PHYS 139/239: Machine Learning in Physics

Lecture 8: Advanced convolutions neural networks

Javier Duarte — January 31, 2023
Caution: image preprocessing

- Good practice to preprocess data, but beware of distortions to physically meaningful features

- Example: jet mass in $W(qq)$ jet images

$$m^2 = \sum_{i<j} \frac{p_{T,i} p_{T,j} (1 - \cos \theta_{ij})}{\cosh \eta_i \cosh \eta_j}$$

- Preprocessing: pixelization, rotation, flip, normalization

- Preprocessing distorts distribution of the jet mass

- Can choose (Lorentz-invariant) preprocessing that preserves jet mass
2D convolution hyperparameters

- 4 × 4 input
- 3 × 3 filter
- 1 × 1 stride
- No zero padding

⇒ 2 × 2 output
In reverse: transposed convolution

- 2 × 2 input
- 3 × 3 filter
- 1 × 1 stride
- 2 × 2 zero padding
  ➞ 4 × 4 output
In reverse: upsampling

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- Upsampling can be used to change the image size
More efficient: depthwise separable convolution

- Standard convolution requires many operations, e.g. for a $15 \times 15 \times 3$ image, 10 $3 \times 3$ filters, no zero-padding, stride 1: 45,630 multiplications

- Depthwise separable convolution factorizes into two separate operations
  - For the same settings: 9,633 multiplications
Reconstruction tasks

- **Classification**: output class of image as a whole

- **Regression**: output a real number for the image as a whole

- **Object detection & localization**: find a “bounding box” for a given object
  - Can also be done for multiple objects

- **Semantic segmentation**: pixel-wise classification
Reconstruction tasks

- Semantic segmentation: pixel-wise classification
- Instance segmentation: classify pixels based on “instances”
  - Panoptic segmentation: generalization to multiple classes
U-Net

- U-Net first proposed for semantic segmentation in biomedical imaging

- Also used for detection of neutrinos [arXiv:1903.05663], galaxies, RF interference [arXiv:1609.09077], …
Generalizations: Data augmentations

- One way to generalize CNNs to rotation-invariant operations:

- Use data augmentations, concatenate feature maps, and apply dense layers
Generalizations: Other symmetry groups

- By employing weight sharing across group actions, we can generalize to other symmetry groups.

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Group Equivariant Convolutional Networks

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University of California Irvine  
Canadian Institute for Advanced Research

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https://medium.com/swlh/geometric-deep-learning-group-equivariant-convolutional-networks-ec687c7a7b41
Generalizations: Other geometries

- Can generalize to other geometries like hexagonal data

HexCNN: A Framework for Native Hexagonal Convolutional Neural Networks

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Next time

• Time series and recurrent neural networks