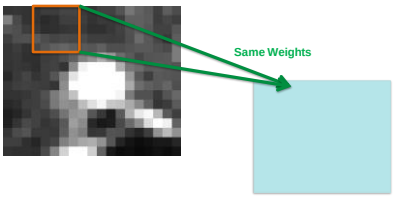
Deep Convolutional Neural Networks



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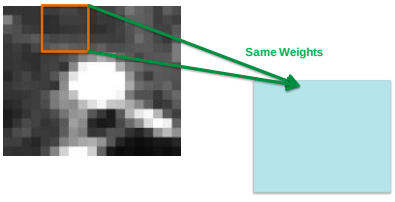
Deep Convolutional Neural Networks



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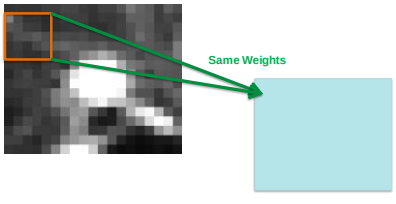
Deep Convolutional Neural Networks



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Deep Convolutional Neural Networks

- Keep the same weights:
  - Reduce the number of weights
  - Ensure translation invariance
- The operation is nothing but convolution with a weight kernel
- This is not deep yet!

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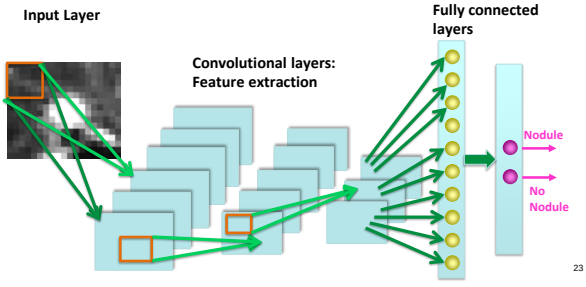
Deep Convolutional Neural Networks



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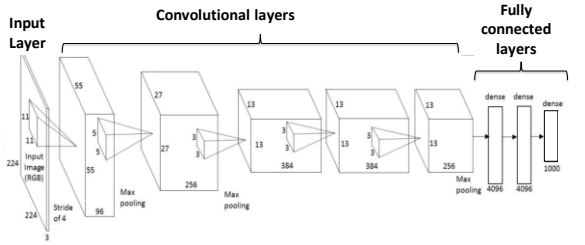
Example: Alexnet



"Alexnet": A Krizhevsky, I Sutskever, GE Hinton "Imagenet classification with deep convolutional neural networks" (NIPS 2012). Slide Credit Junting Pan

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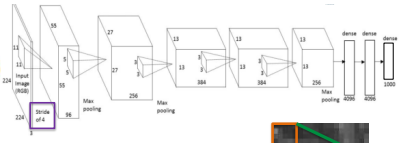
Some Terminology: Stride



Move the kernel by 4 pixels over the input image

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Some Terminology: Max-Pooling

9	8	4	5
7	7	3	4
2	0	7	9
1	3	8	10

9	5
3	10

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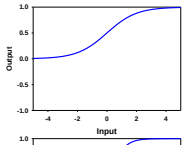
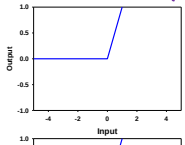
Activation Function: Rectified Linear Units (ReLU)

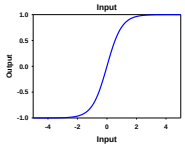
Sigmoid



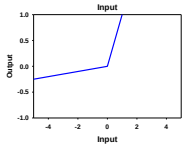
ReLU



tanh



Leaky ReLU



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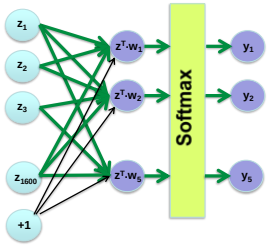
Last Layer: Softmax



$$y_i = \frac{e^{z^T w_i}}{\sum_{j=1}^{N=5} e^{z^T w_j}}$$

y_i can be interpreted as probabilities

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Generalization

- Convolution, stride, max-pooling all reduce the number of weights to train, aimed at improving generalization
- Still, in typical applications in imaging, there may be millions of parameters to tune
- Additional techniques to improve generalization
  - Dropout
  - Data augmentation
  - Pre-training / Transfer learning

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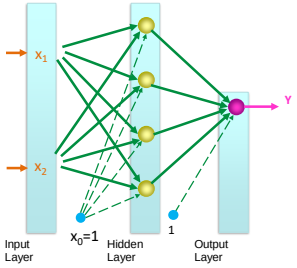
Dropout

- In training, during different iteration cycles, remove some of the connections
- Forward and backward propagation with removed weights
- Testing: Use all weights



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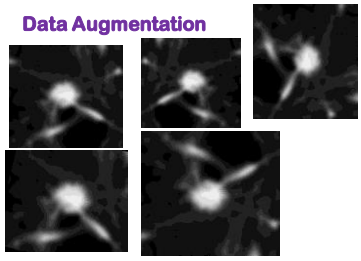
Data Augmentation

- Rotation
- Translation
- Scaling
- Contrast change
- Warping
- Insertion*



*Pezeshk A, Petrick N, Chen W, Sahiner B, "Seamless lesion insertion for data augmentation in CAD training," IEEE Transactions on Medical Imaging, 2016

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Pre-training

- Natural image abound
  - E.g., ImageNet dataset
- First few convolution layers of DNNs are feature extractors
- Use pre-trained early convolution layers of DNNs from natural images
  - Only train late convolution layers or the last fully-connected layers with medical images

96 convolutional kernels of size 11x11x3 learned by the first convolutional layer

A Krizhevsky, I Sutskever, GE Hinton "Imagenet classification with deep convolutional neural networks" (NIPS 2012)

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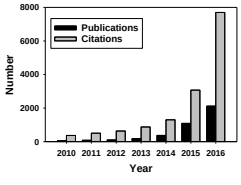
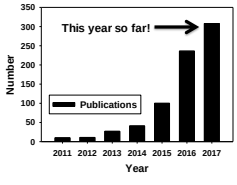
Deep Learning in Medicine

Web of Science Search
All "Deep Learning" Publications



PubMed Search: "Deep Learning"



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Applications in Medical Imaging

- Lesion/disease detection, classification, staging
- Segmentation
- Lesion volumetry
- Landmark detection
- Image quality evaluation
- Image registration
- Low-dose medical imaging

Science Council Session:

Big Data, Deep Learning and AI in Imaging and Radiation Oncology

Rm. 605, Tue 1:45-3:45

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Potential Challenges

- Even more "black box" than feature engineering + ANN
- Limited training data set size in medical imaging
- Finding the right architecture/parameters/pre-training methods for successful training with limited datasets

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Performance Assessment

- Generalize principles from CAD assessment
  - AAPM CAD subcommittee publications
    - "Evaluation of computer-aided detection and diagnosis systems" Med Phys. 2013
    - "Quality assurance and training procedures for computer-aided detection and diagnosis systems in clinical use" Med Phys. 2013
  - FDA CADe Guidances
    - Computer-Assisted Detection Devices Applied to Radiology Images and Radiology Device Data – Premarket Notification [510(k)] Submissions
    - Clinical Performance Assessment: Considerations for Computer-Assisted Detection Devices Applied to Radiology Images and Radiology Device Data - Premarket Approval (PMA) and Premarket Notification [510(k)] Submissions

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- Now I turn it over to Dr. Lubomir Hadjiiski