Can a Convolutional Neural Network implement histogram equalization in image analysis?

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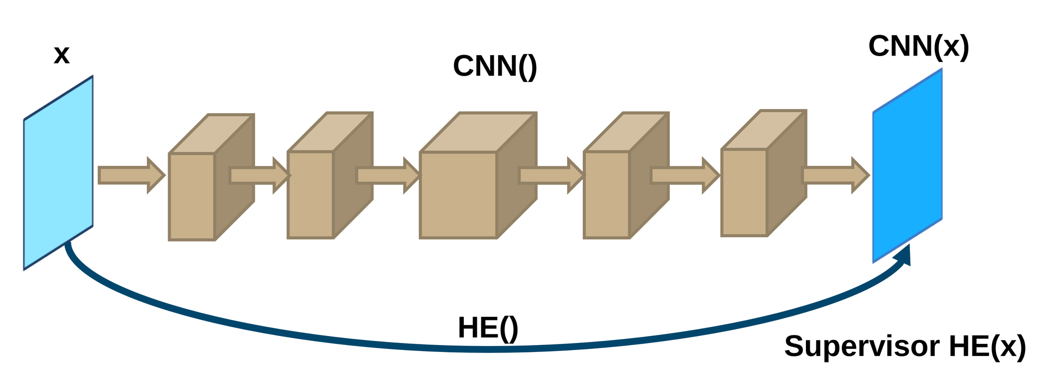
Motivation

The Convolutional Neural Network (CNN) as a typical deep learning technique has been widely used in many image processing applications and achieved remarkable success. The benefit of pre-processing is natural in traditional image processing, but it is questionable in deep learning. For instance, the Histogram Equalization (HE) is a global operation to images but convolutional operations in CNN are localized, and thus we hypothesize that a CNN may inherently be unable to perform HE on images. This study aims to examine this hypothesis.

CNN Architecture

We built a CNN having several layers and its input and output are same size images.

- Input: image ***x***
- Output: supervised by ***HE(x)***

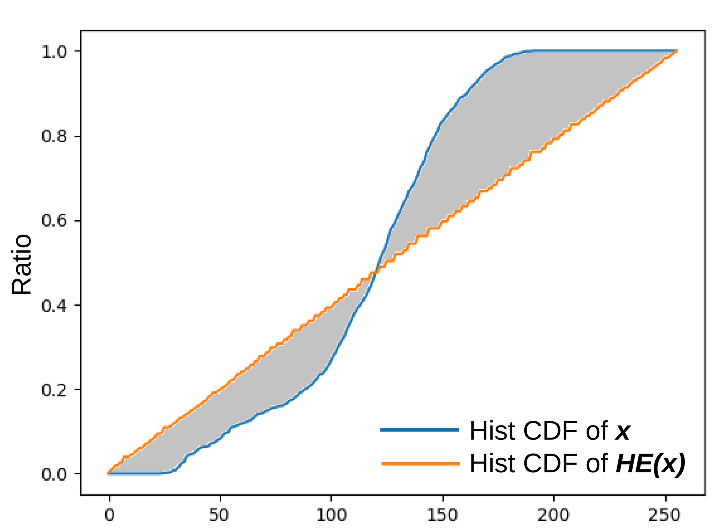


Evaluation Method

Since HE is a operation on histogram, we evaluate the differences between two histograms (Hists) via the Wasserstein distance (W-dist).

$$W_1(p,q) = \inf_{\gamma\in\Pi(p,q)} \iint \gamma(x,y)\, d(x,y)\, dx dy = \int |P-Q|$$

- For two 1-D distributions and $\boldsymbol{d(x,y)=|x-y|}$
- **P**, **Q** are the respective CDFs of histogram ***p*** and ***q***

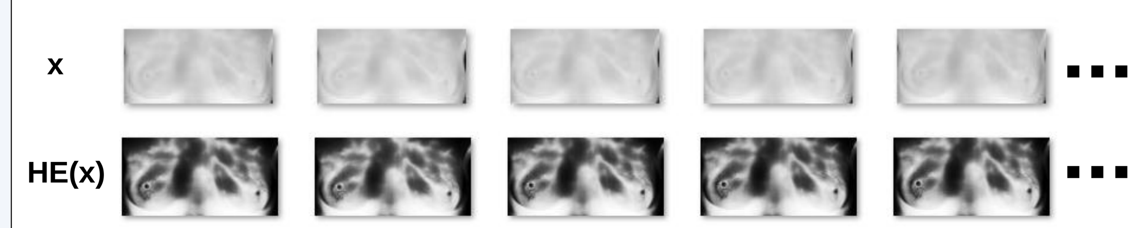


The W-dist of this example is 34.92 (the gray area). The max-value for W-dist is 255.

Experiment 1

Test 1

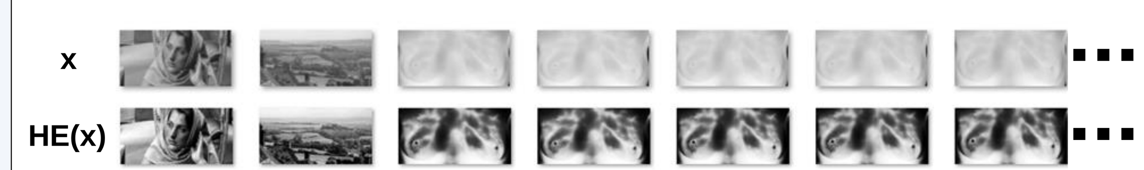
- Train on 10 IR breast images (same patient).



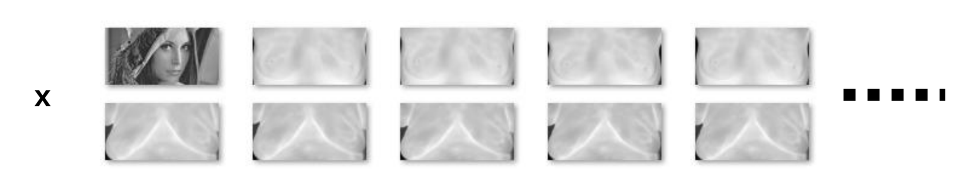
- Validate on 50 IR breast images (including different patients), barbara, goldhill and lenna.

Test 2

- Train on 10 IR breast images (same patient), barbara and goldhill (**more categories**).

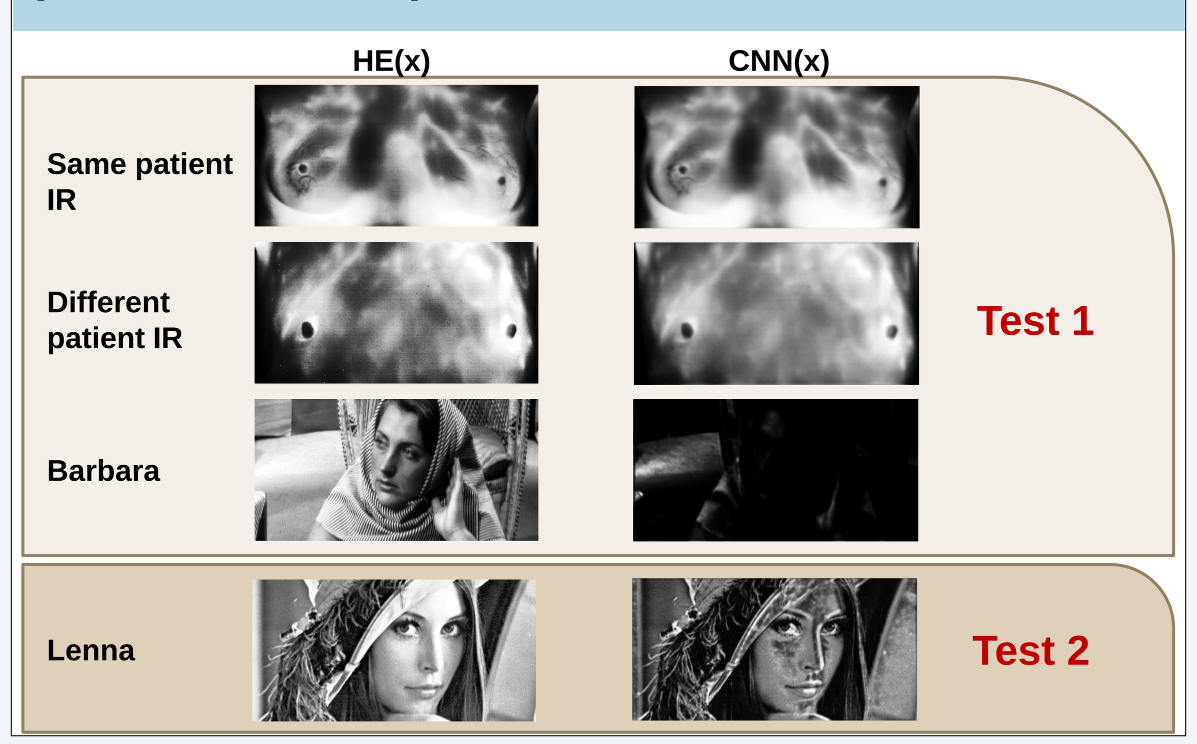


- Validate on 50 IR breast images (including different patients), and lenna.



Results of Experiment 1

For Test 1, when x is from the same patient in training set, CNN(x) looks very close to HE(x). To x is from different patients, CNN(x) looks similar to HE(x). If x is not IR image, CNN(x) looks very different to HE(x). But for Test 2, when x is not IR image, CNN(x) looks similar to HE(x). These results are also reflected on W-dist values (smaller is better).



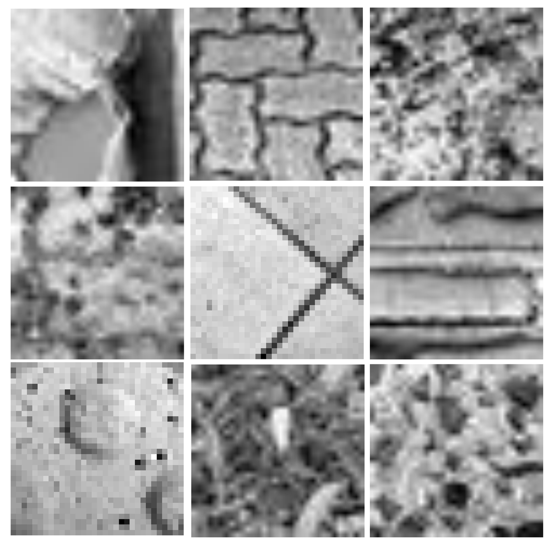
Test 1	Average W-dist	Test 2	Average W-dist
Other Categories	109.73	lenna	49.28
Same patient IR	6.86	Same patient IR	9.14
Other patient IR 1	31.75	Other patient IR 1	35.05
Other patient IR 2	52.58	Other patient IR 2	48.51
Other patient IR 3	39.88	Other patient IR 3	38.10

Experiment 2

We used two open-source image databases (CIFAR-10 and USPtex1.0) to examine our hypothesis by more images. The CIFAR-10 has 60,000 images of animals and transporters and USPtex1.0 has 2,292 texture images. Their contents are very different.

CIFAR-10

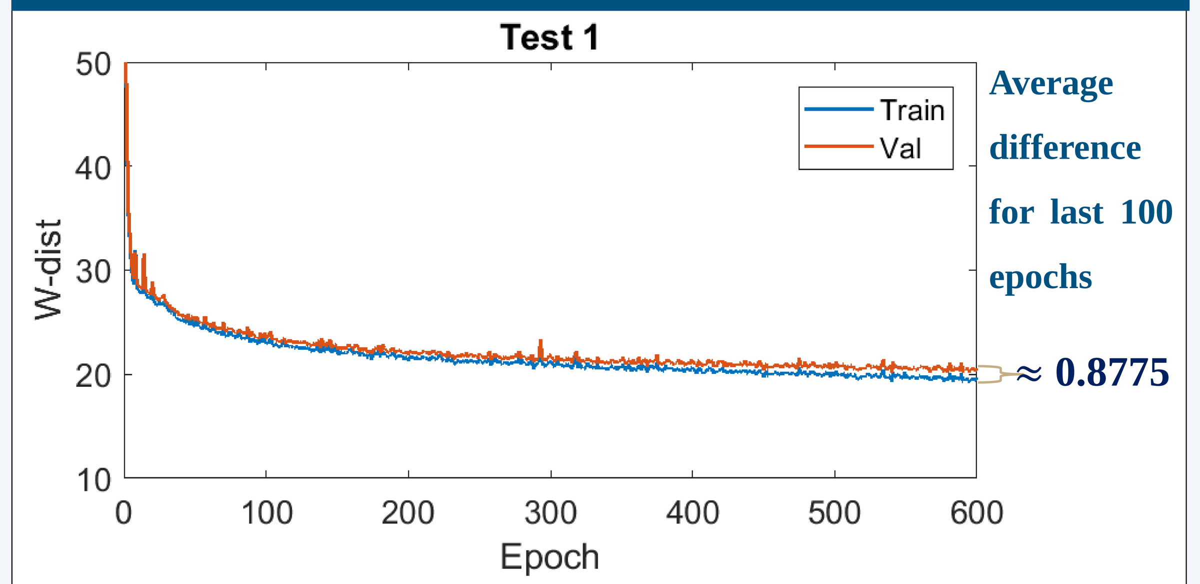
USPtex1.0

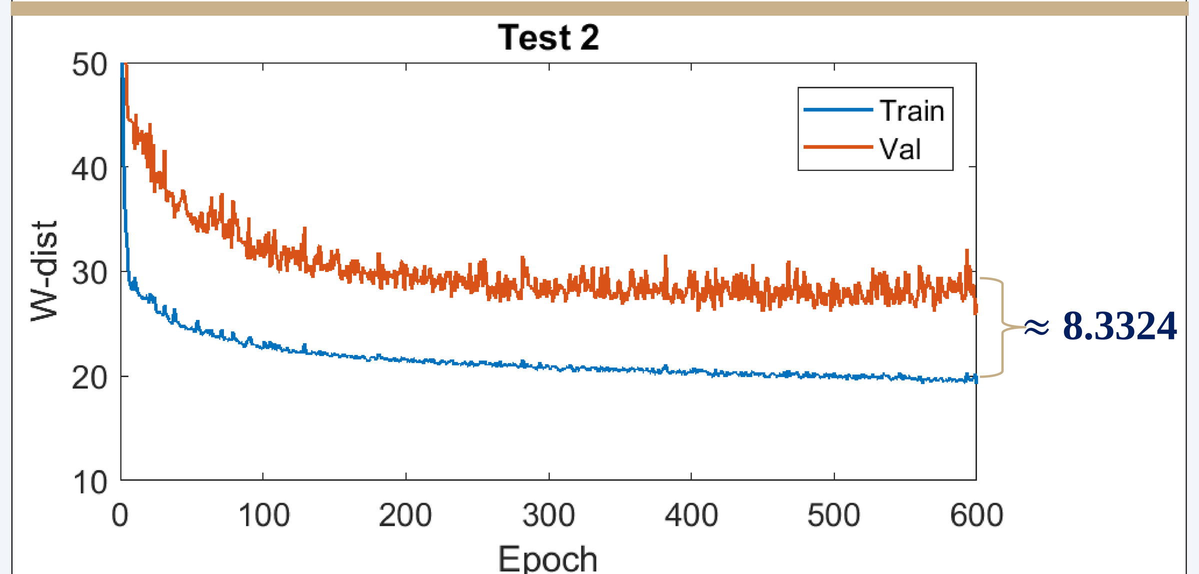


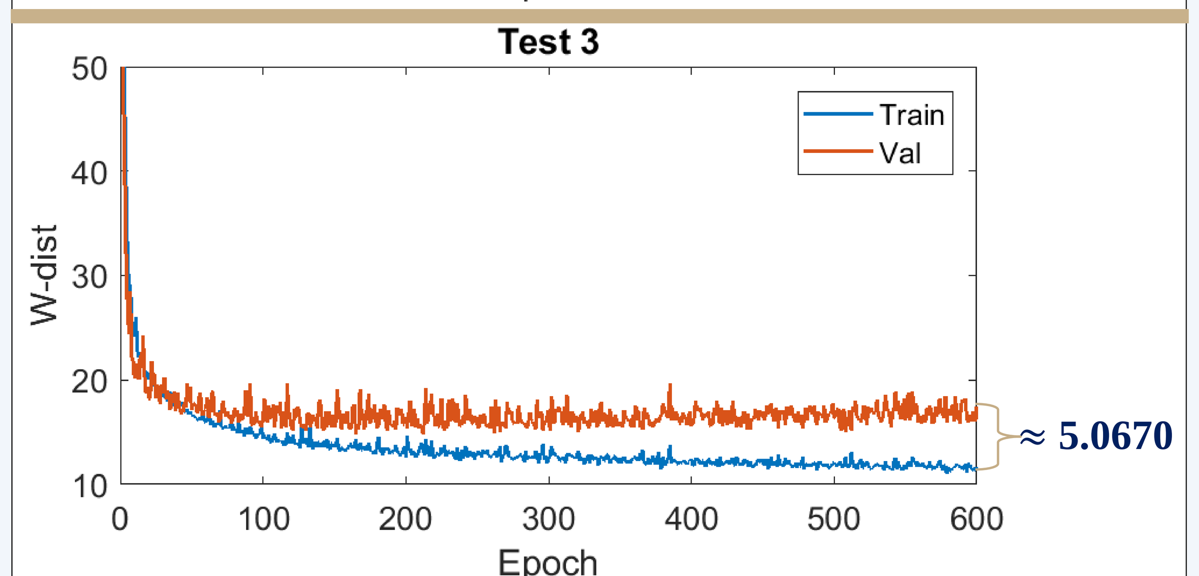
We randomly selected images from the two databases to build 3 tests. For each test, 1,000 images were used to train the CNN and 1,000 images were for validation. After every epoch of training, average W-dists between histograms of CNN(x) and HE(x) for training and validation images were computed. In this experiment, we had much more images to train the CNN to obtain reliable results. And since the W-dist were verified as an effective method to measure the similarity of two images in experiment 1, we evaluate outcomes by the W-dists instead of comparing images by looking. Although training process is conducted by MSE, we only show the W-dists.

Test	Data for training	Validation
1	1000 from CIFAR	1000 from CIFAR
2	1000 from CIFAR	1000 from USPtex
3	1000 from USPtex	1000 from CIFAR

Results of Experiment 2







Conclusions

- **Such results demonstrate CNN does not well learn HE but somewhat image style transformation to a certain category. Otherwise, the W-dist difference between two categories would be zero. Because once HE is learned, it should be implemented as needed for any kind of images.**
- **CNN performs better in Test 3 because USPtex1.0 contains more similar and simpler images than CIFAR-10. CNN might learn the key transformation easier.**
- **Such results imply that image pre-processing such as HE might be needed to apply in CNN applications to improve their performance because CNN cannot implement then automatically.**