

# Adversarial examples in deep learning

G. Châtel  
@rodgzilla  
[github.com/rodgzilla](https://github.com/rodgzilla)

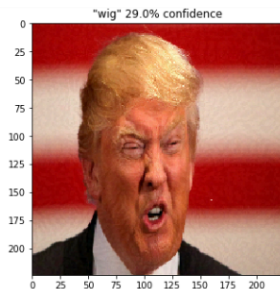
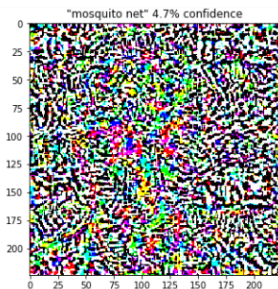
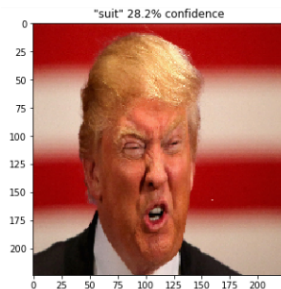
06/07/2017

## What is an adversarial example?

An *adversarial example* is a sample of input data which has been modified *very slightly* in a way that is intended to cause a machine learning classifier to misclassify it.

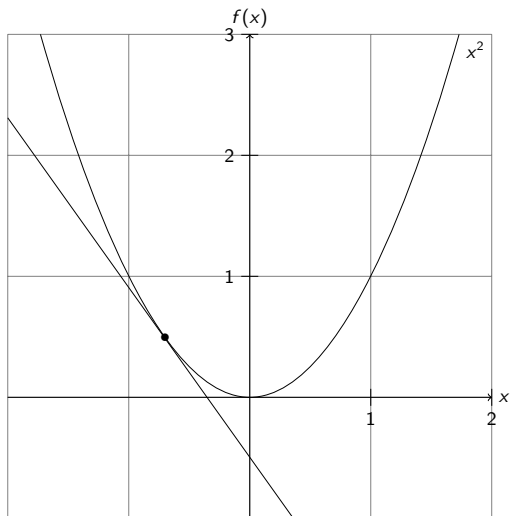
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# Gradient descent

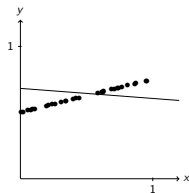
## Basic concept



The curve needs to be *smooth enough* for the gradient descent to work.

# Gradient descent

## Model optimization

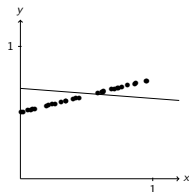


We have a set of points that we want to approximate with a line.

$$y = ax + b$$

# Gradient descent

## Model optimization



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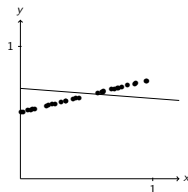
$$y = ax + b$$

First we choose a loss that measures how good our predictions are.

$$L(x, y, a, b) = (y - (ax + b))^2$$

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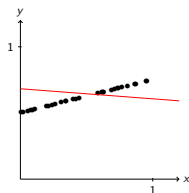
We compute how the loss is affected by small changes of  $a$  and  $b$ .

$$\frac{dL}{da} = 2x(ax + b - y) \qquad \frac{dL}{db} = 2(ax + b - y)$$

And we update  $a$  and  $b$  iteratively until we reach a satisfying result (the average loss for our data points is low enough).

# Gradient descent

Being evil



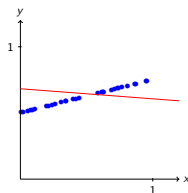
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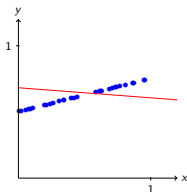
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Now suppose we are an attacker who wants to maximise the loss of a model, its **parameters** being fixed. The only thing we can modify is the **inputs**.

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In order to do this, we compute how the loss is affected by small changes of the input.

$$\frac{dL}{dx} = 2a(ax + b - y)$$

We can now make *imperceptible* changes to an input that will increase the loss value.

# Neural networks

Everything works the same way when working with a neural network on an image classification task.

We also have a differentiable **loss function** (often **categorical cross entropy**) and **inputs** (**pixel values** in the case of images) that we can modify to increase the loss.

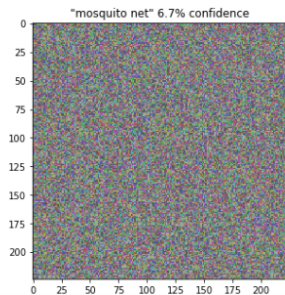
## Random noise perturbation

Do we really need to do that?



# Random noise perturbation

Yep



## Fast Gradient Sign Method [Goodfellow et al. 2015]

Let  $x$  be the original image,  $\theta$  the parameters of the model,  $y$  the target associated with  $x$  and  $J(\theta, x, y)$  the loss function.

We compute the gradient of the loss function according to the input pixels.

$$\nabla_x L(\theta, x, y)$$

The perturbation is the signs of these derivatives multiplied by a small number  $\varepsilon$ .

$$\eta = \varepsilon \text{sign}(\nabla_x L(\theta, x, y))$$

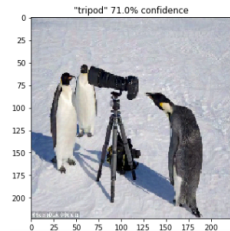
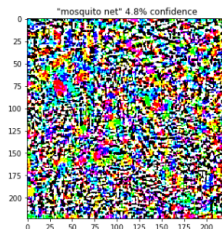
The final adversarial sample is the sum of the original image and the perturbation.

$$x_{adv} = x + \eta$$

# Fast Gradient Sign Method

Using the **VGG16** network with imagenet weights

$$x + \epsilon \text{sign}(\nabla_x L(\theta, x, y)) = x_{\text{adv}}$$



# Black box attack [Papernot et al. 2016]

or good luck getting gradients out of your self-driving car





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Transferability of adversarial samples

We can train a new model  $M'$  to solve the same classification task as the target model  $M$ .

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Once trained, we can create an adversarial sample  $x'_{adv}$  for the  $M'$  model and experiences have shown that  $x'_{adv}$  will also fool  $M$  very often.

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*"After labeling 6,400 synthetic inputs to train our substitute (an order of magnitude smaller than the training set used by MetaMind) we find that their DNN misclassifies adversarial examples crafted with our substitute at a rate of 84.24%"*

- Papernot et al., about their attack on the MetaMind deep neural network.

# Adversarial examples in the physical world [Kurakin et al. 2017]

Being evil, for real

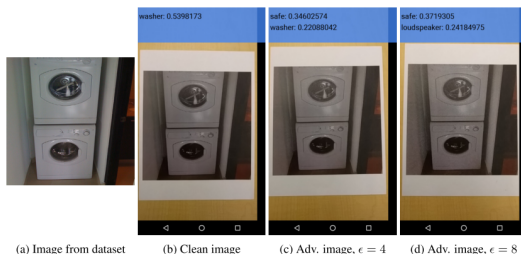
In real world scenarios, the target network does not take our image files as input. It acquires the data by the network's system (e.g. a camera).

# Adversarial examples in the physical world [Kurakin et al. 2017]

Being evil, for real

In real world scenarios, the target network does not take our image files as input. It acquires the data by the network's system (e.g. a camera).

It also works, for free.



*"We used images taken from a cell-phone camera as a input to an Inception v3 image classification neural network. We showed that in such a set-up, a significant fraction of adversarial images crafted using the original network are misclassified even when fed to the classifier through the camera."*

- Kurakin et al.

We can generate adversarial samples, and train the network to produce the correct classification.

- Works against FGSM
- Expensive
- Does not defend more complicated white box attacks (e.g. iterative FGSM or RAND+FGSM)
- Does not defend against black box attack

# Defense

Ensemble adversarial training [Tramèr et al. May 2017]

Augment training data with adversarial inputs from a number of fixed pre-trained models.

- Best defense so far against black-box adversary
- Does not defend white-box attack



# Defending machine learning

## Wide open problem

“Most defenses against adversarial examples that have been proposed so far just do not work very well at all, but the ones that do work are not adaptive. This means it is like they are playing a game of whack-a-mole: they close some vulnerabilities, but leave others open.”

- Ian Goodfellow, Nicolas Papernot, February 2017

# References

- ❶ Goodfellow, I. J., Shlens, J., & Szegedy, C. (2014). Explaining and harnessing adversarial examples. arXiv preprint arXiv:1412.6572.
- ❷ Papernot, N., McDaniel, P., Wu, X., Jha, S., & Swami, A. (2016). Distillation as a defense to adversarial perturbations against deep neural networks. In Security and Privacy (SP), 2016 IEEE Symposium on (pp. 582-597). IEEE.
- ❸ Kurakin, A., Goodfellow, I., & Bengio, S. (2016). Adversarial examples in the physical world. arXiv preprint arXiv:1607.02533.
- ❹ Papernot, N., McDaniel, P., Goodfellow, I., Jha, S., Celik, Z. B., & Swami, A. (2016). Practical black-box attacks against deep learning systems using adversarial examples. arXiv preprint arXiv:1602.02697.
- ❺ Tramèr, F., Kurakin, A., Papernot, N., Boneh, D., & McDaniel, P. (2017). Ensemble Adversarial Training: Attacks and Defenses. arXiv preprint arXiv:1705.07204.