# Convolutional neural networks can be deceived by visual illusions





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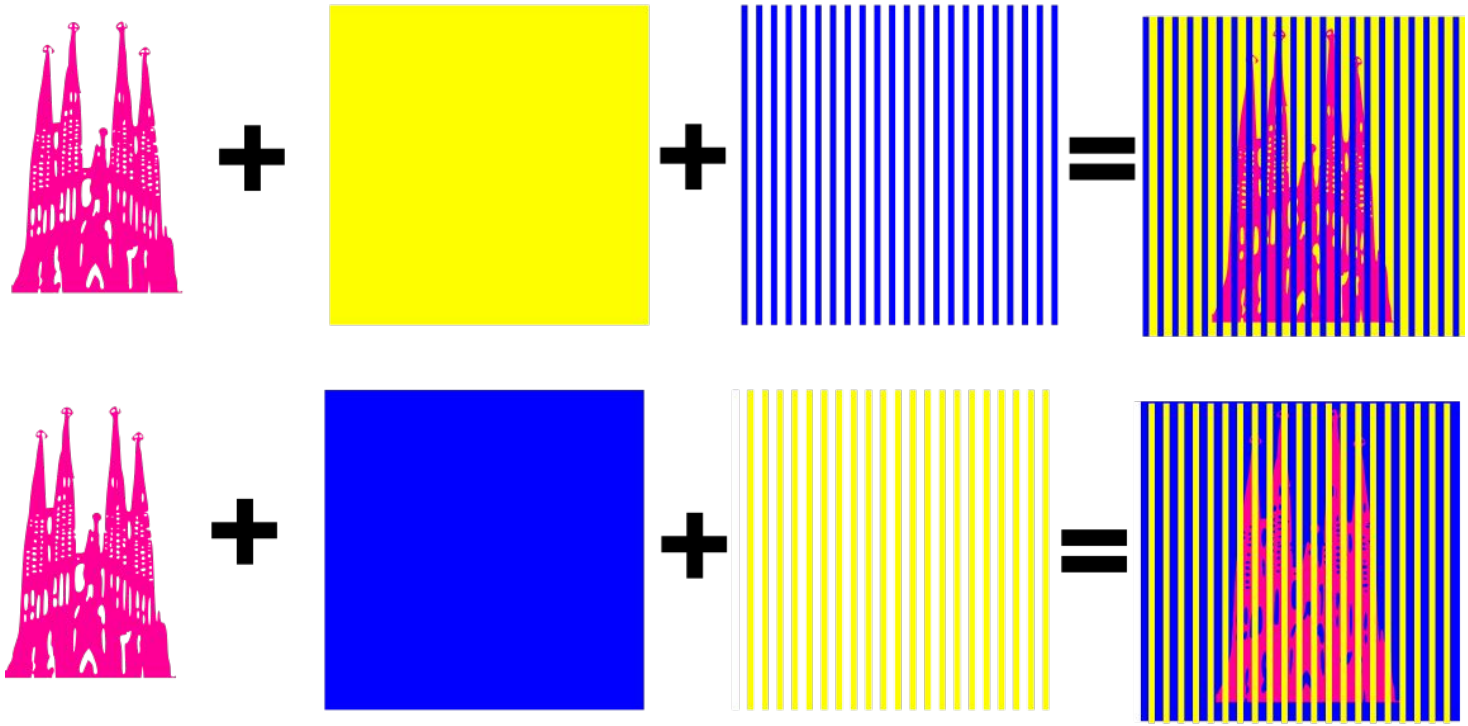
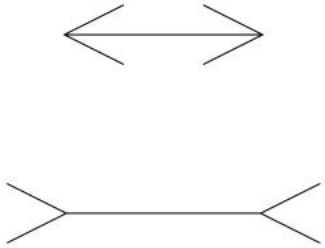
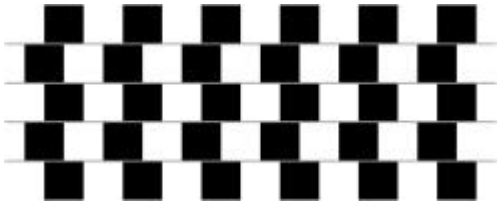
# Visual Illusions



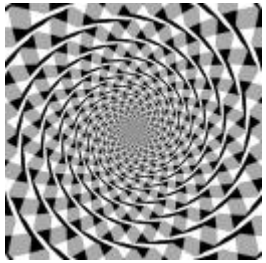
# Visual Illusions



Müller-Lyer illusion

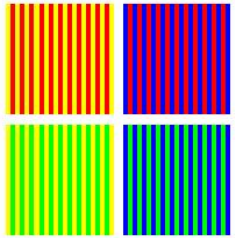


Cafe Walls illusion

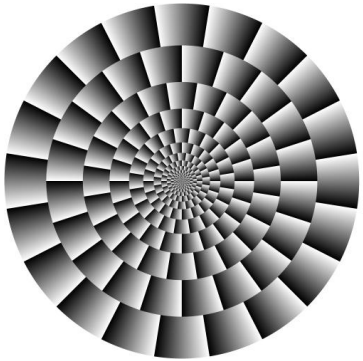


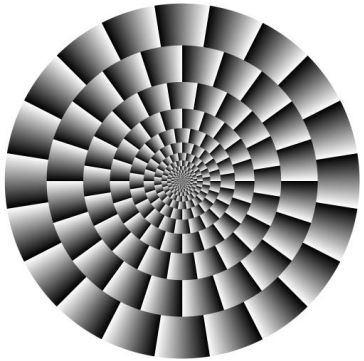
Fraser's spiral illusion

Brightness contrast



Color assimilation



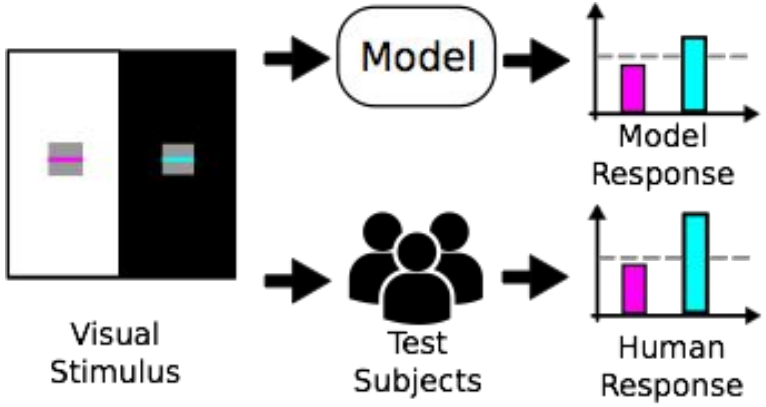


Fraser-Wilcox illusion

'A Catalogue of illusions' from Prof. Akitaoka
http://www.psy.ritsumei.ac.jp/~akitaoka/cataloge.html

# Why are Visual illusions important in vision science?

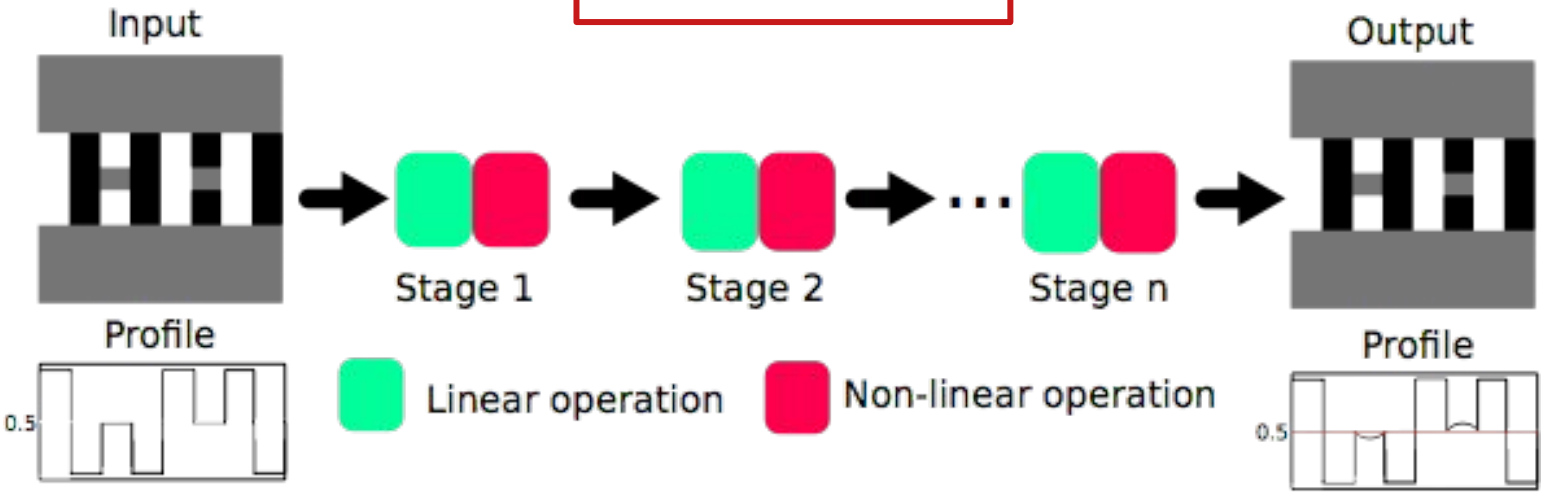
- Reveal differences between perception and reality.
- These *perception errors* are key to understand how vision works.
- Good vision models should reproduce human perception of visual illusions.



# Cascade of Linear + Non Linear Operations

**Perception** is explained in many models of vision science and neuroscience as a **cascade** of modules composed by a **linear operation followed by a nonlinearity**.

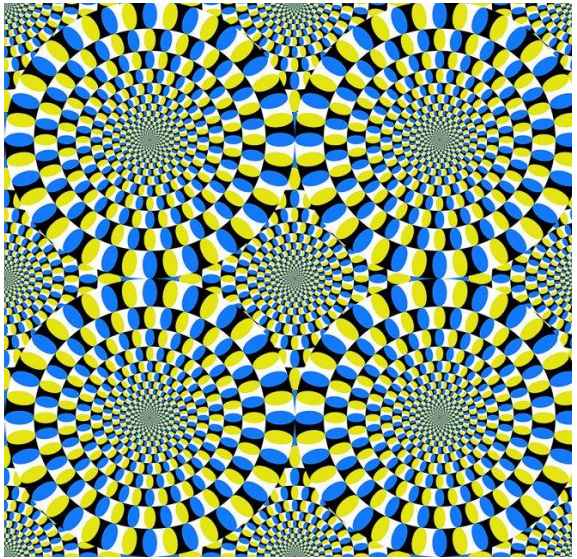
$$x^{k+1} = f_{k+1}(L_{k+1}x^k, \theta_{k+1})$$



# Other works linking CNNs and Visual Illusions

- *E. Watanabe et al. Illusory motion reproduced by deep neural networks trained for prediction. Frontiers in psychology, 9:345, 2018. 2*

- Kim, B., Reif, E., Wattenberg, M. and Bengio, S., 2019. Do Neural Networks Show Gestalt Phenomena? An Exploration of the Law of Closure. arXiv preprint arXiv:1903.01069.
- Sun, E.D. and Dekel, R., 2019. ImageNet-trained deep neural network exhibits illusion-like response to the Scintillating Grid. arXiv preprint arXiv:1907.09019.
- Ward, E.J., 2019. Exploring perceptual illusions in deep neural networks. bioRxiv, p.687905.
- Anonymous (ICLR 2020 submission). The function of contextual illusions.https://openreview.net/forum?id=H1gB4RVKvB
- Jacob, G., Pramod, R. T., Katti, H., Arun, S. P. Do deep neural networks see the way we do?



# Choosing three imaging tasks related with HVS

Denoise

Deblur

Restoration

$I$

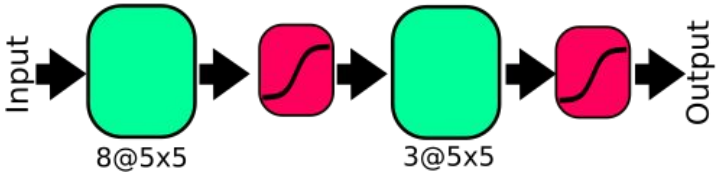
$I$ + noise

$I$ + blur

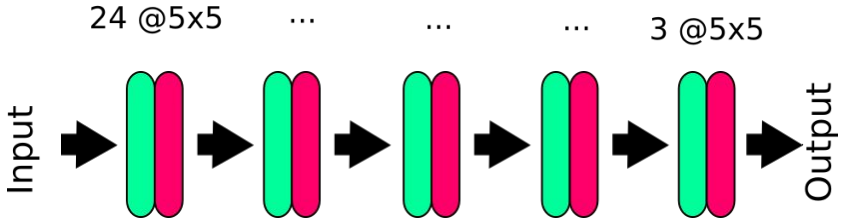
$I$ + blur + noise

# CNN Implementation details

**DN-NET, DB-NET, Restore-Net**




**Deep DN-NET, DB-NET, and Restore-Net**





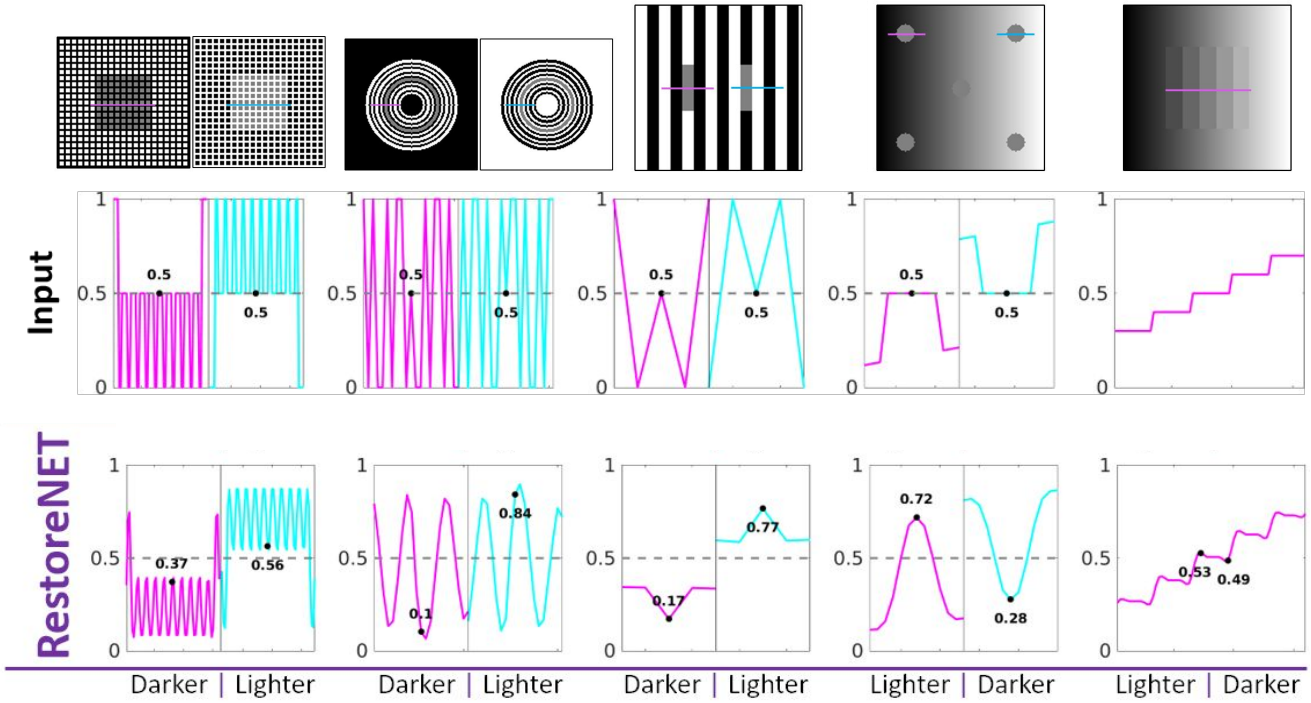
**Zhang et al:** Denoising deep CNN with state-of-the-art performance

Zhang, K., Zuo, W., Chen, Y., Meng, D. and Zhang, L., 2017. Beyond a gaussian denoiser: Residual learning of deep cnn for image denoising. IEEE Transactions on Image Processing, 26(7), pp.3142-3155.

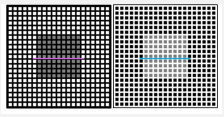
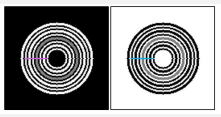
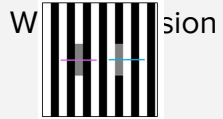
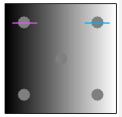
**Dataset:** All of them trained on a subset of ImageNet

**Loss:** Mean squared error

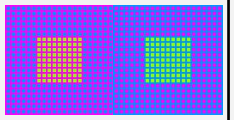
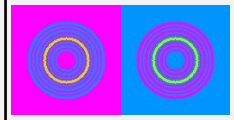
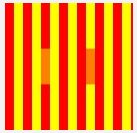
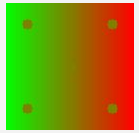
# Results


Input
RestoreNET
0.5
0.37
0.56
0.1
0.84
0.17
0.77
0.72
0.28
0.53
0.49
Darker | Lighter
Darker | Lighter
Darker | Lighter
Lighter | Darker
Lighter | Darker

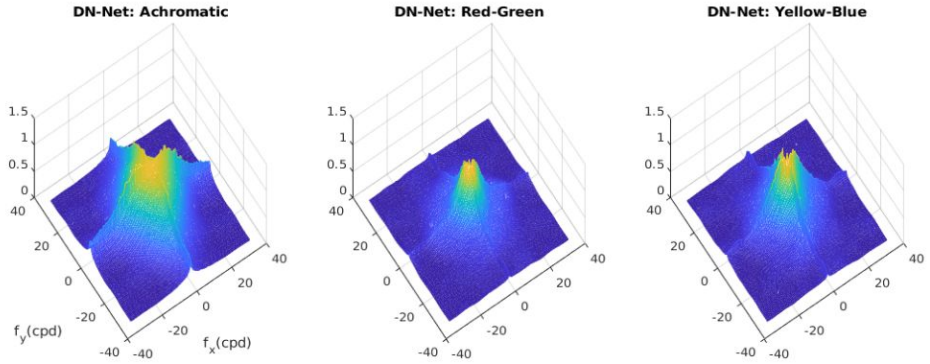
# Summary of replication of grayscale VIs

| Visual Illusion |  |  |  |  |  |
|---|---|---|---|---|---|
| DN-NET | ✓ | ✓ | ✓ | ✓ | ✗ |
| DB-NET | ✓ | ✓ | ✓ | ✓ | ✓ |
| Restore-Net | ✓ | ✓ | ✓ | ✓ | ✓ |
| Deep DN-NET | ✓ | ✓ | ✓ | ✗ | ✗ |
| Deep DB-NET | ✗ | ✓ | ✓ | ✓ | ✓ |
| Deep RestoreNet | ✓ | ✓ | ✓ | ✓ | ✓ |
| Zhang et al. | ✓ | ✗ | ✗ | ✓ | ✗ |

# Summary of replication of color VIs

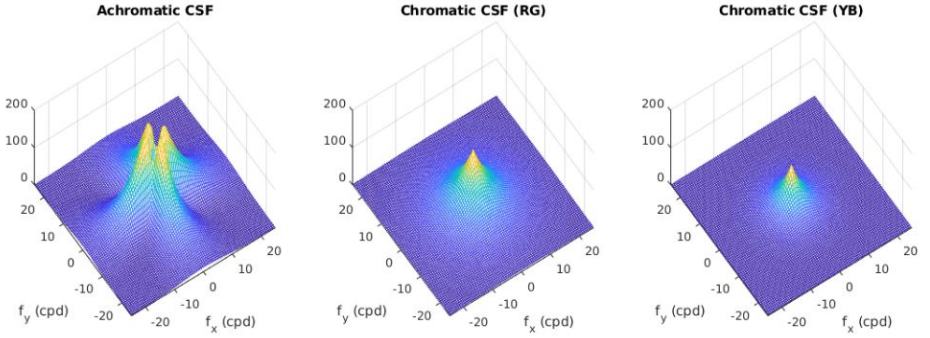
| Visual Illusion |  |  |  |  |  |
|---|---|---|---|---|---|
| DN-NET | ✓ | ✓ | ✓ | ✗ | ✓ |
| DB-NET | ✓ | ✓ | ✓ | ✗ | ✓ |
| Restore-Net | ✓ | ✓ | ✓ | ✗ | ✓ |
| Deep DN-NET | ✓ | ✓ | ✓ | ✗ | ✓ |
| Deep DB-NET | ✓ | ✓ | ✓ | ✓ | ✓ |
| Deep RestoreNet | ✓ | ✓ | ✓ | ✗ | ✓ |
| Zhang et al. | ✓ | ✗ | ✗ | ✓ | ✗ |

# A comparison with human perception




Contrast sensitivity function of DB-NET

Gomez-Villa, A., Martín, A., Vazquez-Corral, J., Bertalmío, M. and Malo, J., 2019. Visual Illusions Also Deceive Convolutional Neural Networks: Analysis and Implications. arXiv preprint arXiv:1912.01643.




Human contrast sensitivity functions

*Mullen, K. T. (1985). The contrast sensitivity of human colour vision to red-green and blue-yellow chromatic gratings. The Journal of physiology, 359(1), 381-400.*

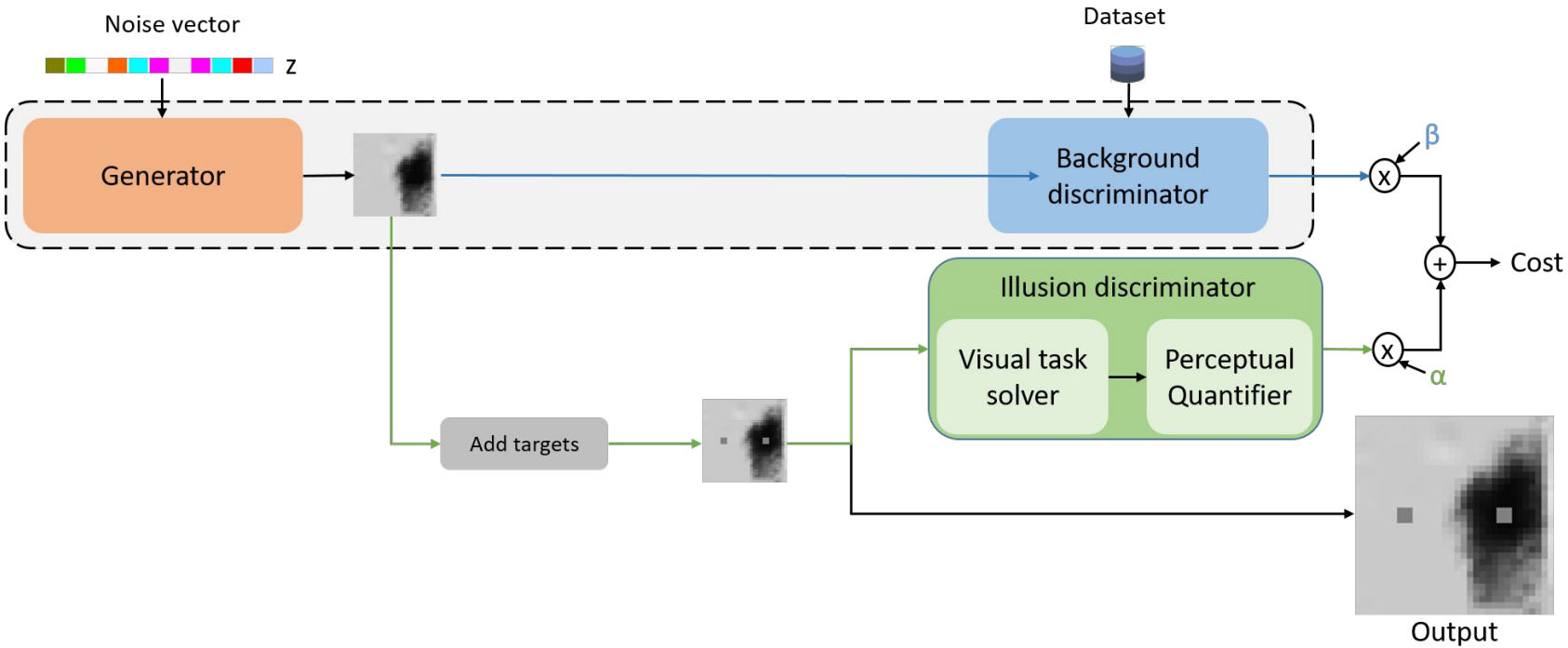
*Watson, A. B., & Malo, J. (2002, September). Video quality measures based on the standard spatial observer. In Proceedings. International Conference on Image Processing(Vol. 3, pp. III-III). IEEE.*

# Can we synthesize new visual illusions?

- Until now, we have tested the effect of visual stimuli that create a visual illusion for humans in CNNs.

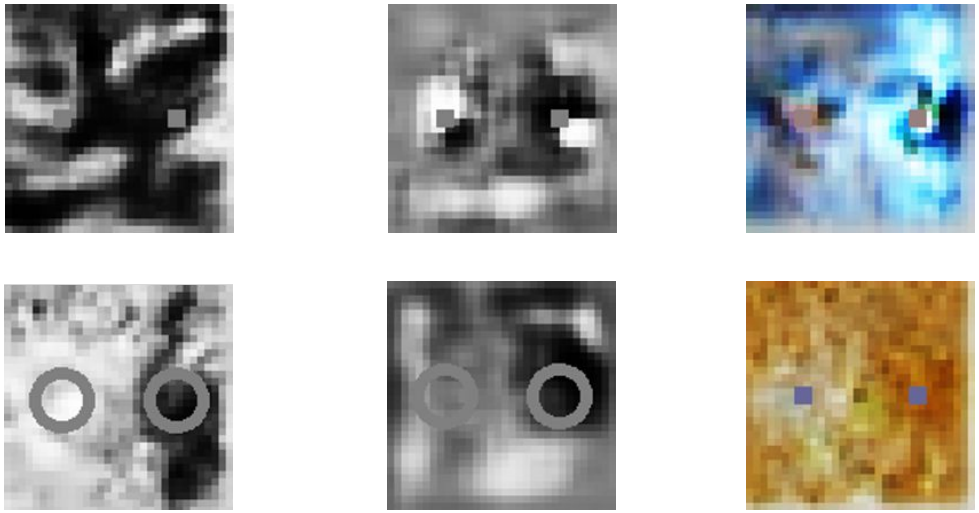
- Can we do the opposite? Can we generate stimuli that create a visual illusion for CNNs that is also a visual illusion for humans?

# Phantasmagoria framework



# Synthetizing Lightness Visual Illusions

Dataset: **DTD** Dataset: **CIFAR-10** **Color**



Go to our preprint for details!

Gomez-Villa, Alexander, et al. "Synthesizing Visual Illusions Using Generative Adversarial Networks." arXiv preprint arXiv:1911.09599 (2019).

We conducted psychophysical experiments that show these are indeed illusions for human too!

# Conclusions and future work

- CNNs trained to perform imaging tasks with natural images can reproduce human response to some visual illusions.
- This finding may be used to develop artificial neural network architectures that are closer to human perception, e.g. models more robust to adversarial attacks.
- We present the first framework to synthesize new visual illusions following a generative adversarial network strategy.
- Future work includes the generation of other types of visual illusions such as motion or completion.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All the circles on this image have the same color!

Image credits: David Novick