



# On the Machine Illusion

## Empirical Study on Adversarial Samples

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# Outline



Acknowledgments

Problem Overview

Background

Defend against Adversarial Samples

Generate Adversarial Texts

Generate *Natural* Adversarials

Summary

Bibliography

# Acknowledgments



Family Shuting, my parents

Advisor Dr. Wei-Shinn Ku and Dr. Anh Nguyen

Committees Dr. Xiao Qin, Dr. Shiwen Mao and Dr. Yang Zhou

Collaborators Dr. Bo Li

Colleagues DATA SCIENCE &  
ENGINEERING LAB



Thanks Xin Wu, Wenlu Wang

Funding  AUBURN  
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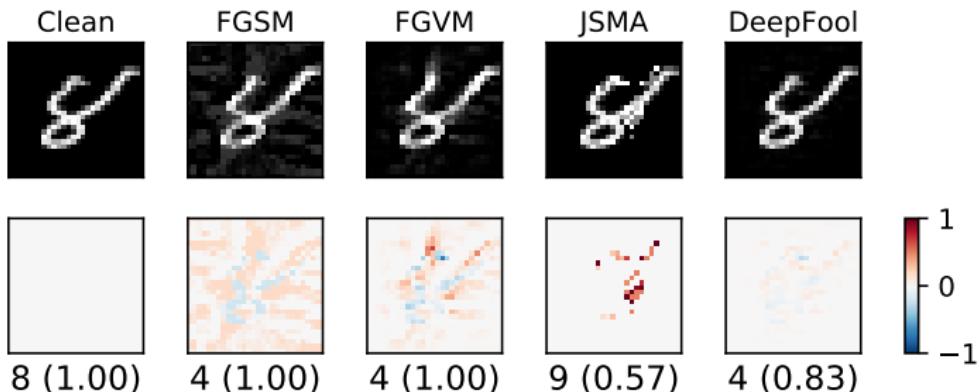
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# Adversarial Samples I



1. Noises are very subtle, visually indistinguishable.
2. Trick machines into wrong predictions with high confidence.



## Adversarial Samples II

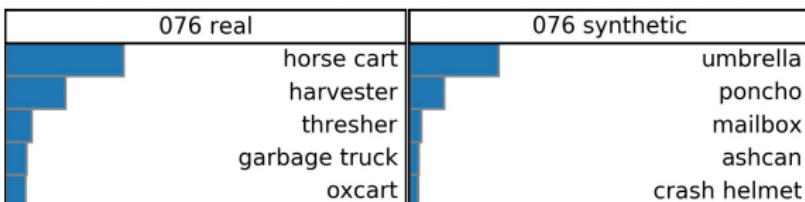
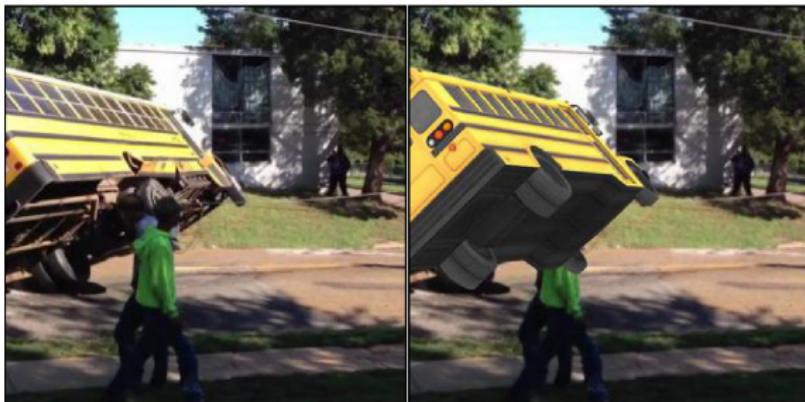
Clean Text	Label	WMD (n/L)	Adversarial Text
Quick summary of the book : [...] The book was n't bad , but was sooooooo cliché     Now about the movie [...] (IMDB)	0→1	0.0317 (0.0050)	Quick summary of the book : [...] The book was n't bad , but was sooooooo TahitiNut     Now about the movie [...]
zulchzulu <SM> TO OFFER SPECIAL DIVIDEND Southmark Corp said it will issue its shareholders a special dividend right [...] (REUTERS-2)	1→0	0.0817 (0.0125)	zulchzulu <SM> TO OFFER OFFERS SHARES Southmark Corp said it will issue its shareh olders a special dividend right [...]
U . K . MONEY MARKET GIVEN FURTHER 68 MLN STG HELP The Bank of England said it provided the market with a further [...] (REUTERS-5)	3→2	0.0556 (0.0077)	U . K . MONEY MARKET GIVEN FURTHER 68 ARL STG HELP The Bank of England said it provided the market with a further [...]

The highlighted words are changed.  $n/L$  is the number of words changed divided by the total number of words. (credit: [Gon+18, Gong et al.])

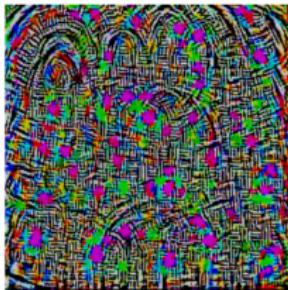
# Adversarial Samples III



Objects in weird poses are also tricky! (credit: [Alc+18, Michael et al.])



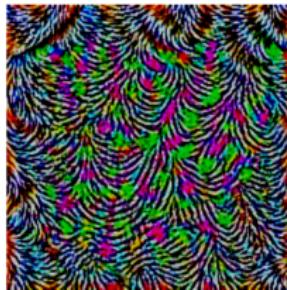
# Adversarial Patterns for Machines



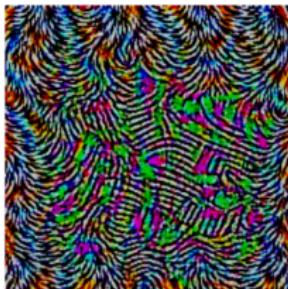
(a) CaffeNet



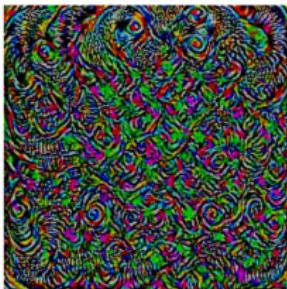
(b) VGG-F



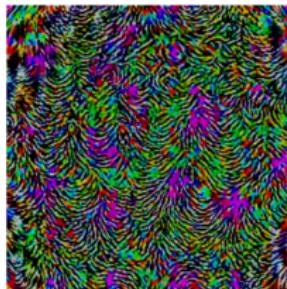
(c) VGG-16



(d) VGG-19



(e) GoogLeNet



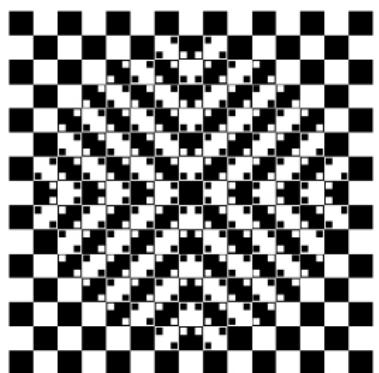
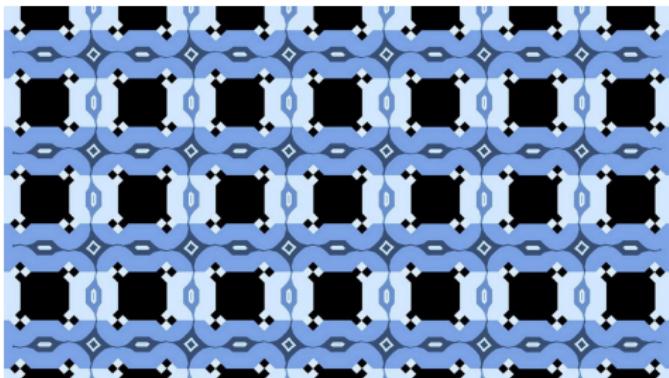
(f) ResNet-152

Figure: Adversarial patterns for different neural nets [Moo+16].

# Adversarial Patterns for Humans



Illusion possibly caused by the fringed edges [KPB04]. More examples <http://www.psy.ritsumei.ac.jp/~akitaoka>





## Motivation

This phenomenon is interesting both in practice and in theory.

1. It undermines the models' reliability.
2. Hard to ignore due to it being transferable and universal.
3. It provides new insights into neural networks:
  - ▶ Local generalization does not seem to hold.
  - ▶ Data distribution: they appear in dense regions.
  - ▶ Trade-off between robustness and generalization.
  - ▶ ...

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# Neural Networks



It is a connectionist model.

1. Any state can be described as an  $N$ -dimensional vector of numeric activation values over neural units in a network.
2. Memory is created by modifying the strength of the connections between neural units.

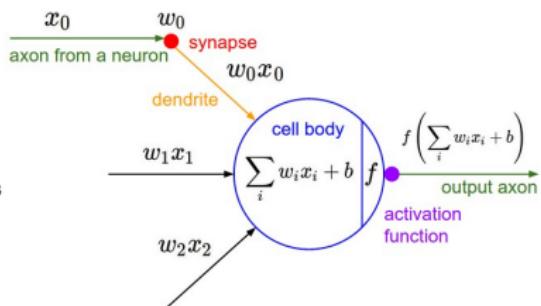
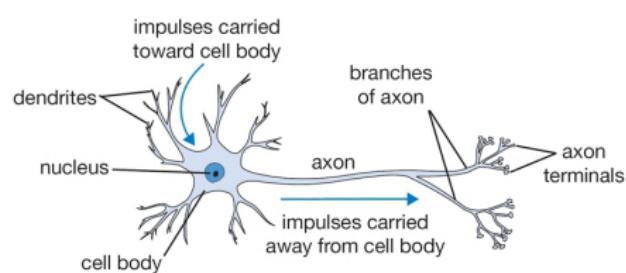


Figure: Biological neuron versus neuron model (credit: [cs231n](#))

# Case Study: Multi-Layer Perceptron (MLP)



MLP is one of the most simple feedforward architectures.

1. Each neuron outputs to the neurons in the next layer.
2. Neurons in the same layer have no connections.

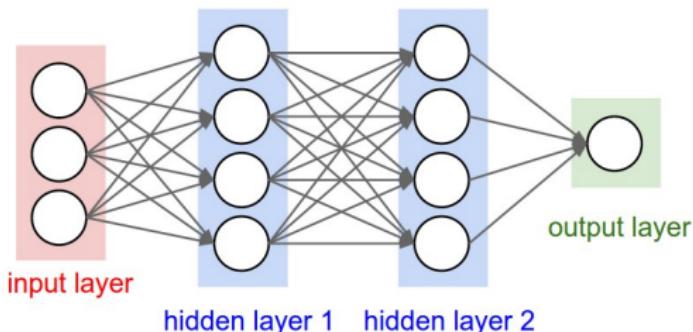


Figure: Multi-layer perceptron (credit: [cs231n](#))

# Case Study: Convolutional Neural Network (CNN)



CNN is inspired by eye structure, widely used in computer vision.

1. Each neuron receives inputs from a pool of neurons in previous layer, just like the convolution operation.
2. Neurons in the same layer have no connections

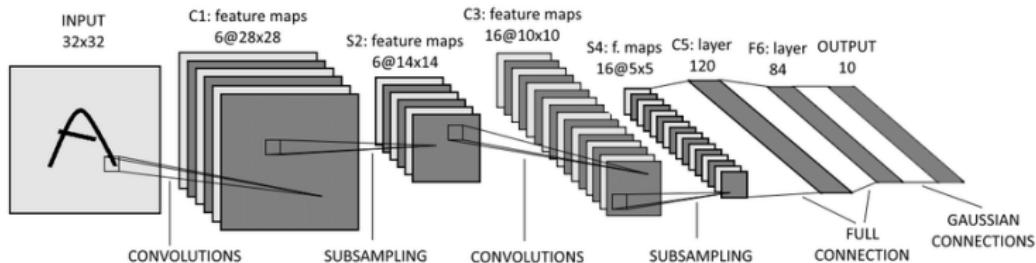


Figure: LeNet-5 [LeC+98]

# Case Study: Recurrent Neural Network (RNN)



Some neurons get part of input from its output.

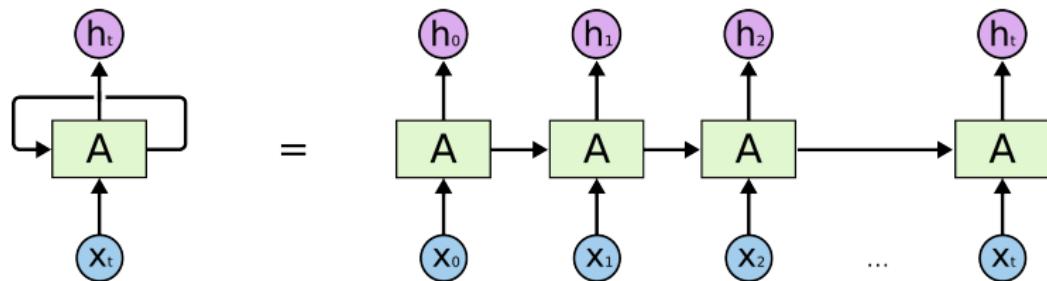


Figure: Dynamic unrolling of recurrent cells. (credit: [colah's blog](#))

# Case Study: Recurrent Neural Network (RNN)



Some neurons get part of input from its output.

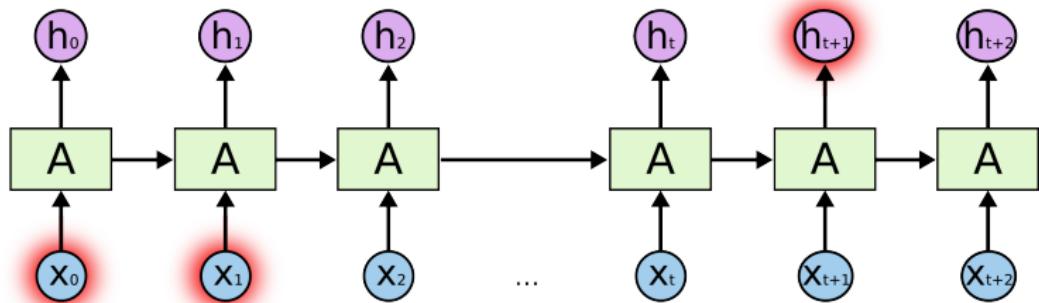


Figure: The double-edged sword: long term dependencies between outputs and inputs. (credit: [colah's blog](#))

# Generate Adversarial Images



## Intuitions behind the adversarial methods

1. Move the data points
  - ▶ towards the decision boundary [MFF15; Moo+16],
  - ▶ in the direction where loss increases for the clean samples [GSS14; KGB16a], or decreases for the adversarial samples [Sze+13], or
  - ▶ where the probability of the correct label increases or the probability of the target label increases [Pap+15; CW16].
2. Map between clean and adversarial data points [ZDS17; BF17; Xia+18].

# Intuition

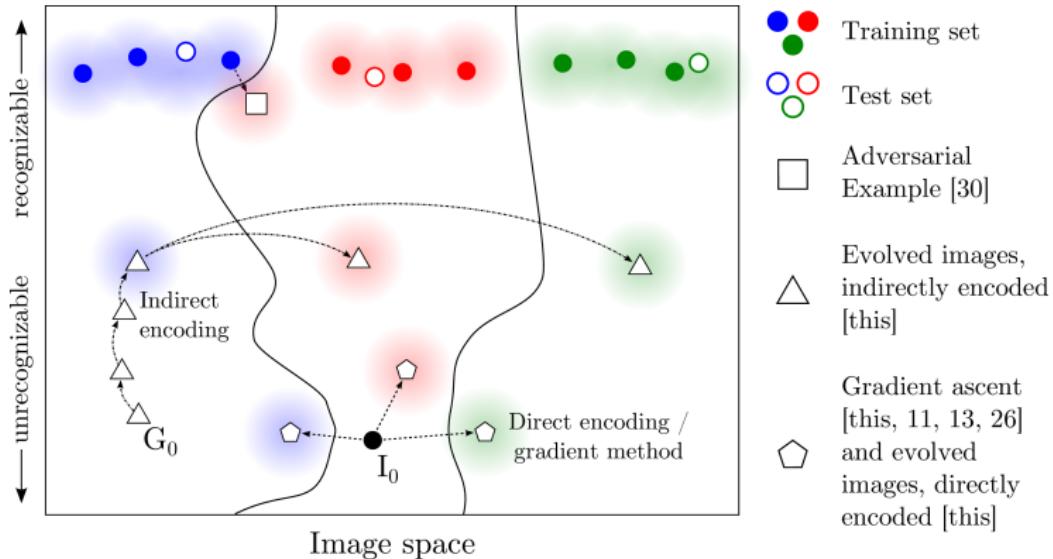


Figure: Data space hypothesis [NYC14]

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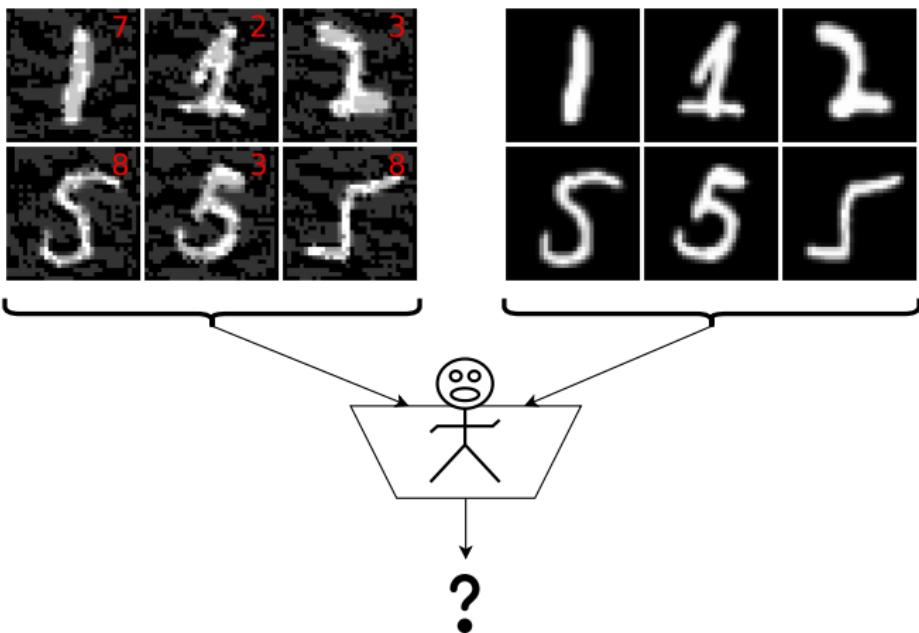
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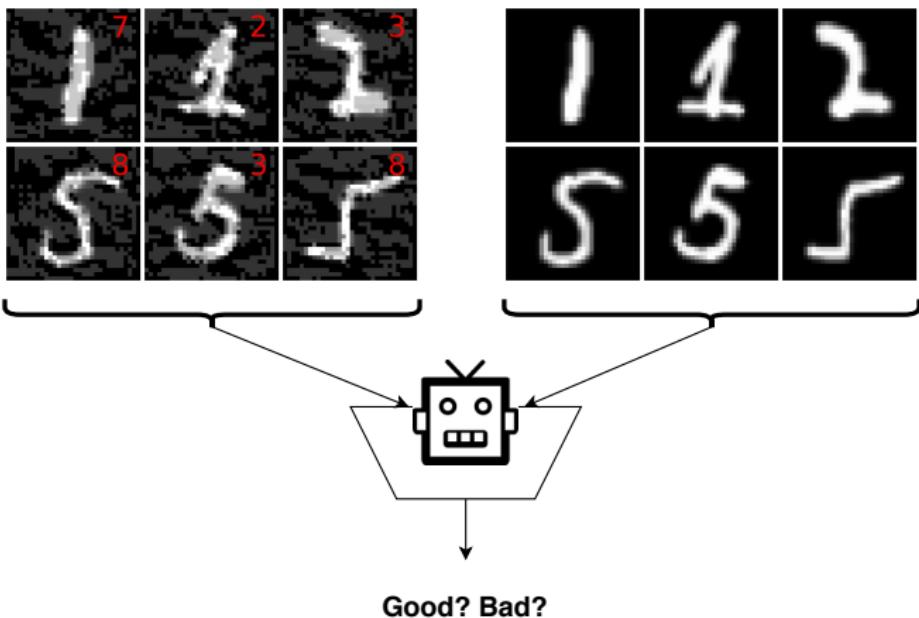
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They look similar for humans.



They look different for machines.



## Binary Classifier as A Defense



We propose to use a binary classifier to separate adversarial samples from clean ones [GWK17] based on the following observations:

1. The adversarial noise follows a specific direction [GSS14].
2. The neural nets are sensitive to individual pixel values [Sze+13].

Code: <https://github.com/gongzhitao/adversarial-classifier>

## Related Work



Adversarial training Augment training data with adversarial samples [GSS14; Mad+17].

$$\theta^* = \arg \min_{\theta} \mathbb{E}_{x \in \mathcal{X}} \left[ \max_{\delta \in [-\epsilon, \epsilon]^N} L(x + \delta; f_{\theta}) \right]$$

Preprocess Transform input images, e.g., denoising [Xie+18; Lia+17b], compression [Pra+18], quilting [Guo+17].

Detecting classifier [Met+17], density ratio estimation [Gon17].

# Adversarial Examples



Dataset	$X$	$\tilde{X}$
MNIST	0.9914	0.0213
CIFAR-10	0.8279	0.1500
SVHN	0.9378	0.2453

Table: The target model accuracy.

# Classifier Efficiency and Robustness

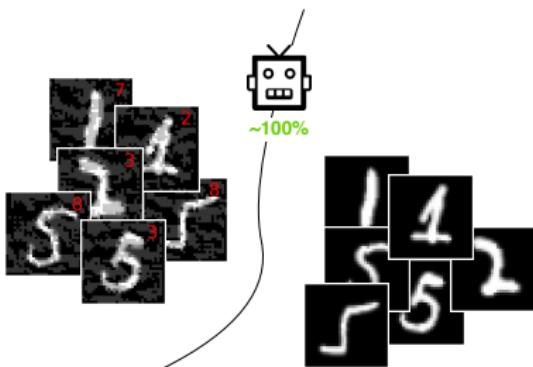


Dataset	$X$	$\tilde{X}_f$	$\{\tilde{X}_f\}_g$
MNIST	1.00	1.00	1.00
CIFAR-10	0.99	1.00	1.00
SVHN	1.00	1.00	1.00

# Classifier Efficiency and Robustness



Dataset	$X$	$\tilde{X}_f$	$\{\tilde{X}_f\}_g$
MNIST	1.00	1.00	1.00
CIFAR-10	0.99	1.00	1.00
SVHN	1.00	1.00	1.00



# Classifier Efficiency and Robustness



Dataset	$X$	$\tilde{X}_f$	$\{\tilde{X}_f\}_g$
MNIST	1.00	1.00	1.00
CIFAR-10	0.99	1.00	1.00
SVHN	1.00	1.00	1.00

The classifier is not easily fooled.



## Problem with Classifier Defense

**Limitation:** different hyper-parameters, different adversarial algorithms may elude the binary classifier or adversarial training.

$\epsilon$	$X$	$\tilde{X}$
0.3	0.9996	1.0000
0.1	0.9996	1.0000
0.03	0.9996	0.9997
0.01	0.9996	0.0030

**Table:** The binary classifier, trained with FGSM adversarials with  $\epsilon = 0.03$ , is unable to recognize the adversarials with  $\epsilon = 0.01$  (more subtle noise).

# Problem with Adversarial Training

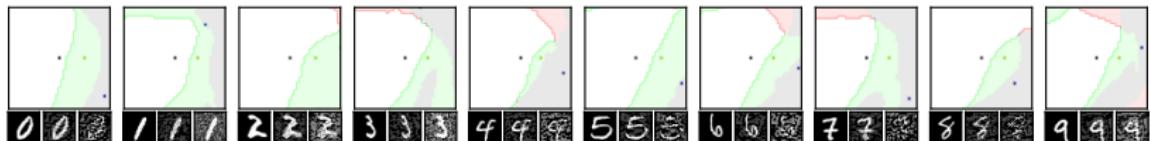


Figure: Adversarial training [Hua+15; KGB16b] is not sufficient. In the church window plot [WG16], each pixel  $(i, j)$  is a data point  $\tilde{x}$  such that  $\tilde{x} = x + \mathbf{h}\epsilon_j + \mathbf{v}\epsilon_i$ , where  $\mathbf{h}$  is the FGSM direction and  $\mathbf{v}$  is a random orthogonal direction. The  $\epsilon$  ranges from  $[-0.5, 0.5]$ . (credit: [GWK17, Gong et al.])

1.  (  ) always correct (incorrectly).
2.   correct with adversarial training.
3.   correct without adversarial training.

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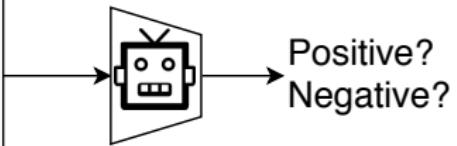
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# Text Classification



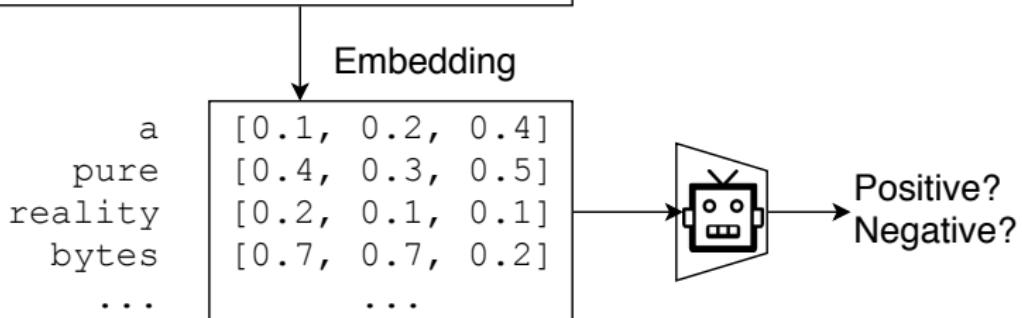
a pure reality bytes film. Fragile, beautiful and amazing first film of the director. Represented Spain on the Berlinale 2002. Some people has compared the grammar of the film with Almodovar's films...Well, that shouldn't be a problem...



# Text Classification



a pure reality bytes film. Fragile, beautiful and amazing first film of the director. Represented Spain on the Berlinale 2002. Some people has compared the grammar of the film with Almodovar's films...Well, that shouldn't be a problem...





## Text Embedding

wait for the video  $\xrightarrow{\text{tokenize}}$  [ wait, for, the, video ]  $\xrightarrow{\text{indexer}}$  [2, 20, 34, 8]  $\xrightarrow{\text{embedding}}$   $\mathbb{R}^{4 \times D}$ , where  $D$  is the embedding size.

- ▶ Each sentence will be converted to  $\mathbb{R}^{L \times D}$  before being fed into the convolution layer, where  $L$  is the sentence length.
- ▶ We usually truncate/pad sentences to the same length so that we could do *batch training*.
- ▶ Embedding may also be on the character-level.

# Problem Overview



**Goal** change as few words as possible to change category.

Difficulties we face:

1. The text space is discrete. Moving the data points in small steps following a certain direction does not work, directly.
2. Text quality is hard to measure. *Much to learn, you still have* (the Yoda-style) v.s. *You still have much to learn* (the mundane-style)

General directions:

1. Three basic operations are available, *replacement*, *insertion*, and *deletion*.
2. They may work at character, word or sentence level.



# Methods

In text space This class of methods need to solve two problems:

1. what to change, e.g., random,  $\nabla L$  [Lia+17a], manually picking [SM17].
2. change to what, e.g., random, synonyms [SM17] or nearest neighbors in embedding space, or forged facts [JL17; Lia+17a].

In latent space GAN [Goo+14] is used to map from a latent space (e.g., Gaussian noise) to sentences [ZDS17].



We propose another method in the embedding space.



Vocabulary is represented by a point ● in a high dimensional space. Each word of I AM HUNGRY is first mapped into embedding space.



We propose another method in the embedding space.



Each point of the input word is perturbed to a new position following a small displacement calculated by our framework.

# Adversarial Text Framework



We propose another method in the embedding space.



We then replace each **yellow circle** with its nearest neighbor since **yellow circles** usually does not correspond to a word. After the nearest neighbor search, we got **I AM FULL**.



## Results On Word-Level

Method	Dataset	Accuracy				
		$\epsilon$	0.40	0.35	0.30	0.25
FGSM	IMDB		0.1334	0.1990	0.4074	0.6770
	Reuters-2		0.6495	0.7928	0.9110	0.9680
	Reuters-5		0.5880	0.7162	0.7949	0.8462
FGVM		$\epsilon$	15	30	50	100
	IMDB		0.8538	0.8354	0.8207	0.7964
	Reuters-2		0.7990	0.7538	0.7156	0.6523
DeepFool	Reuters-5		0.7983	0.6872	0.6085	0.5111
		$\epsilon$	20	30	40	50
	IMDB		0.8298	0.7225	0.6678	0.6416
DeepFool	Reuters-2		0.6766	0.5236	0.4910	0.4715
	Reuters-5		0.4034	0.2222	0.1641	0.1402

Table: Word-level CNN accuracy under different parameter settings.  $\epsilon$  is the noise scaling factor.

# Case Study: DeepFool I

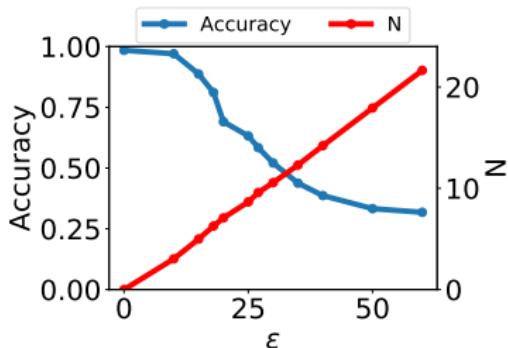
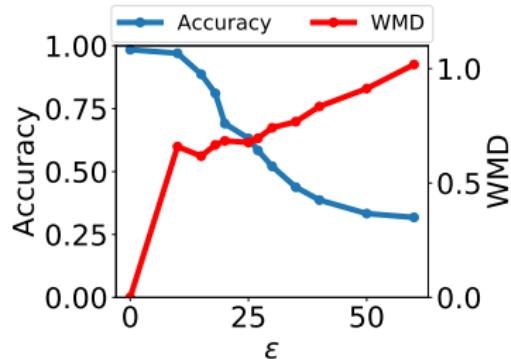


Figure: Word-level model's accuracy with varying DeepFool overshoot value. The WMD and  $N$  (number of words changed) empirically show the quality of the adversarial texts. (credit: [Gon+18, Gong et al.])



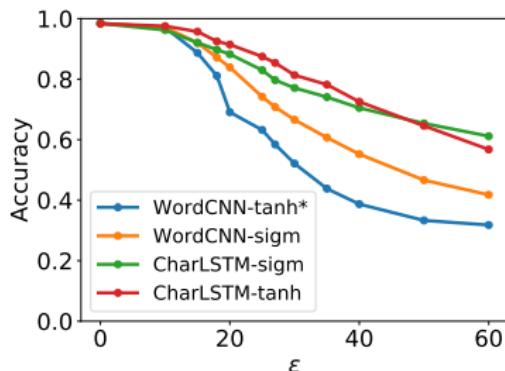
# Case Study: DeepFool II

0.0556 1 (0.77%)	U . K . MONEY MARKET GIVEN FURTHER 68 <b>MLN ARL</b> STG HELP The Bank of England said it provided the market with a further 68 mln stg assistance this afternoon , [...]
0.1762 8 (2.93%)	GERMAN BANKERS ' REMARKS REVIVE AXIOM TALK OF RATE FROM CUT [...] discussion ! ; currency dealers said . [...] required cuts in interest rates higher . Separately , West Berlin state central bank president Dieter Hies Thein told journalists [...] forecast on out interest rates , however . [...] It allocated 6 . 1 billion marks in new liquidity , much less than the 14- 9 ... 9 billion leaving the market as a prior pact expired . [...] Koehler said in a speech in [...] regardless of whether central banks banking intervened or exchange forex rates fell . " [...]
0.4406 12 (6.14%)	ITALY DEFICIT NOT DUE TO LIBERALIZATION SOUNDSCAPE - MINISTER GOVERNOR Italy ' s Foreign Trade Minister Mario Nintendo <unk> monk , commenting on speculation in the Italian press , said a sharp balance of payments deficit spending in May [...] - bearing deposits on down foreign securities purchases . " The deficit can be better attributed to premature and delayed foreign trade five payments and receipts ( leads and lags ) rather than capital outflow to portfolio investment <unk> Hippo_Tron <unk> Libera_me said in a statement . [...] " non - banking capital investment outflows cashflows <unk> " In practice , it seems that there has been a constant flow of capital to foreign securities or investments outside our borders <unk> cat_girl25 said the newspaper . [...]

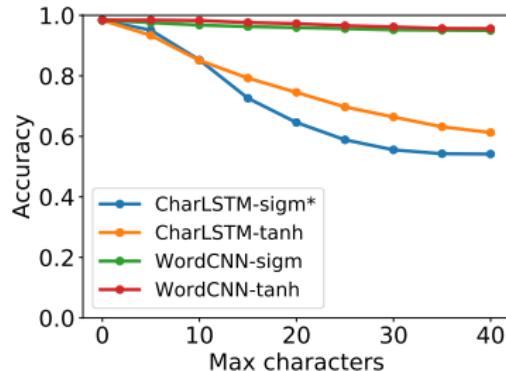
Figure: Adversarial texts sample from Reuters-5 dataset. Original is the original token, replaced is the adversarial token. [...] denotes omitted tokens due to space constraint.

More results: <https://gongzhitao.org/adversarial-text>

# Transferability



**Figure:** Transferability of adversarial texts generated via our framework on word-level.



**Figure:** Transferability of adversarial texts generated via Hotflip on character-level.

\* denotes the target model. (credit: [Gon+18, Gong et al.] )

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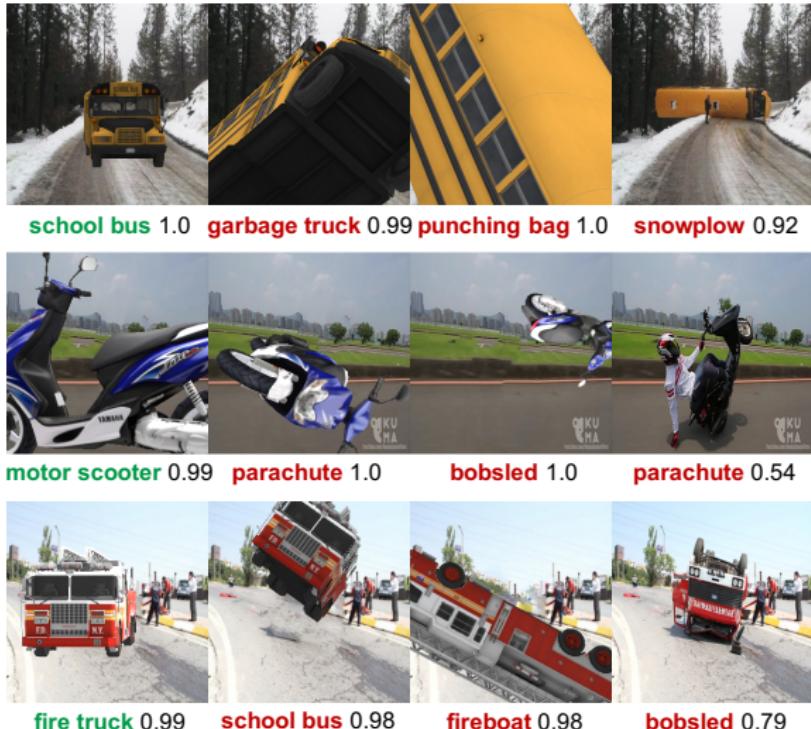


Figure: Objects in weird poses. (credit: [Alc+18, Michael et al.])

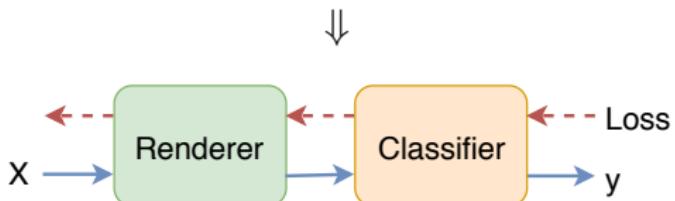
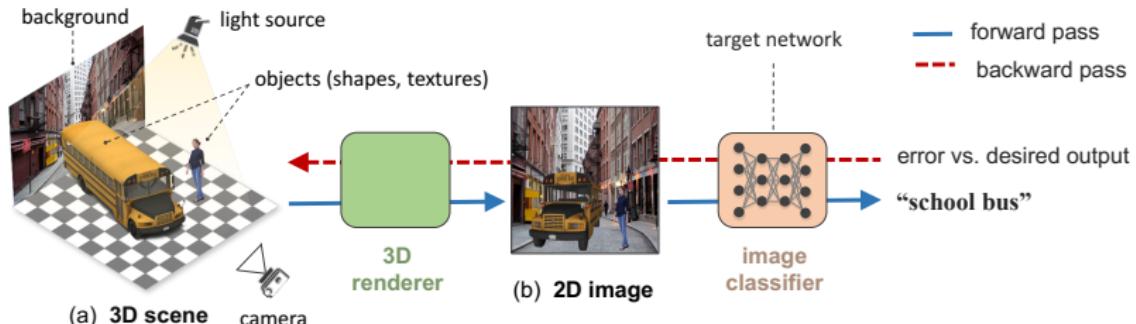


A *descriptive* study on the adversarial pose properties:

1. Effectiveness. Only 3% are correctly recognized.
2. Imperceptible. Small rotation ( $10.30^\circ$  in yaw) results in an adversarial sample.
3. Good transferability. 99% against Inception-v3 transfer to AlexNet and ResNet-50, 75% transfer to YOLO-v3.
4. Adversarial training is not a silver bullet.

Intuition: <https://gongzhitao.org/strike-with-a-pose>

# Framework



$X$  pose parameters, 6D,  $(x, y, z, \theta_x, \theta_y, \theta_z)$   
 $y$  prediction, a probability distribution over all labels.



# Methods

Random search Randomly sample the 6D space.

Gradient descent

$$X_{k+1} = X_k + \nabla_{x_k} L(y_k, \tilde{y})$$

- ▶ Differentiable renderer, neural renderer [KUH18]
- ▶ Non-differentiable renderer, ModernGL [Dom19]

# Random Search



The distributions of each pose parameters for high-confidence ( $p \geq 0.7$ ) correct/wrong classifications. (credit: [Alc+18, Michael et al.])

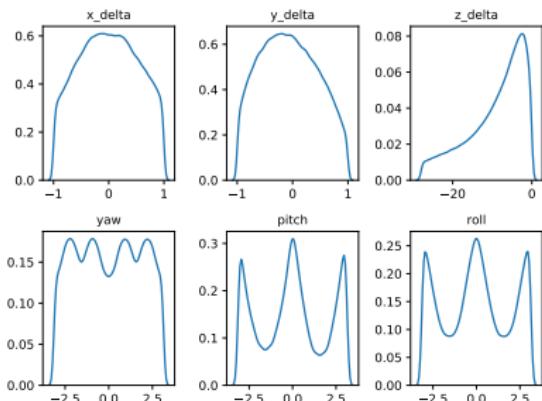


Figure: Correct

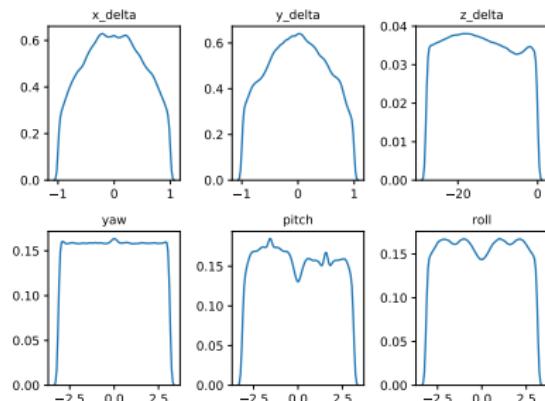
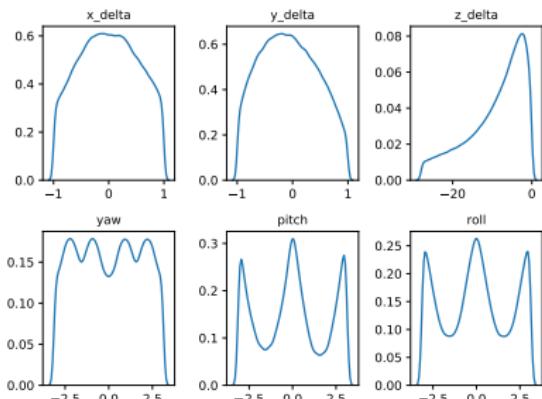


Figure: Wrong

# Random Search

The distributions of each pose parameters for high-confidence ( $p \geq 0.7$ ) correct/wrong classifications. (credit: [Alc+18, Michael et al.])



Parameter	Fail %	$\Delta_{\min}$
$x_\delta$	42	2.0
$y_\delta$	49	4.5
$z_\delta$	81	5.4%
$\theta_y$	69	10.31°
$\theta_p$	83	8.02°
$\theta_r$	81	9.17°

Figure: Correct

# Methods Comparison



ZRS: z-focused random search

FD-G: finite difference approximated gradient

DR-G: differentiable renderer

	Hit Rate %	Target Probability
ZRS	78	0.29
FD-G	92	0.41
DR-G <sup>†</sup>	32	0.22



# Problem with Adversarial Training (again)

PT: AlexNet trained with vanilla ImageNet

AT: training data augmented with adversarial samples

	Error	PT	AT
All	Train	99.67	6.7
	Test	99.81	89.2
$p \geq 0.7$	Train	87.8	1.9
	Test	48.2	33.3

Conclusion: adversarial training does not help models generalize to unseen adversarial samples.



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## Summary



1. Binary classifier as a defense is effective and limited.
2. Text adversarials are also not difficult to generate.
3. Objects in weird poses are also difficult for neural nets.

# Future Work

Image credit [[Kar16](#)]



Machine detects

- ▶ objects
- ▶ faces
- ▶ figure components
- ▶ ...

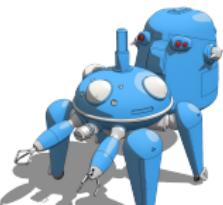
# Future Work

Image credit [[Kar16](#)]



Cannot understand

- ▶ mirror
- ▶ shadows
- ▶ jokes
- ▶ ...





DeepMind

Fall 2019: Research Engineer at Google DeepMind (Montreal)

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