

## Module 3.4: Learning Parameters : Gradient Descent

*Now let us see if there is a more efficient and principled way of doing this*

## Goal

Find a better way of traversing the error surface so that we can reach the minimum value quickly without resorting to brute force search!

vector of parameters,  
say, randomly initialized

$$\theta = [w, b]$$

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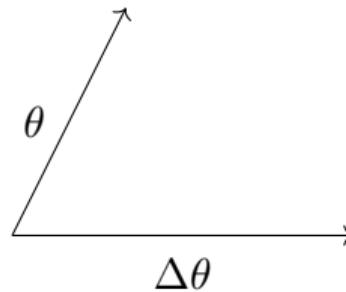
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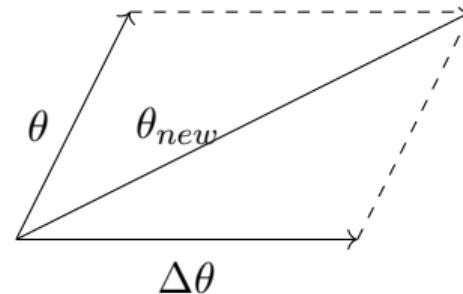


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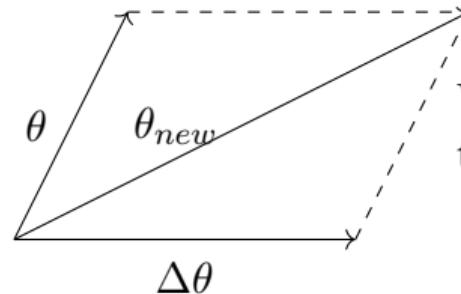


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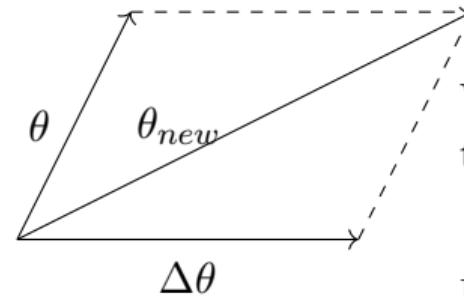


We moved in the direction of  $\Delta\theta$

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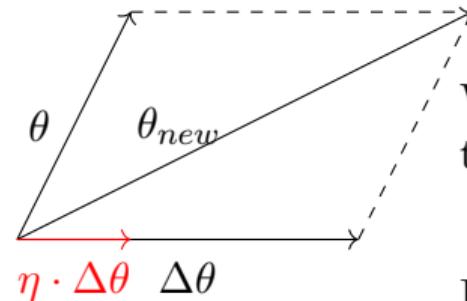
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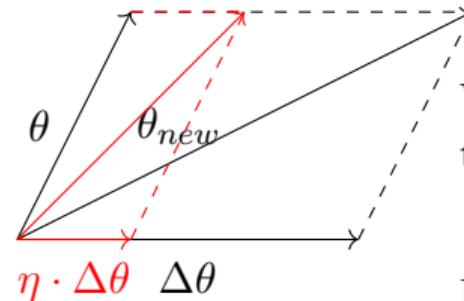
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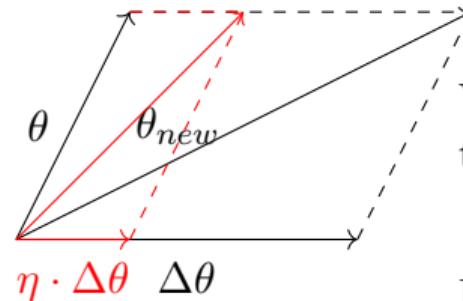
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$$\theta_{new} = \theta + \eta \cdot \Delta\theta$$



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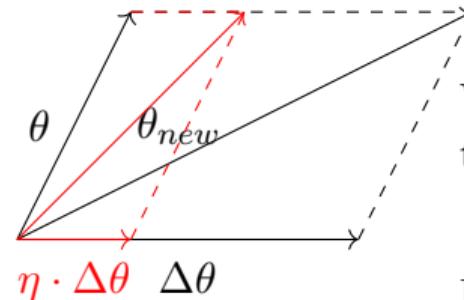
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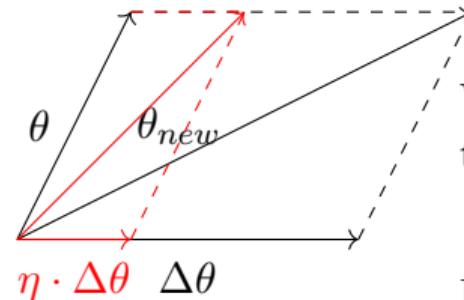
**Question:** What is the right  $\Delta\theta$  to use ?

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The answer comes from Taylor series

For ease of notation, let  $\Delta\theta = u$ , then from Taylor series, we have,

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$$\mathcal{L}(\theta + \eta u) = \mathcal{L}(\theta) + \eta * u^T \nabla \mathcal{L}(\theta) + \frac{\eta^2}{2!} * u^T \nabla^2 \mathcal{L}(\theta) u + \frac{\eta^3}{3!} * \dots + \frac{\eta^4}{4!} * \dots$$

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Note that the move ( $\eta u$ ) would be favorable only if,

$$\mathcal{L}(\theta + \eta u) - \mathcal{L}(\theta) < 0 \text{ [i.e., if the new loss is less than the previous loss]}$$

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This implies,

$$u^T \nabla \mathcal{L}(\theta) < 0$$

Okay, so we have,

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multiply throughout by  $k = \|u\| * \|\nabla \mathcal{L}(\theta)\|$

$$-k \leq k * \cos(\beta) = u^T \nabla \mathcal{L}(\theta) \leq k$$

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Thus,  $\mathcal{L}(\theta + \eta u) - \mathcal{L}(\theta) = u^T \nabla \mathcal{L}(\theta) = k * \cos(\beta)$  will be most negative when  $\cos(\beta) = -1$  i.e., when  $\beta$  is  $180^\circ$

## Gradient Descent Rule

- The direction  $u$  that we intend to move in should be at  $180^\circ$  w.r.t. the gradient

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## Parameter Update Equations

$$w_{t+1} = w_t - \eta \nabla w_t$$

$$b_{t+1} = b_t - \eta \nabla b_t$$

where,  $\nabla w_t = \frac{\partial \mathcal{L}(w, b)}{\partial w}$  at  $w = w_t, b = b_t$ ,  $\nabla b = \frac{\partial \mathcal{L}(w, b)}{\partial b}$  at  $w = w_t, b = b_t$

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So we now have a more principled way of moving in the  $w$ - $b$  plane than our “guess work” algorithm

- Let us create an algorithm from this rule ...

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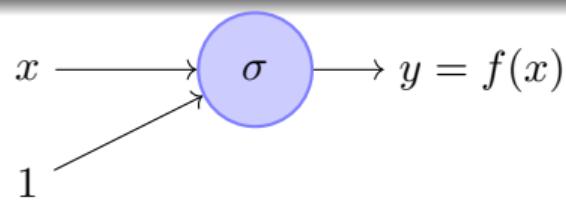
**Algorithm:** gradient\_descent()

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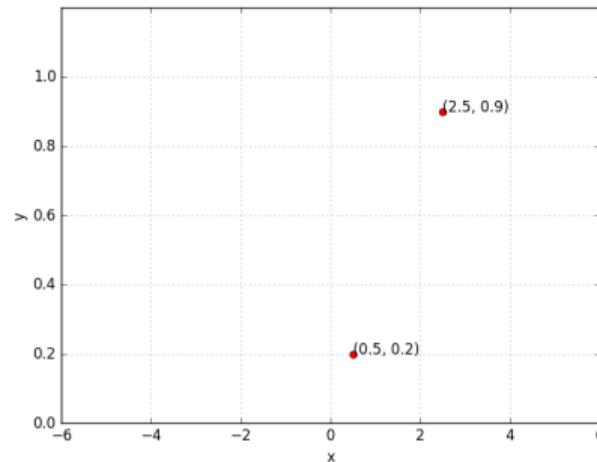
```
t ← 0;  
max_iterations ← 1000;  
while  $t < max\_iterations$  do  
    |  $w_{t+1} \leftarrow w_t - \eta \nabla w_t;$   
    |  $b_{t+1} \leftarrow b_t - \eta \nabla b_t;$   
end
```

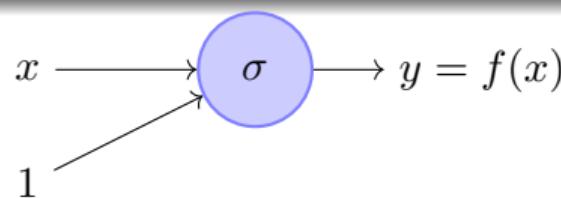
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- To see this algorithm in practice let's first derive  $\nabla w$  and  $\nabla b$  for our toy neural network



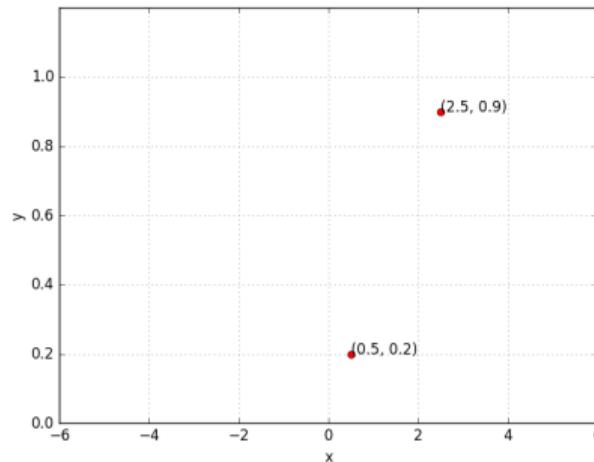
$$f(x) = \frac{1}{1+e^{-(w \cdot x + b)}}$$

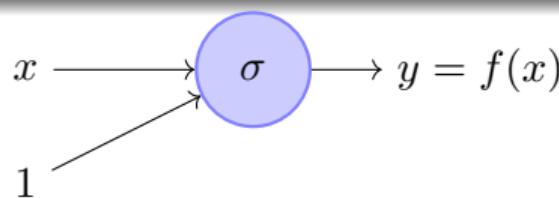




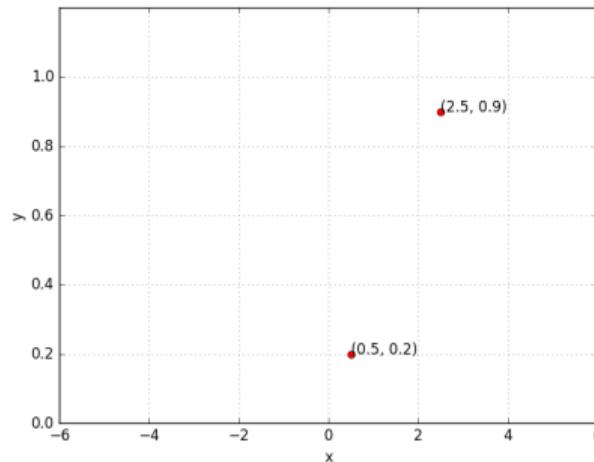
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Let's assume there is only 1 point to fit  
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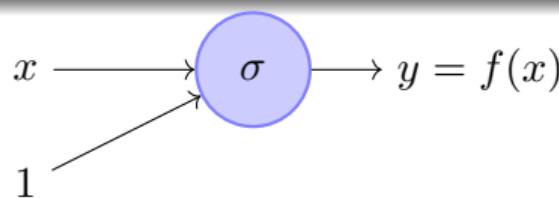


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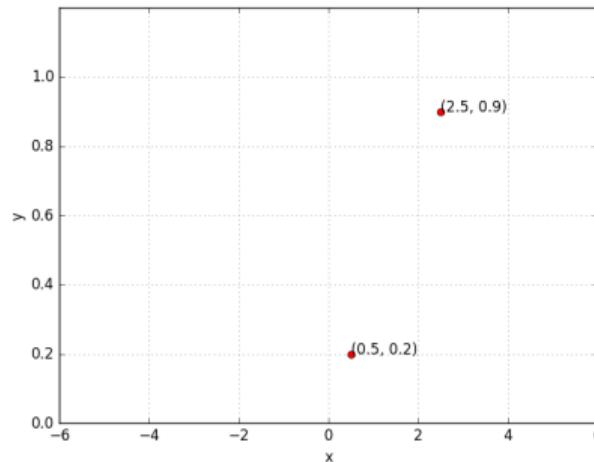


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$$\mathcal{L}(w, b) = \frac{1}{2} * (f(x) - y)^2$$



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$$\begin{aligned}\mathcal{L}(w, b) &= \frac{1}{2} * (f(x) - y)^2 \\ \nabla w &= \frac{\partial \mathcal{L}(w, b)}{\partial w} = \frac{\partial}{\partial w} \left[ \frac{1}{2} * (f(x) - y)^2 \right]\end{aligned}$$

$$\nabla w = \frac{\partial}{\partial w} \left[ \frac{1}{2} * (f(x) - y)^2 \right]$$

$$\begin{aligned}\nabla w &= \frac{\partial}{\partial w} \left[ \frac{1}{2} * (f(x) - y)^2 \right] \\ &= \frac{1}{2} * [2 * (f(x) - y) * \frac{\partial}{\partial w} (f(x) - y)]\end{aligned}$$

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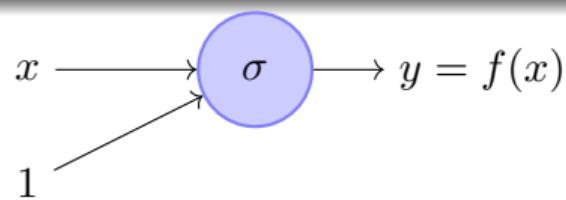
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 &= \frac{1}{(1 + e^{-(wx+b)})} * \frac{e^{-(wx+b)}}{(1 + e^{-(wx+b)})} * (x) \\
 &= f(x) * (1 - f(x)) * x
 \end{aligned}$$

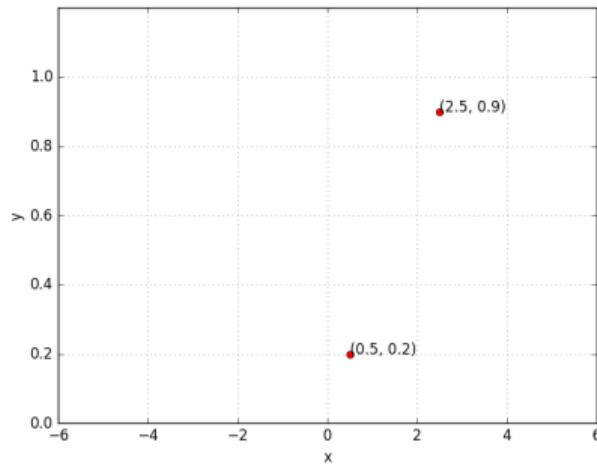
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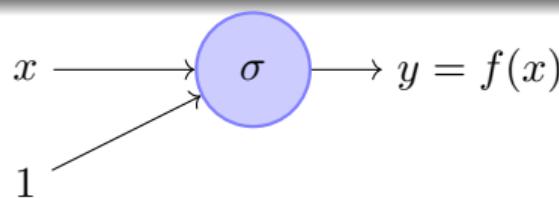
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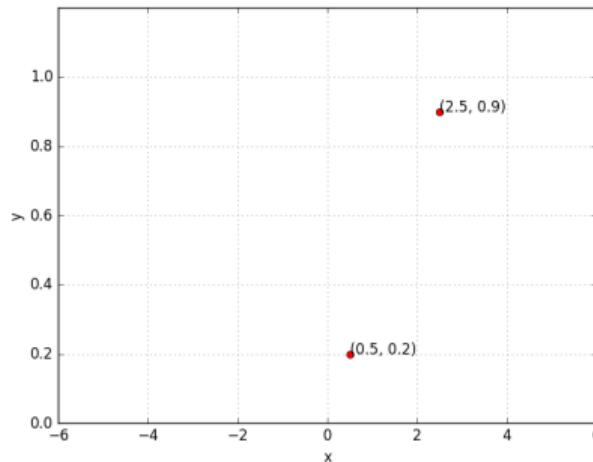
$$f(x) = \frac{1}{1+e^{-(w \cdot x + b)}}$$

So if there is only 1 point  $(x, y)$ , we have,



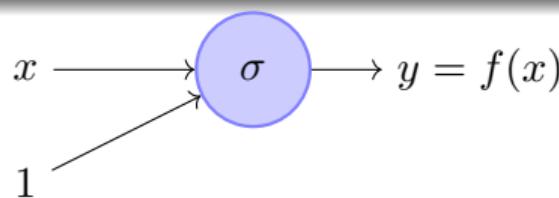


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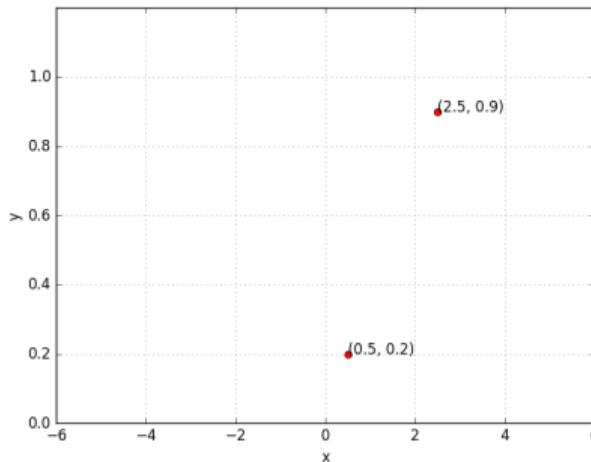


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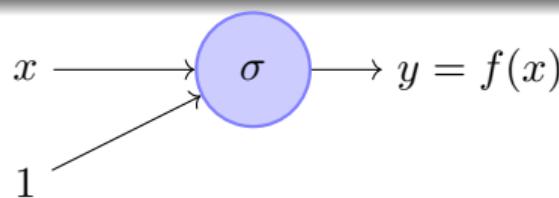
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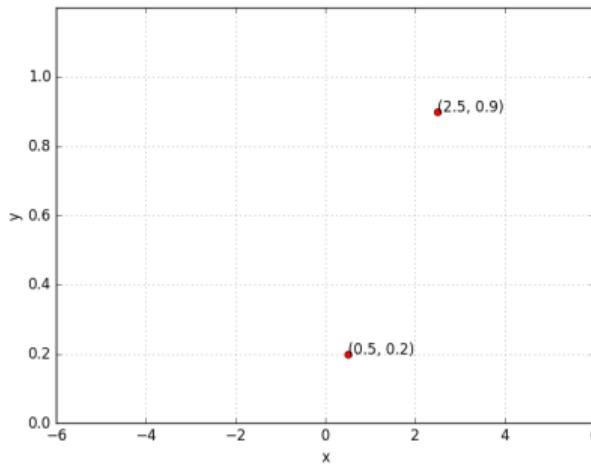
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For two points,



$$f(x) = \frac{1}{1+e^{-(w \cdot x + b)}}$$

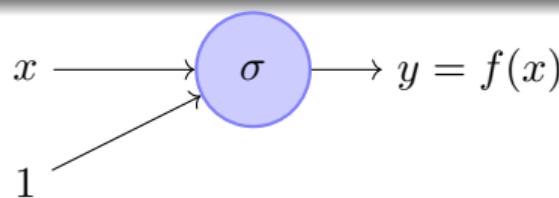


So if there is only 1 point  $(x, y)$ , we have,

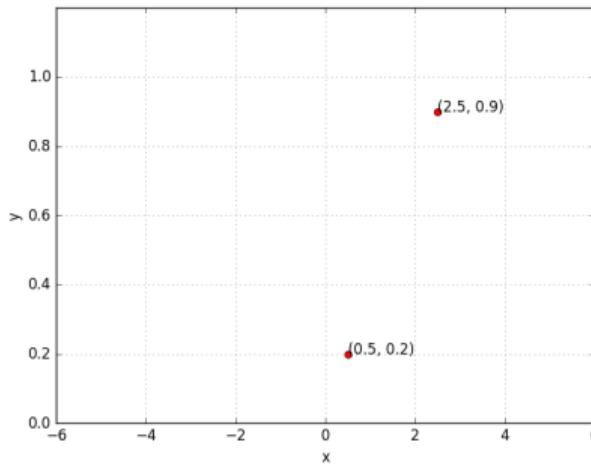
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For two points,

$$\nabla w = \sum_{i=1}^2 (f(x_i) - y_i) * f(x_i) * (1 - f(x_i)) * x_i$$



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Y = [0.2, 0.9]
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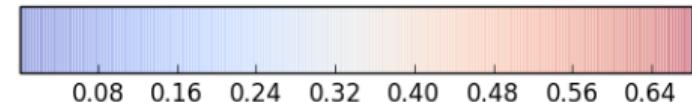
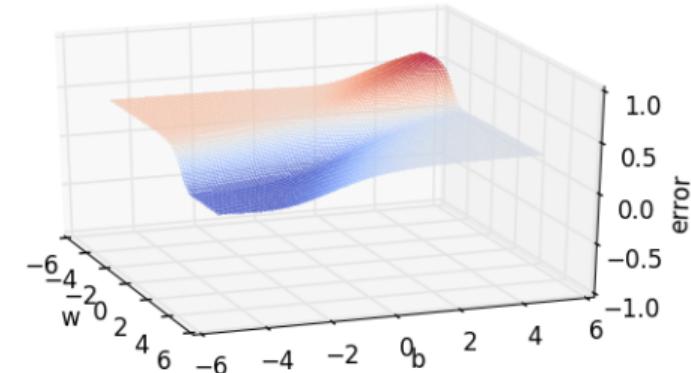
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Random search on error surface



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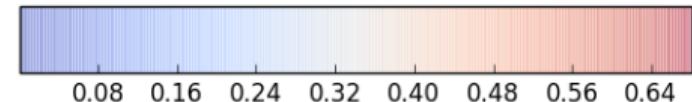
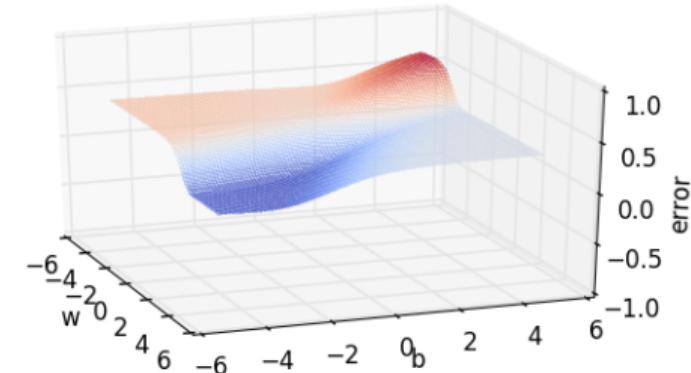
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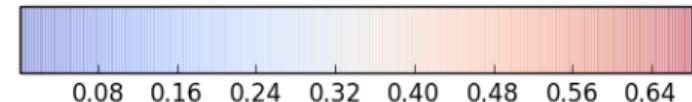
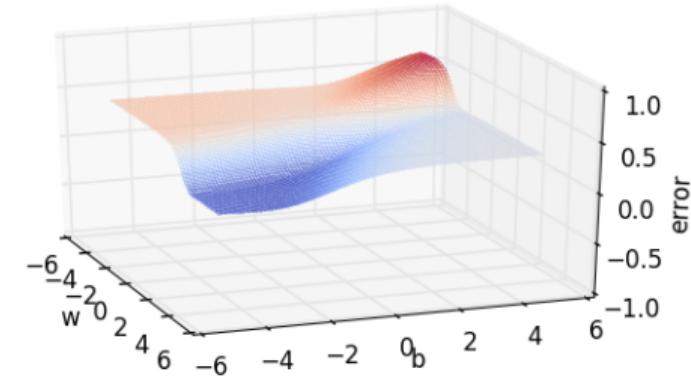
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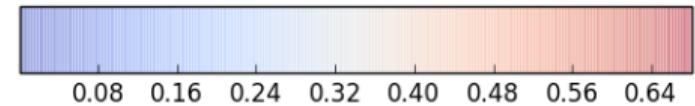
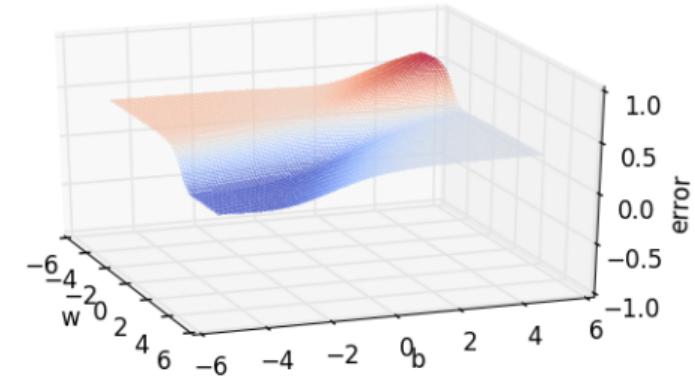
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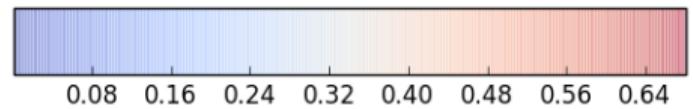
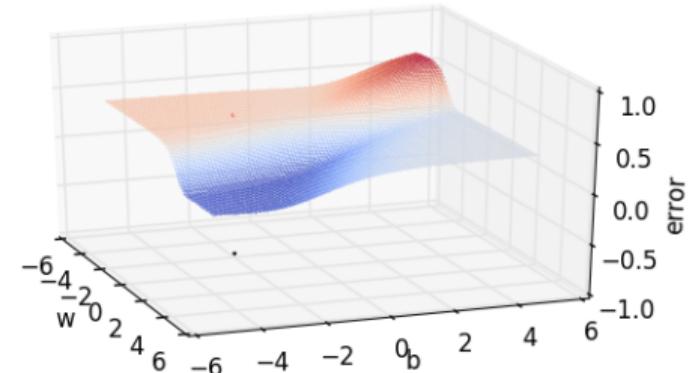
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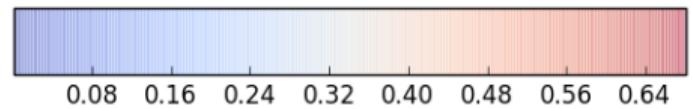
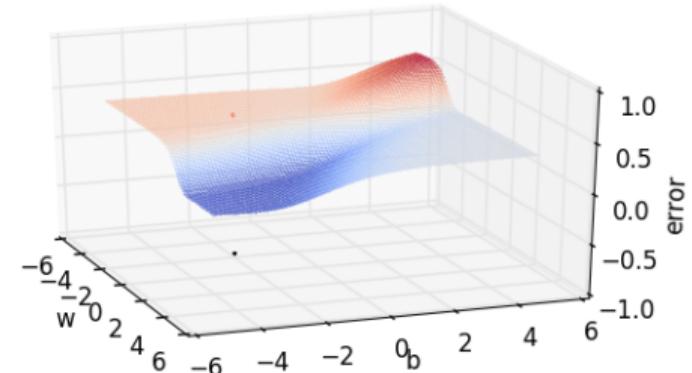
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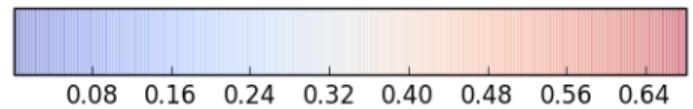
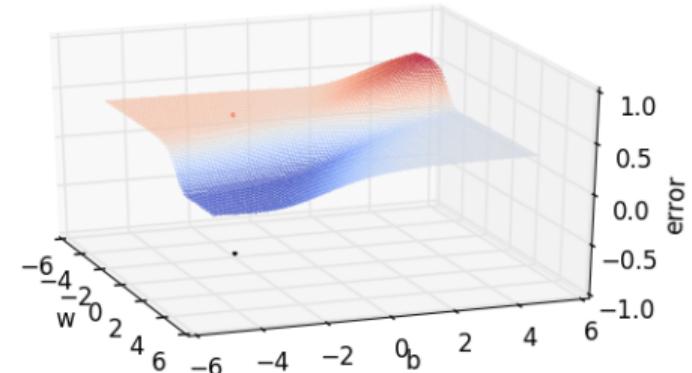
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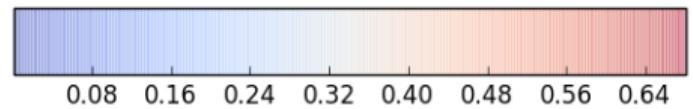
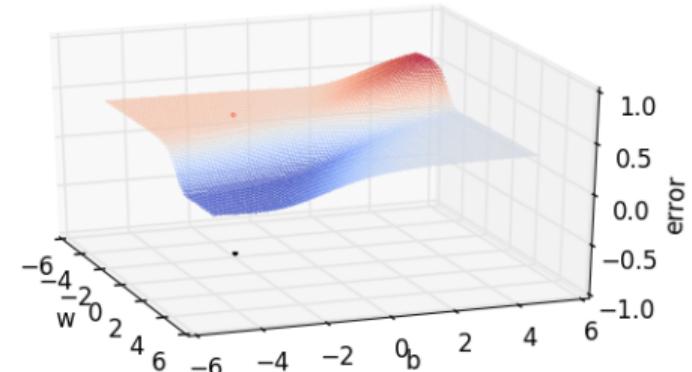
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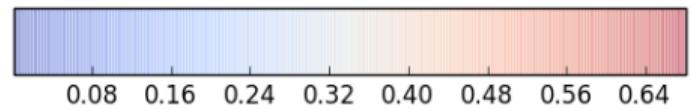
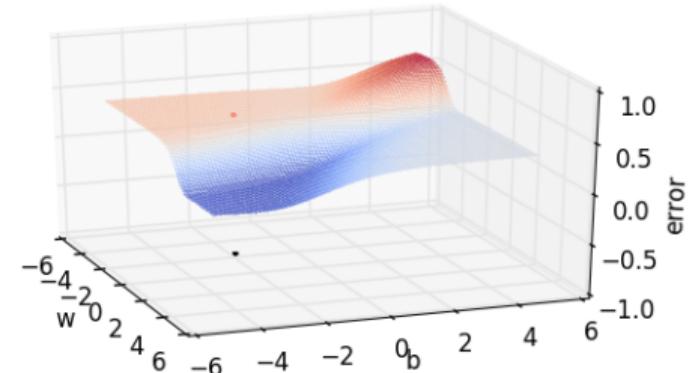
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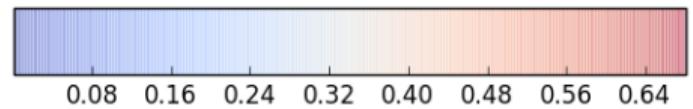
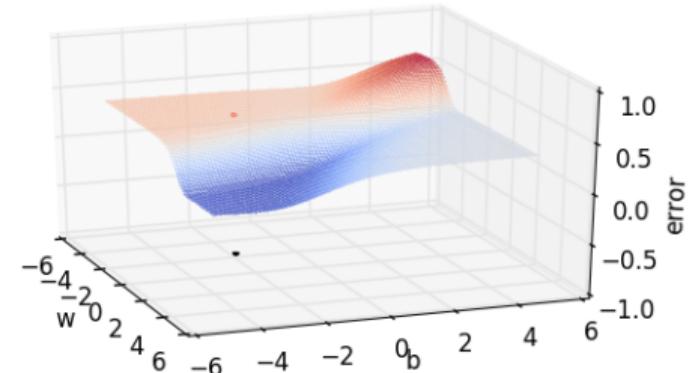
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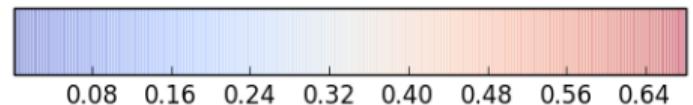
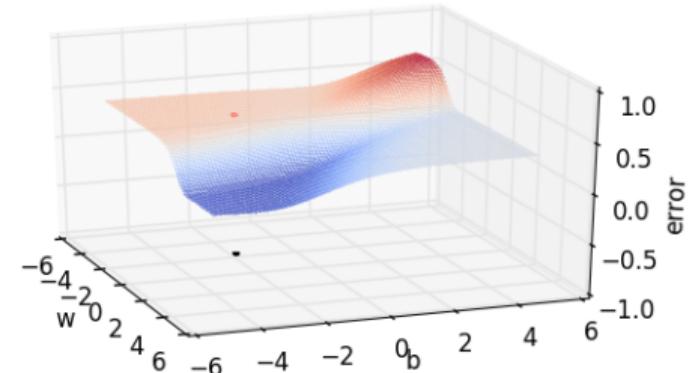
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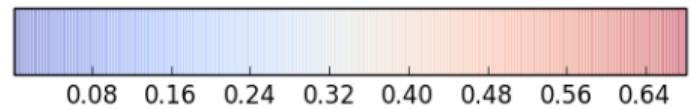
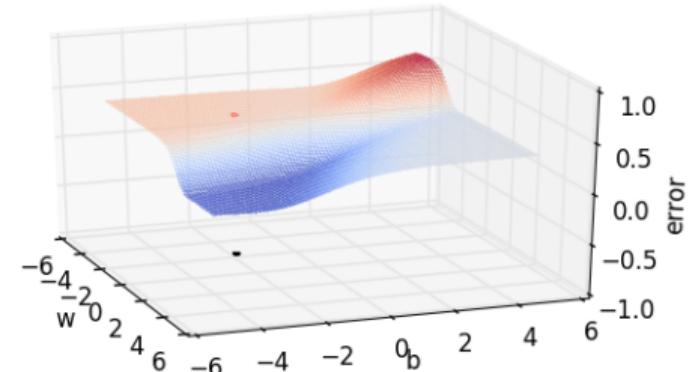
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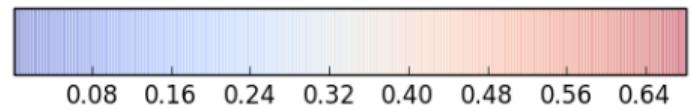
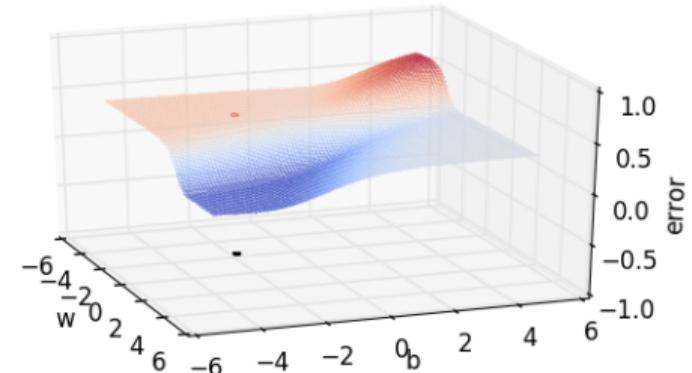
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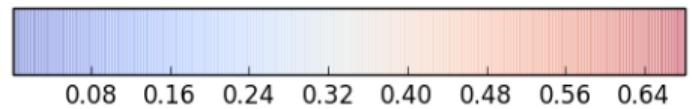
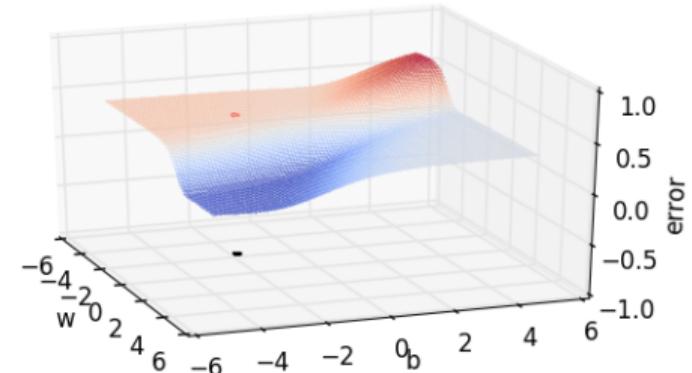
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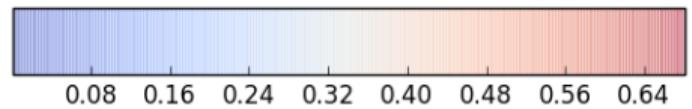
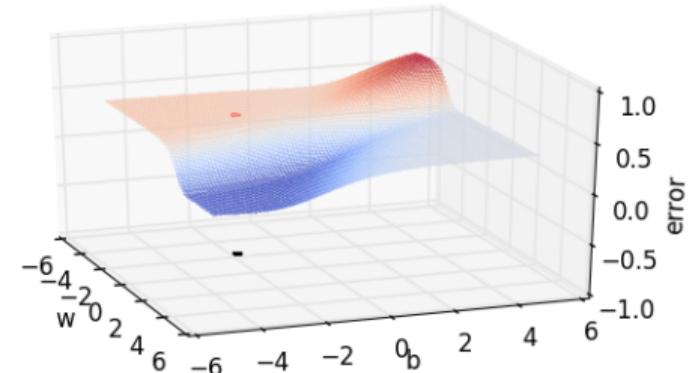
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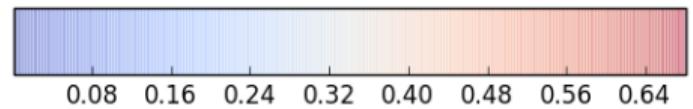
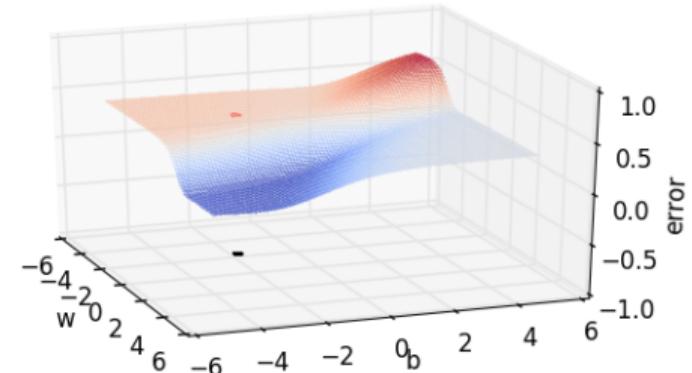
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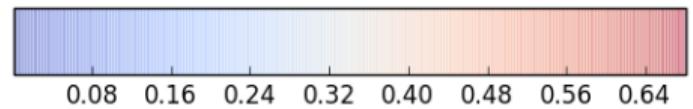
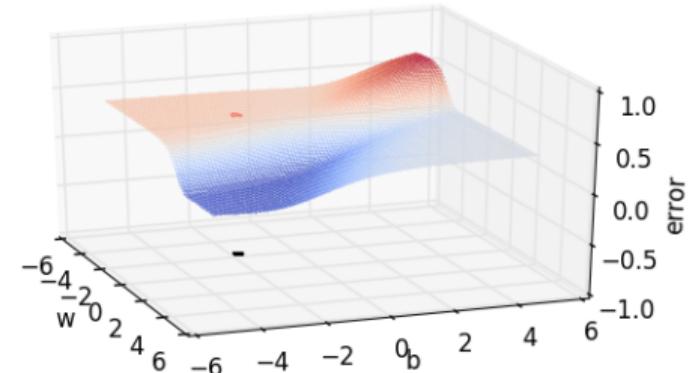
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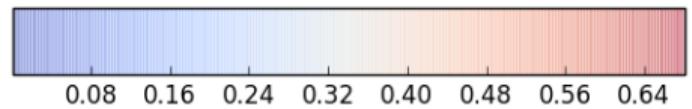
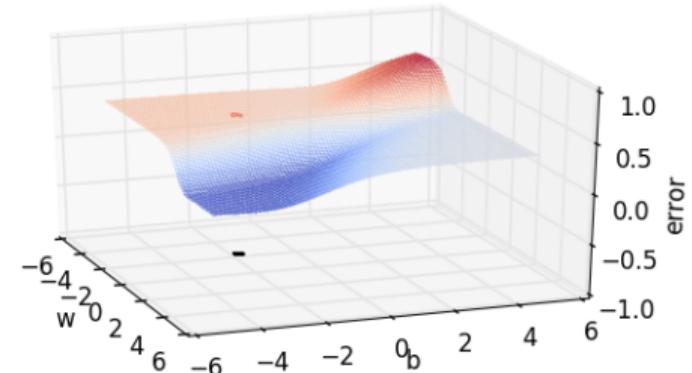
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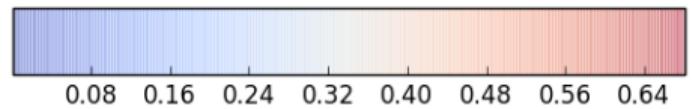
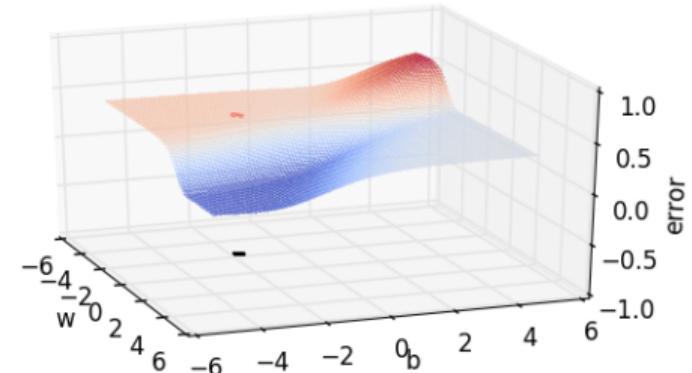
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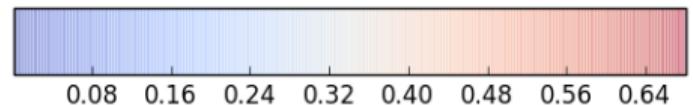
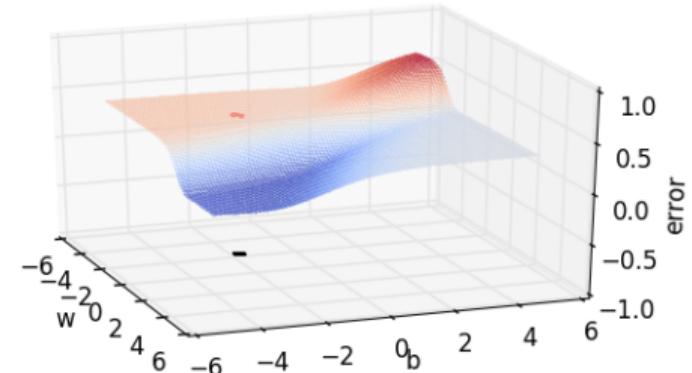
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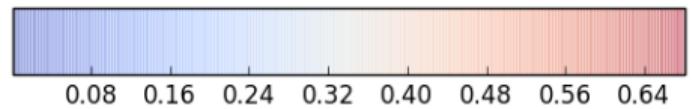
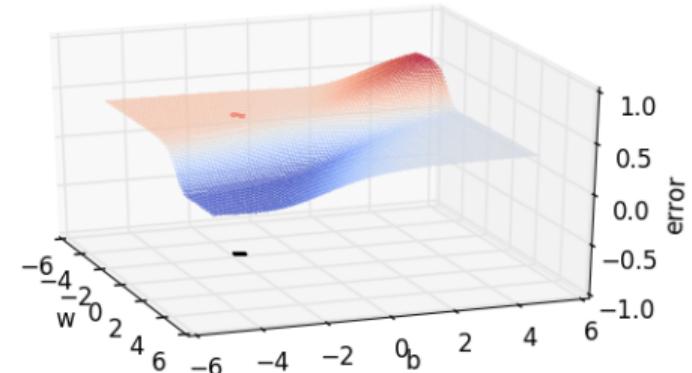
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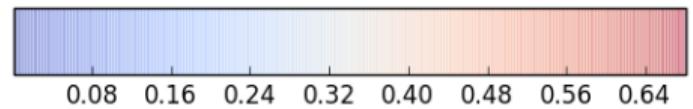
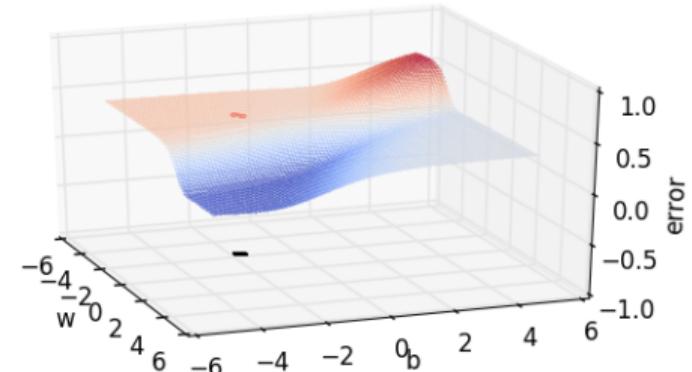
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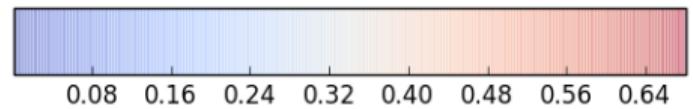
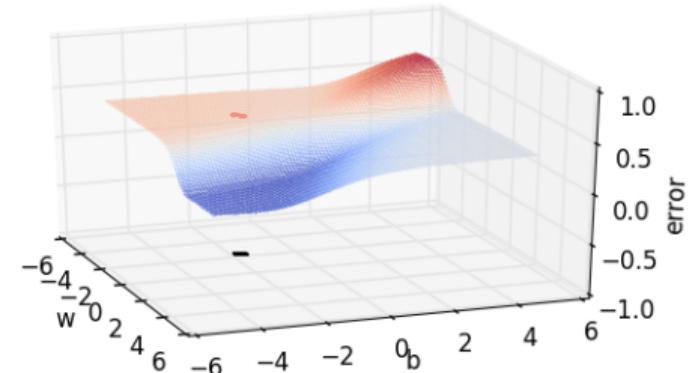
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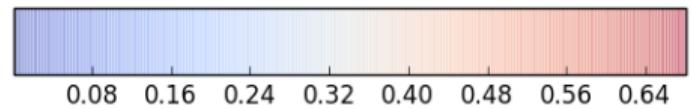
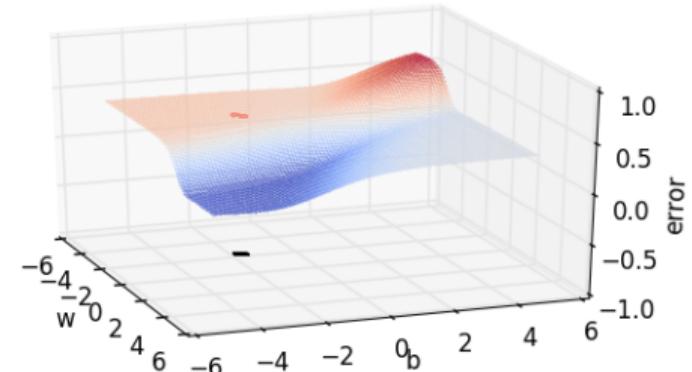
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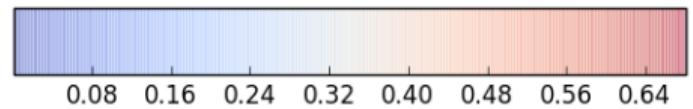
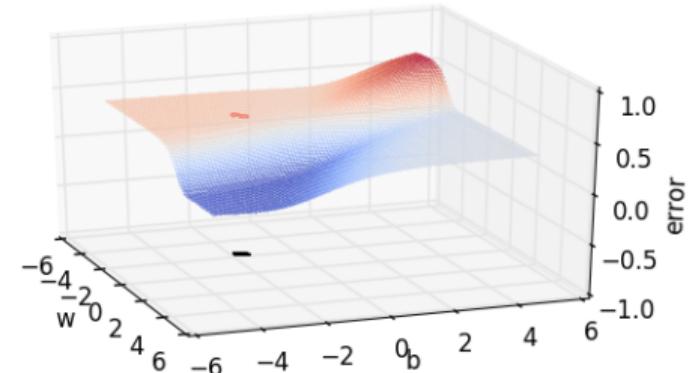
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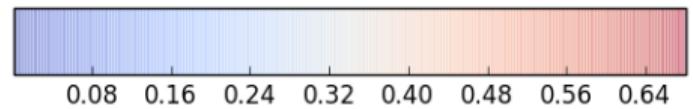
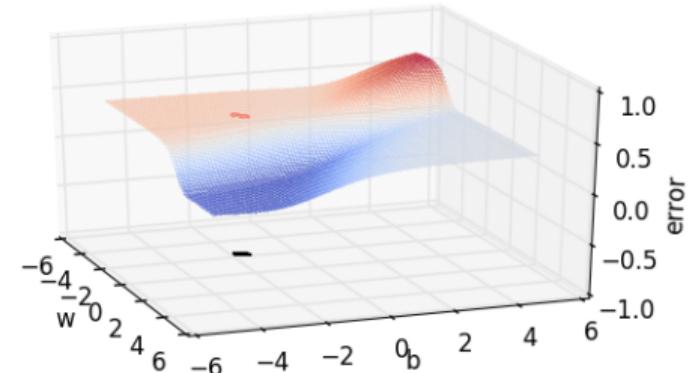
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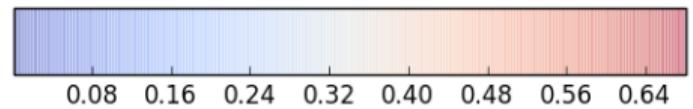
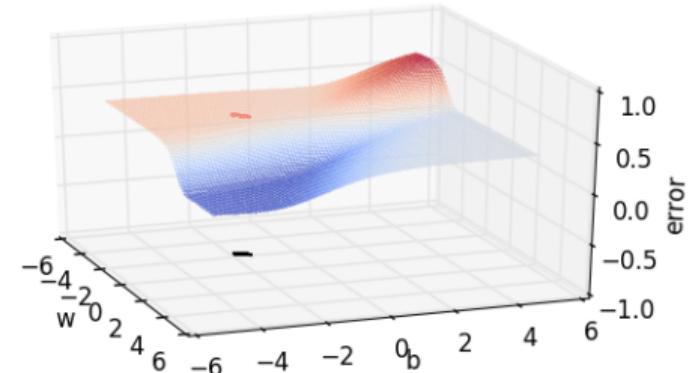
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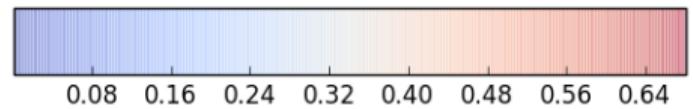
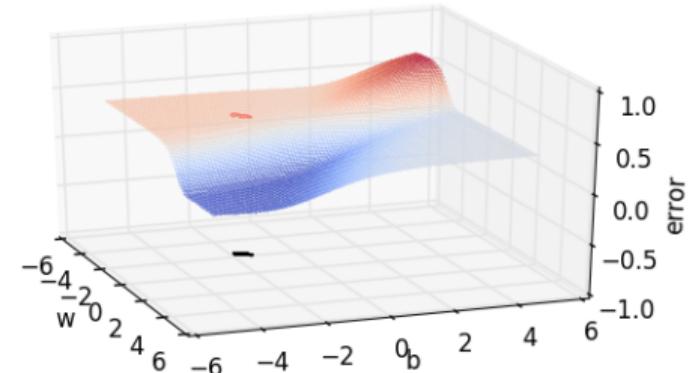
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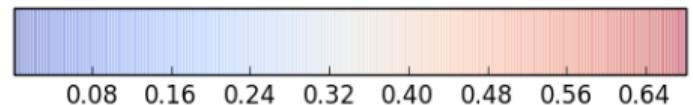
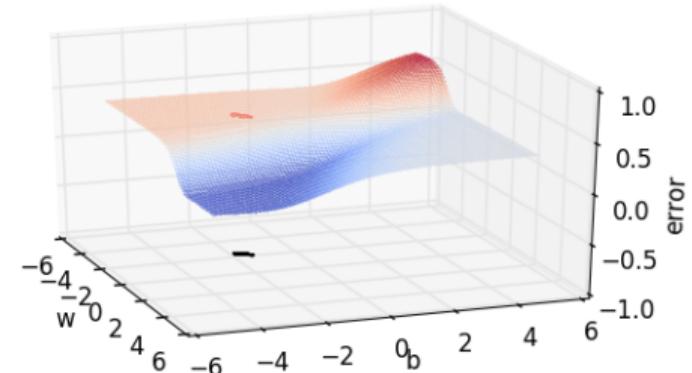
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## Gradient descent on the error surface



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[X = [0.5, 2.5]
Y = [0.2, 0.9]

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def error (w, b) :
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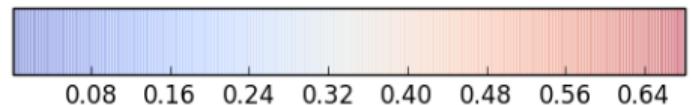
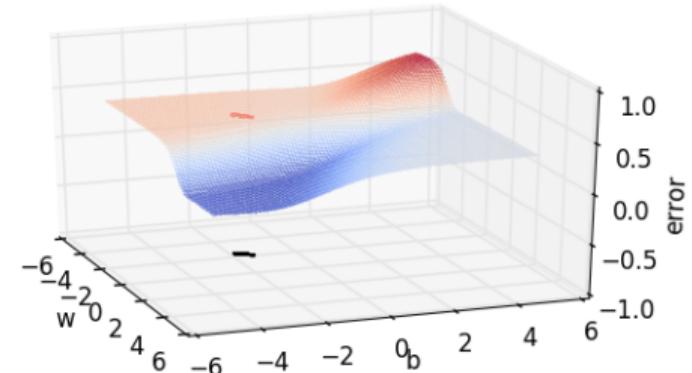
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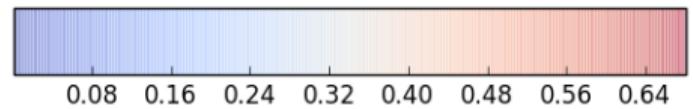
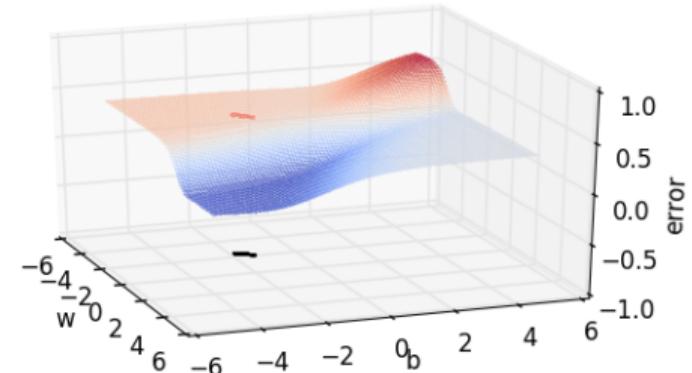
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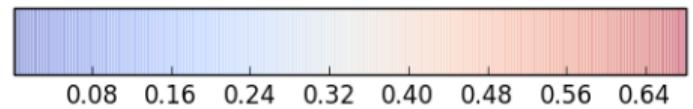
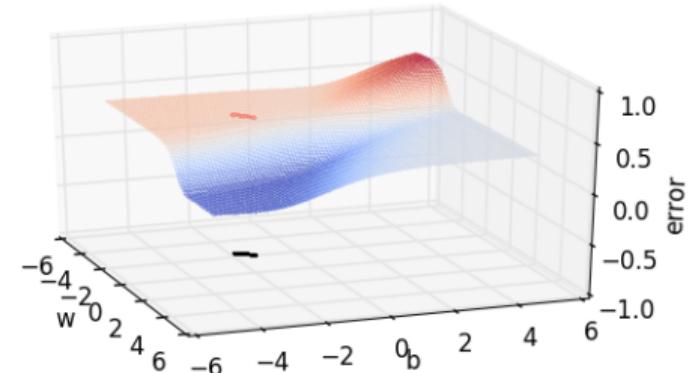
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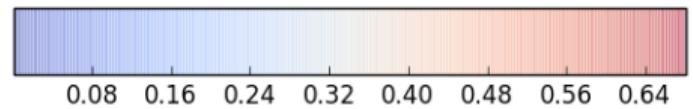
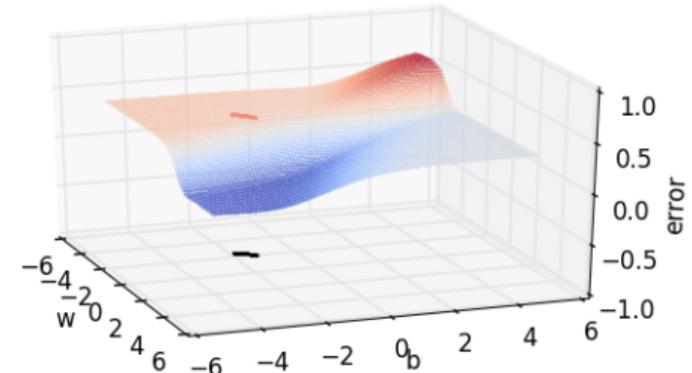
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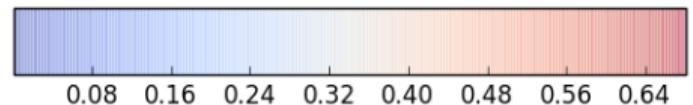
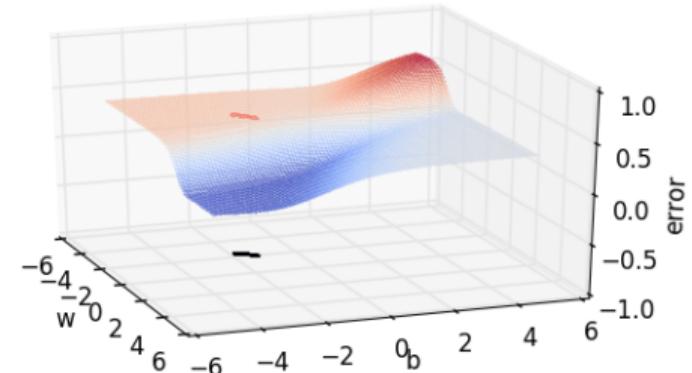
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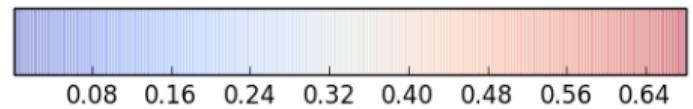
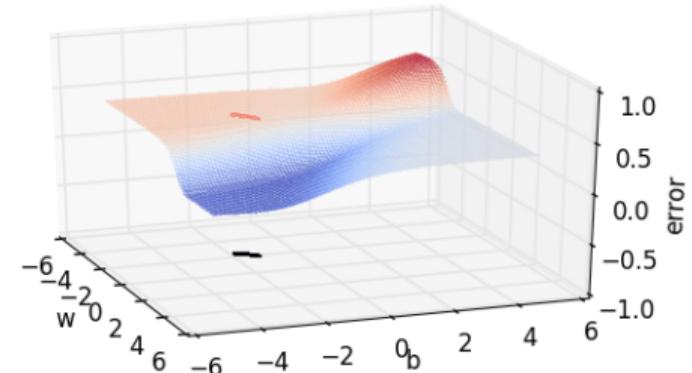
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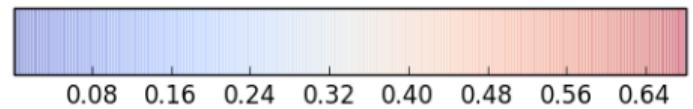
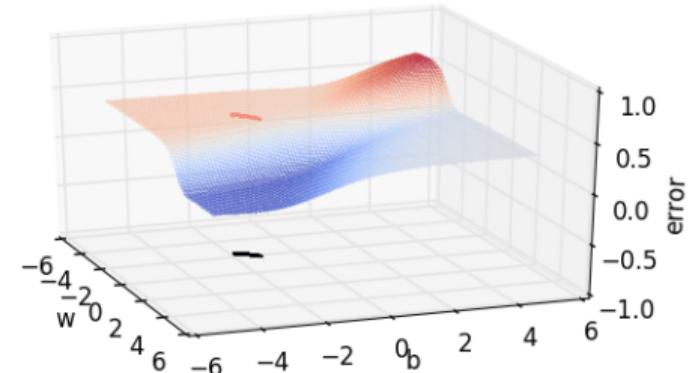
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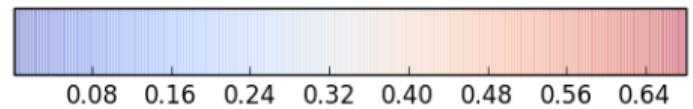
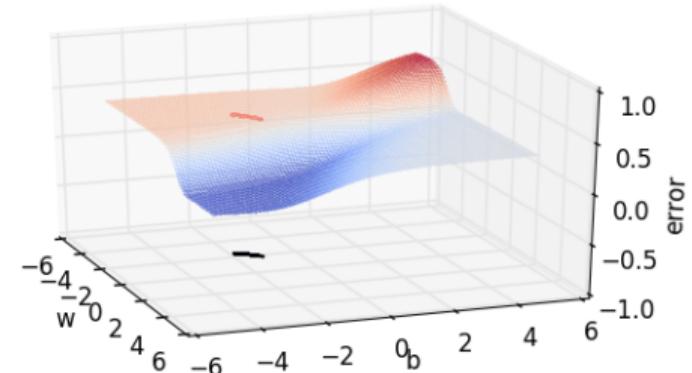
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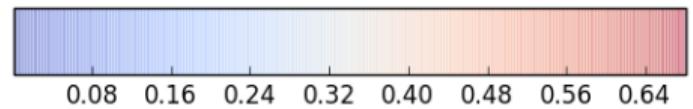
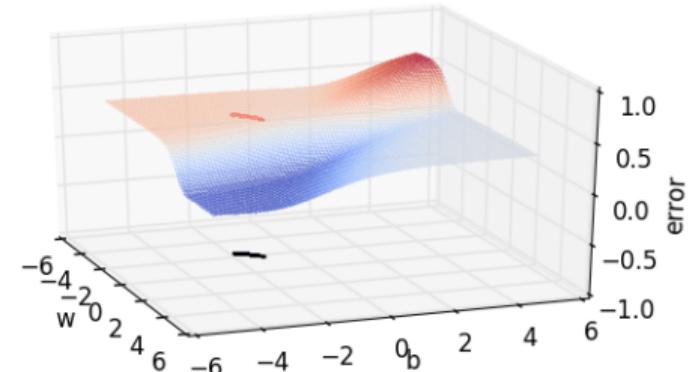
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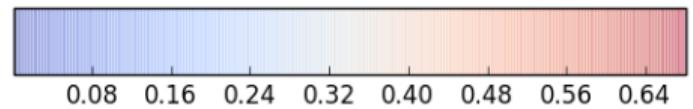
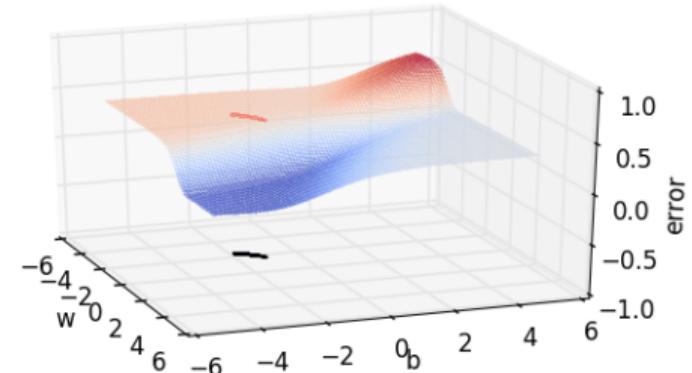
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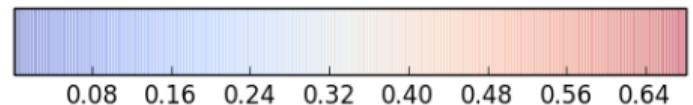
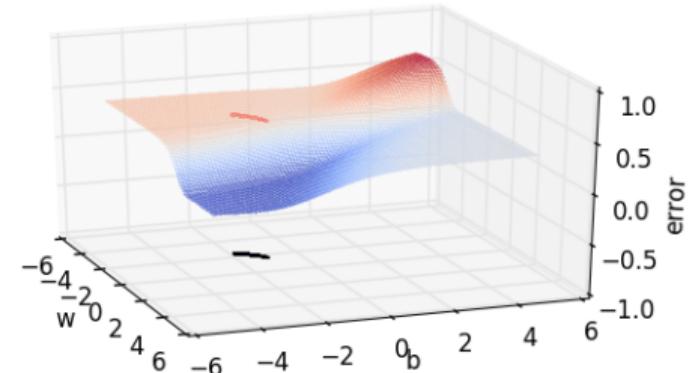
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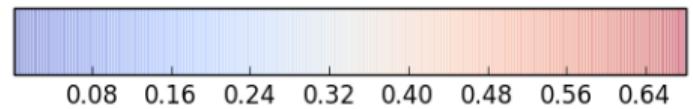
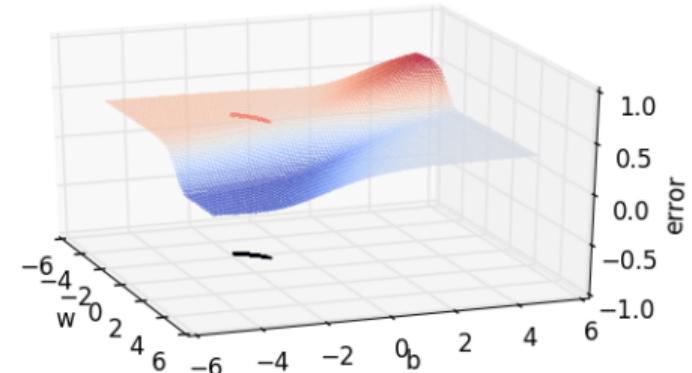
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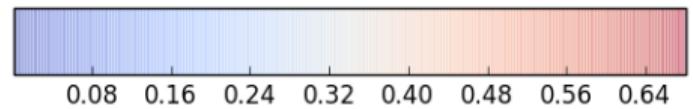
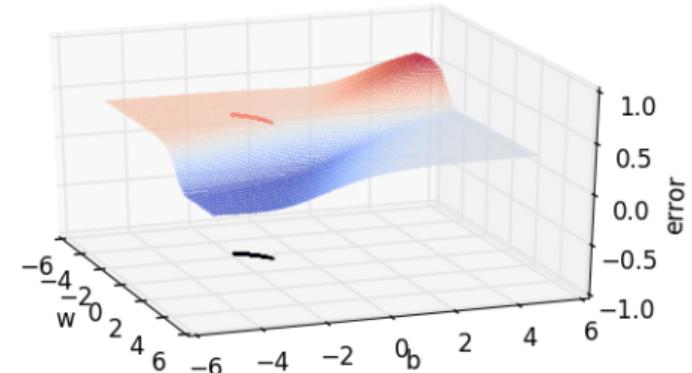
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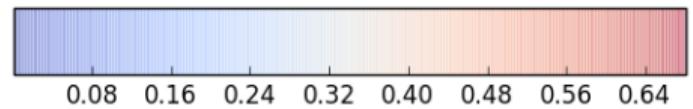
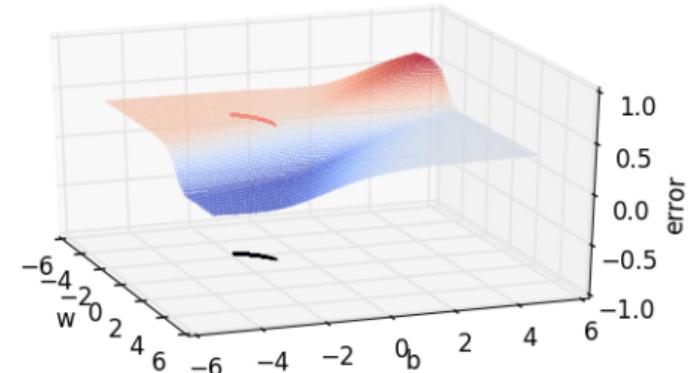
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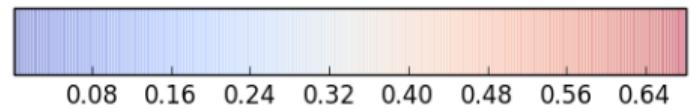
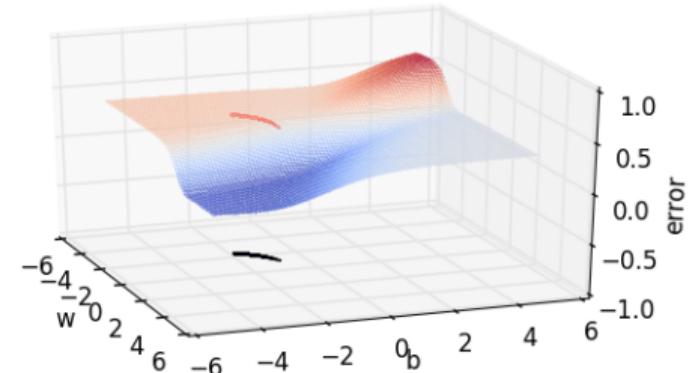
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## Gradient descent on the error surface



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Y = [0.2, 0.9]

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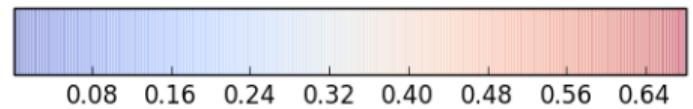
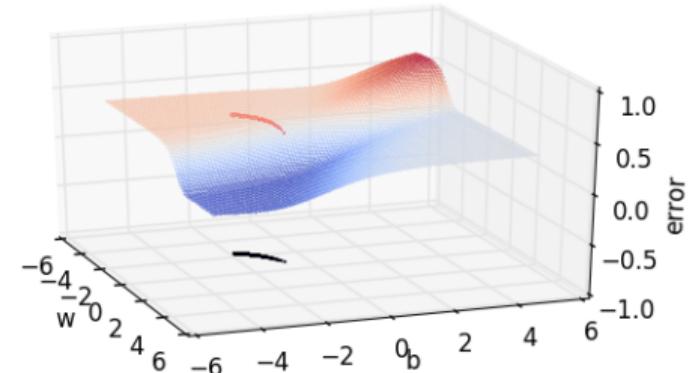
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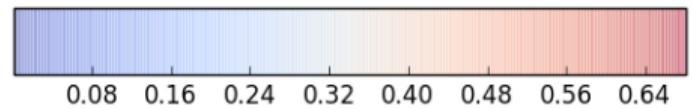
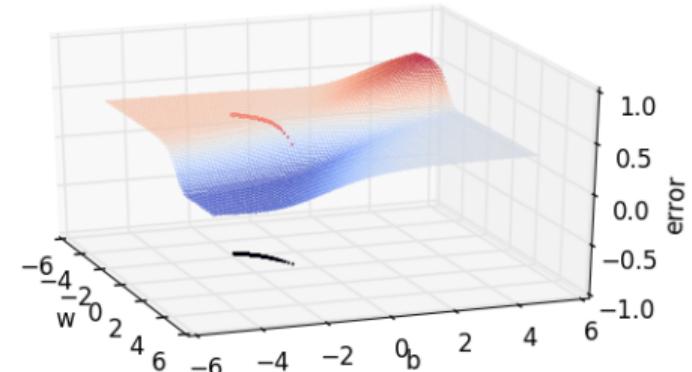
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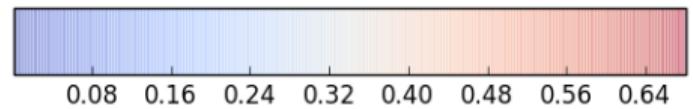
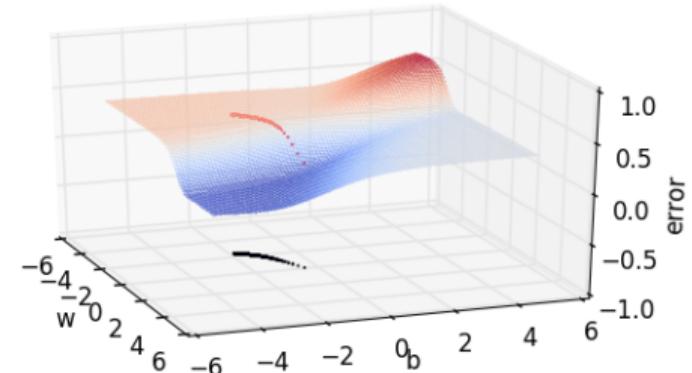
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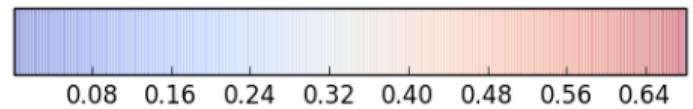
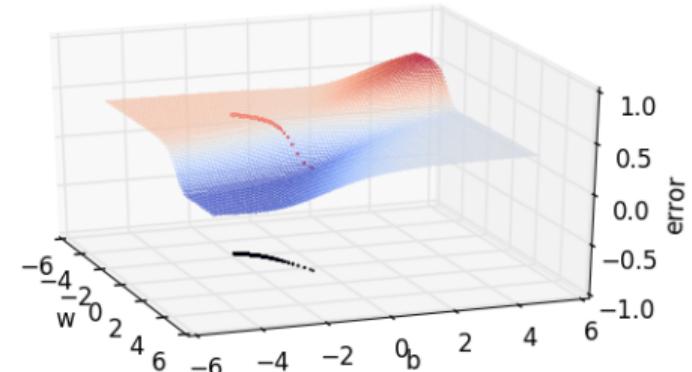
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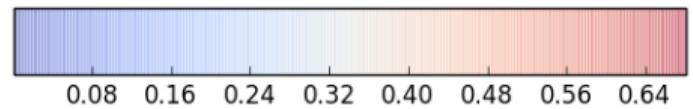
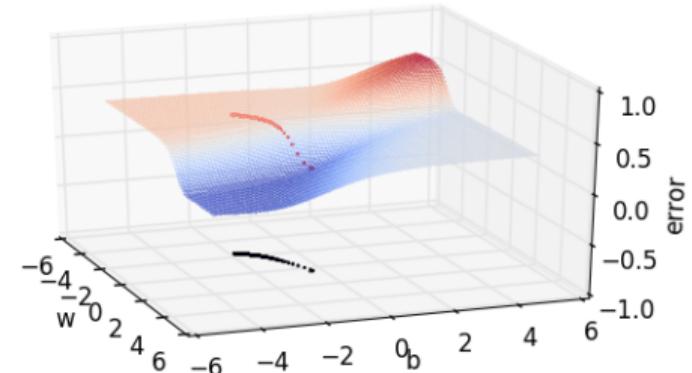
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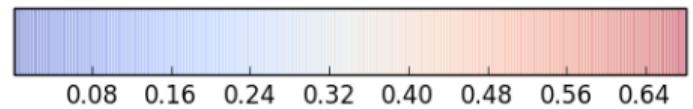
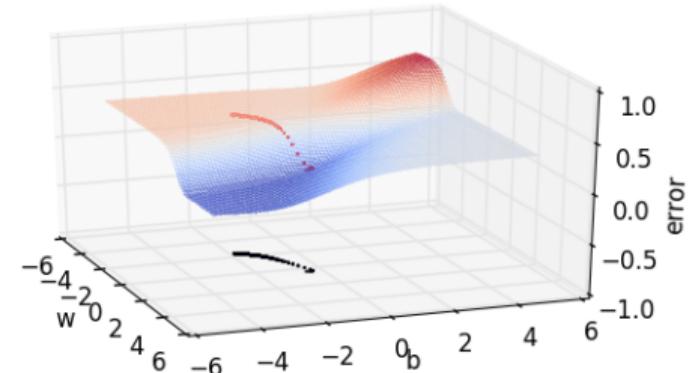
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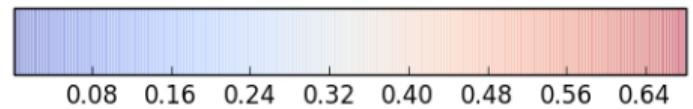
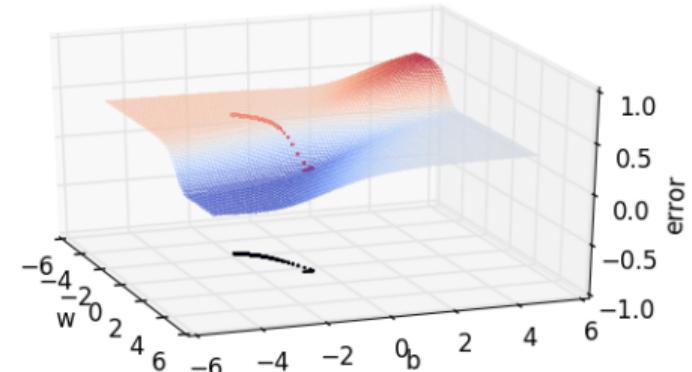
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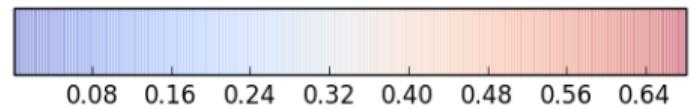
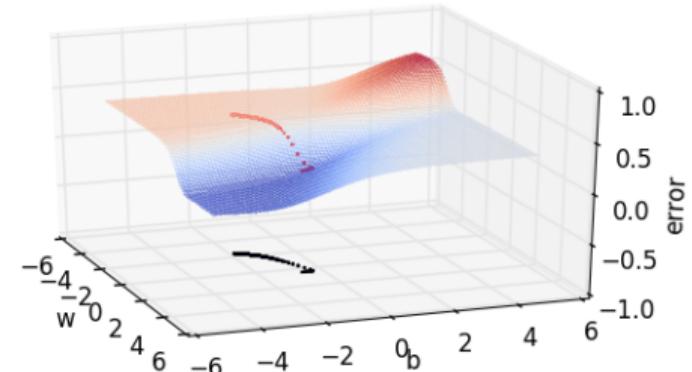
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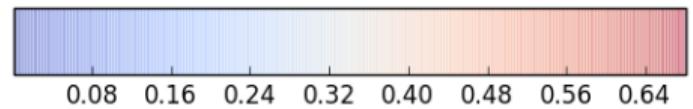
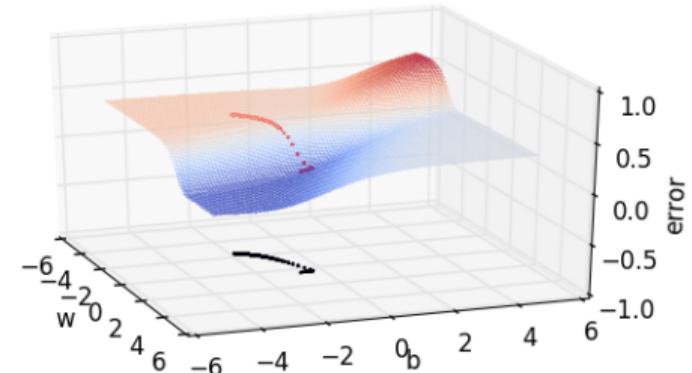
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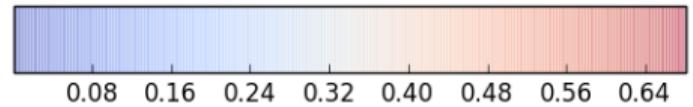
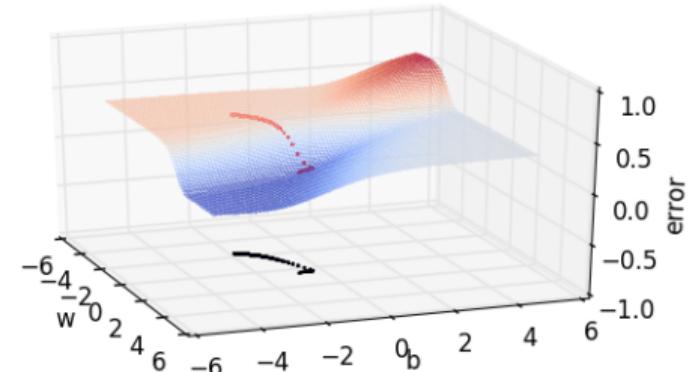
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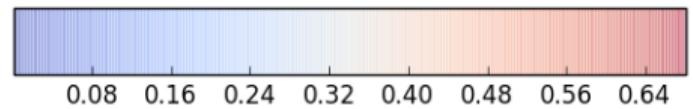
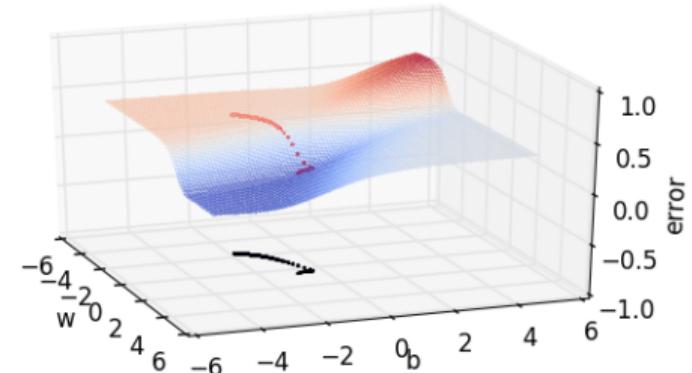
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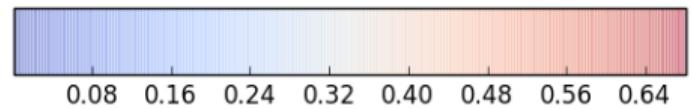
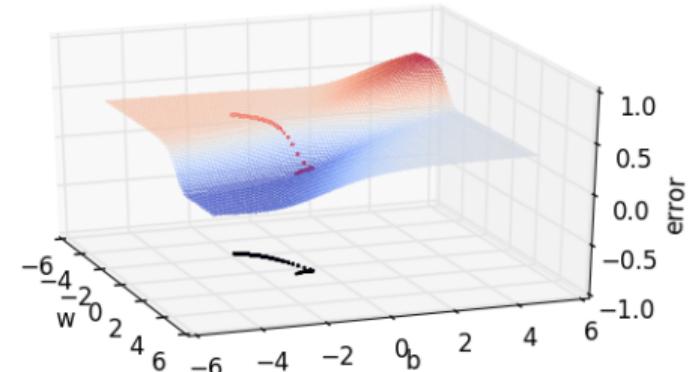
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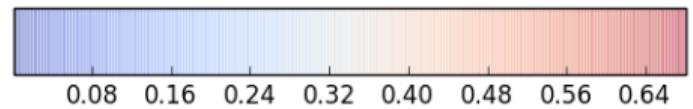
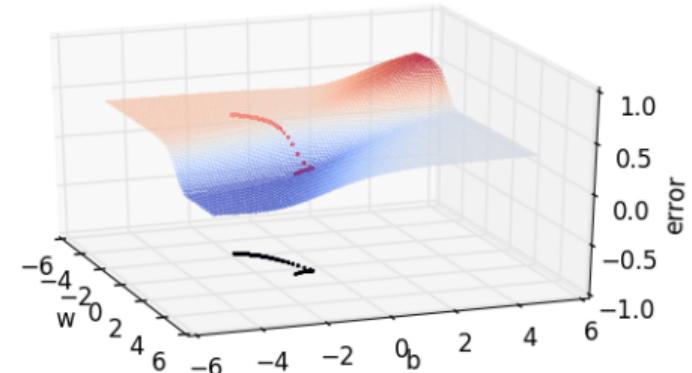
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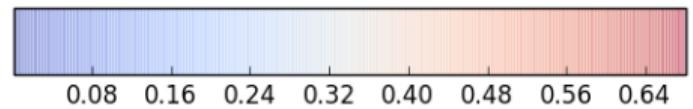
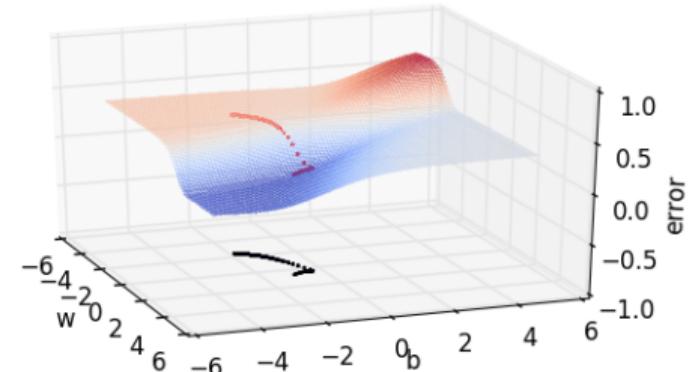
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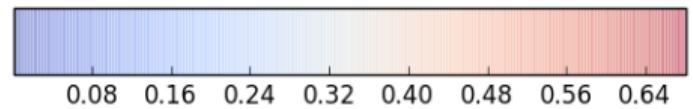
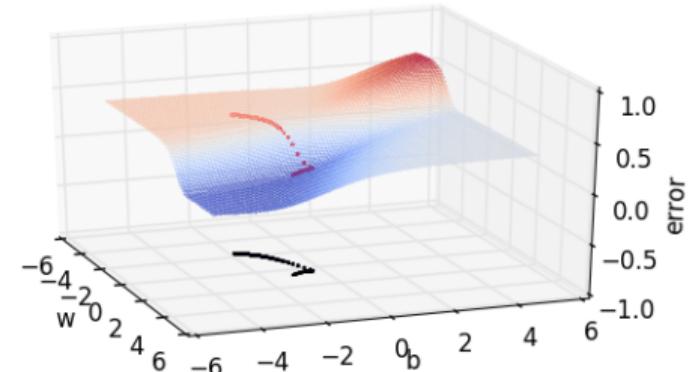
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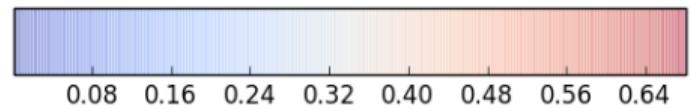
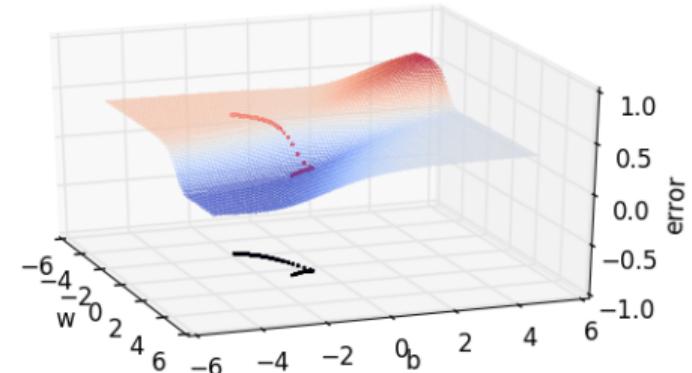
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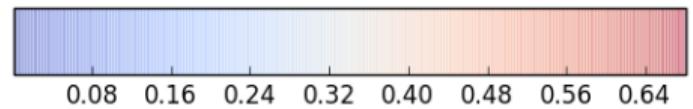
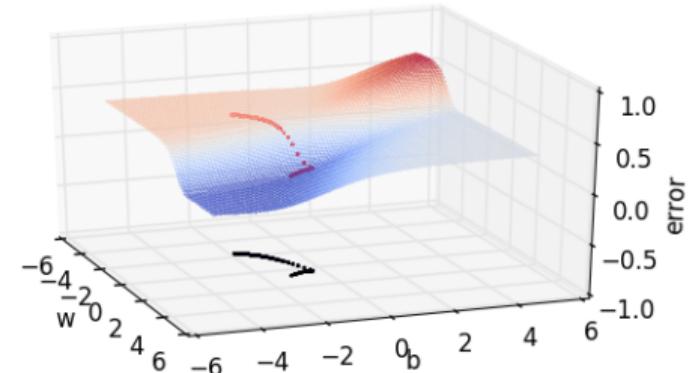
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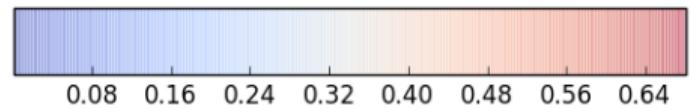
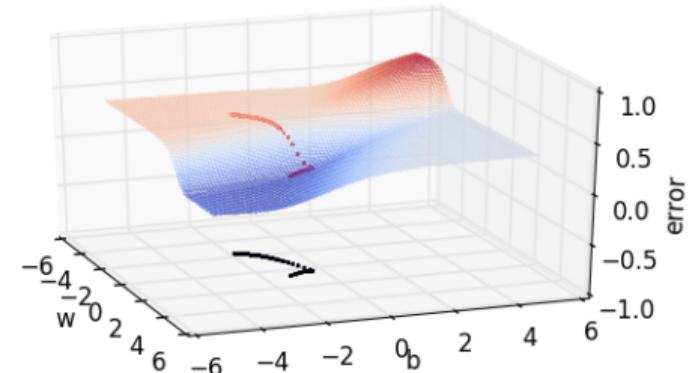
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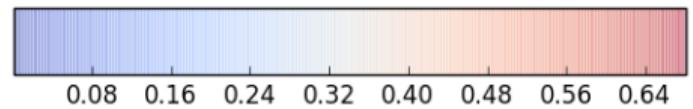
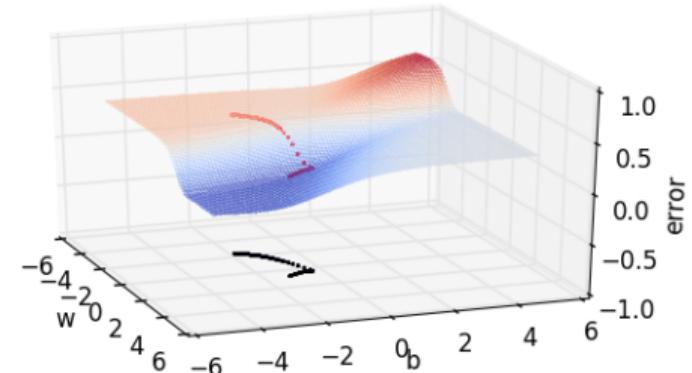
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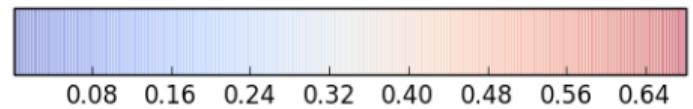
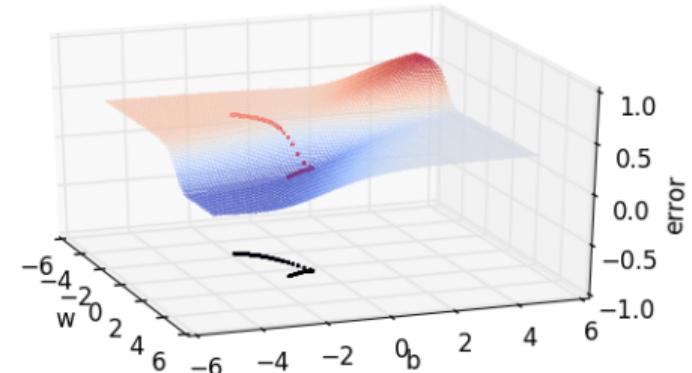
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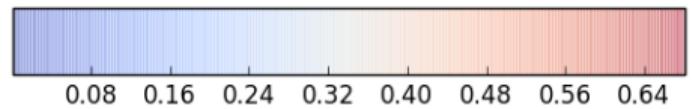
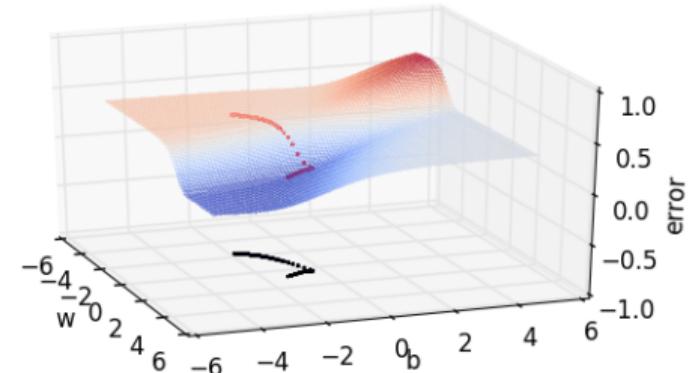
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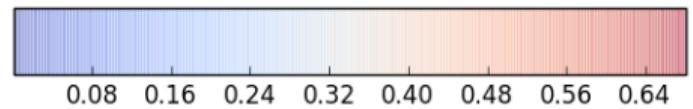
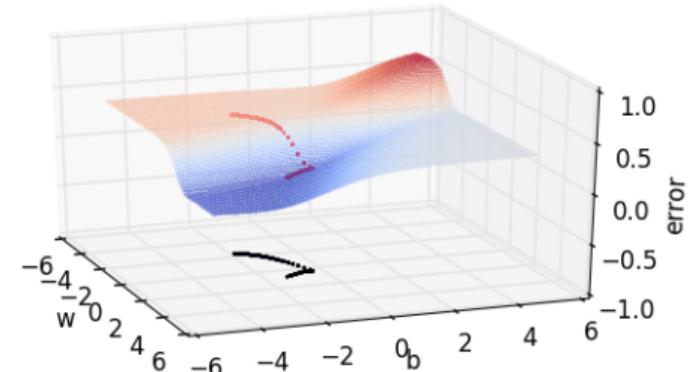
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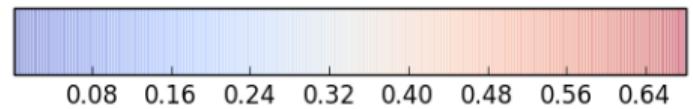
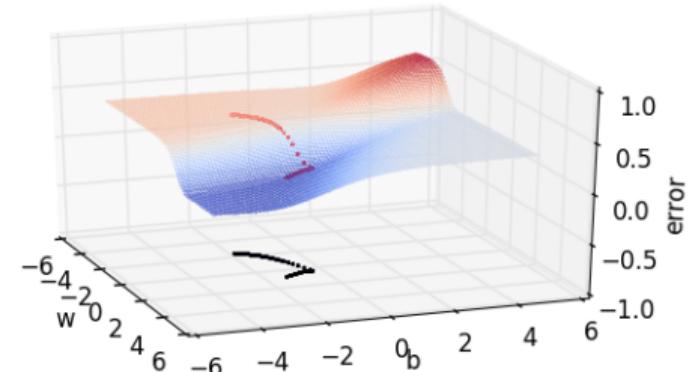
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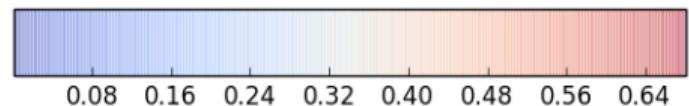
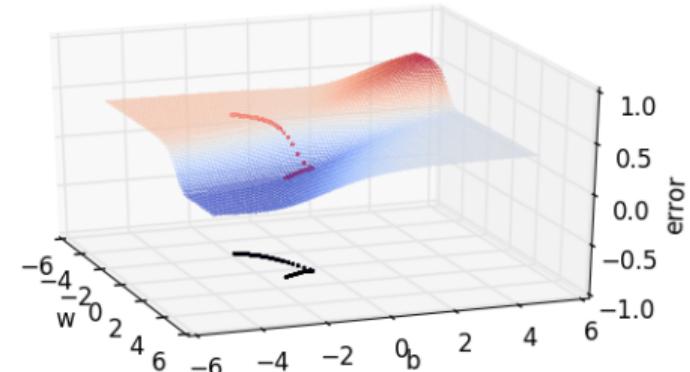
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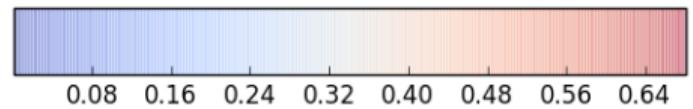
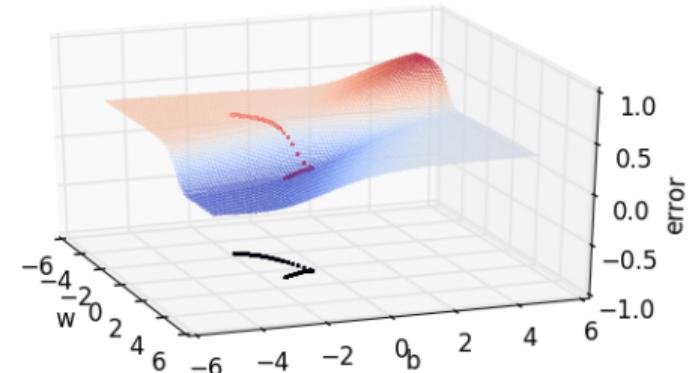
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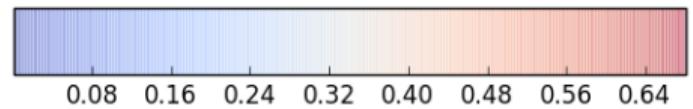
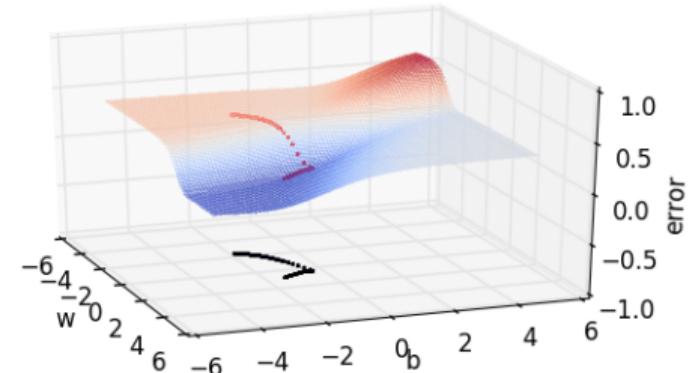
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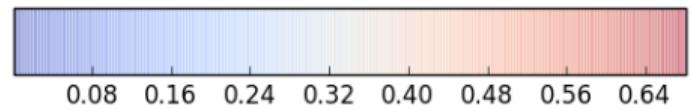
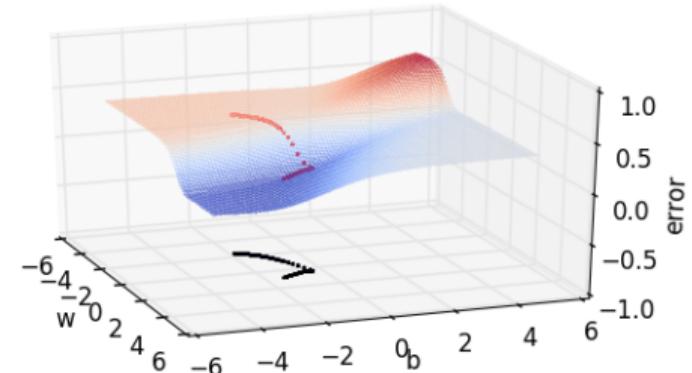
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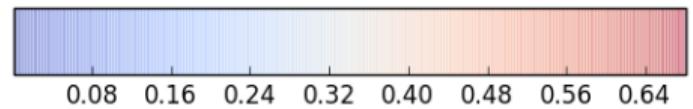
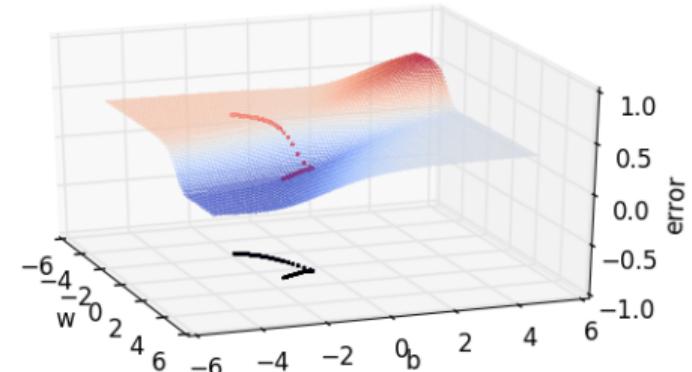
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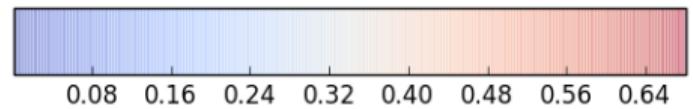
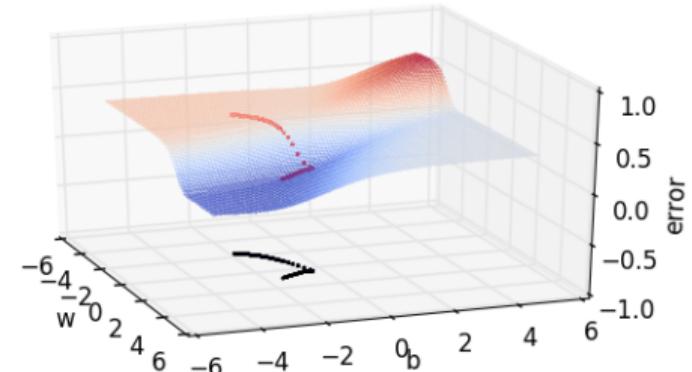
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## Gradient descent on the error surface



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Y = [0.2, 0.9]

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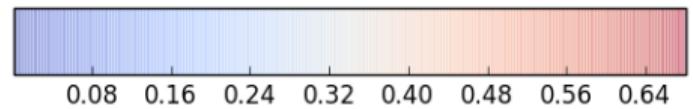
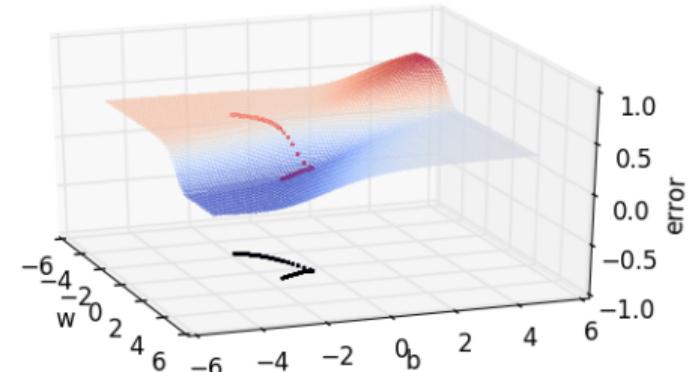
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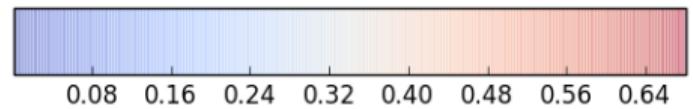
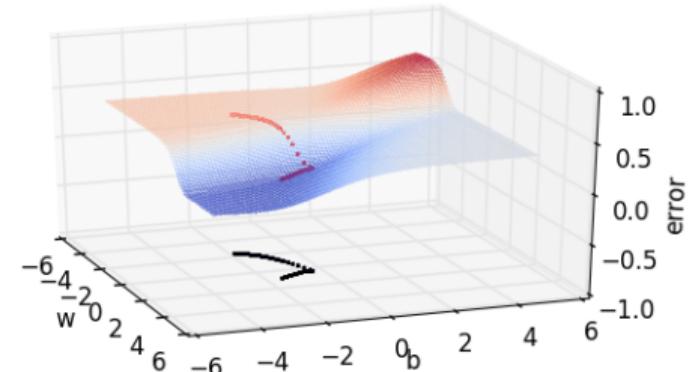
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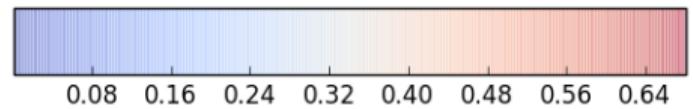
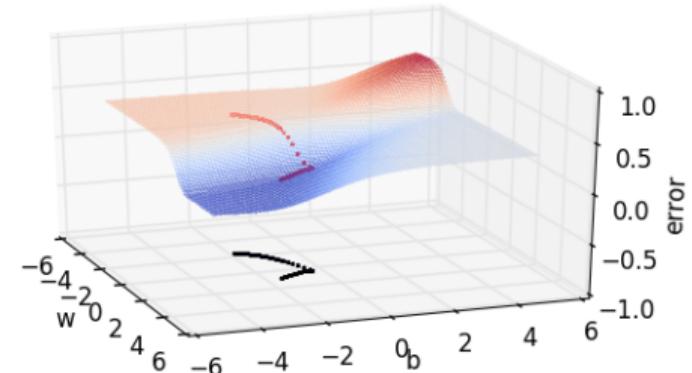
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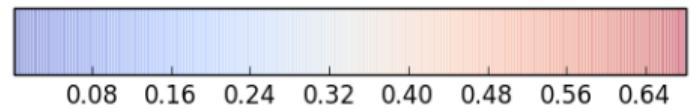
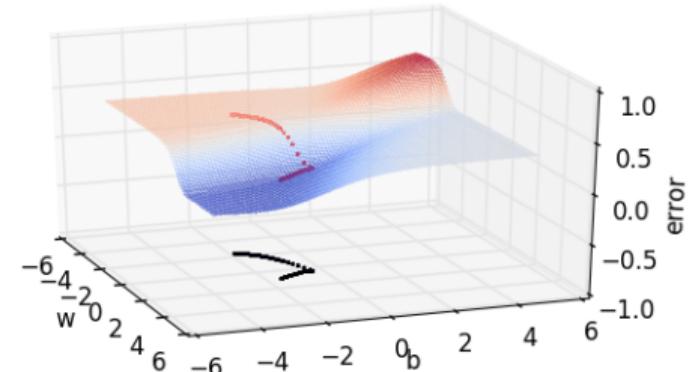
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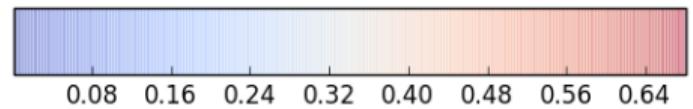
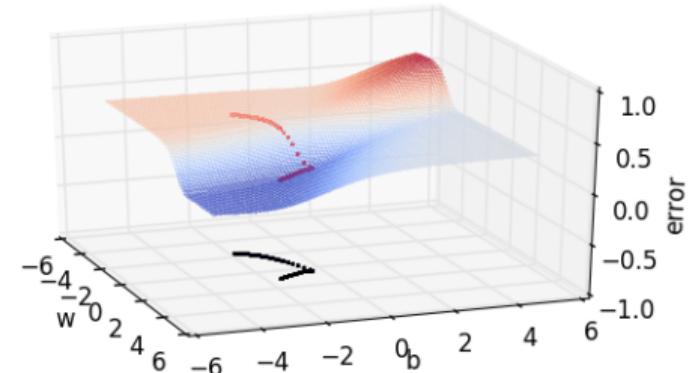
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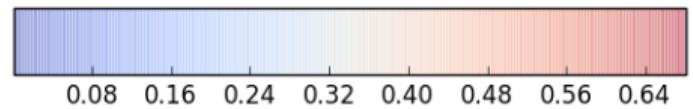
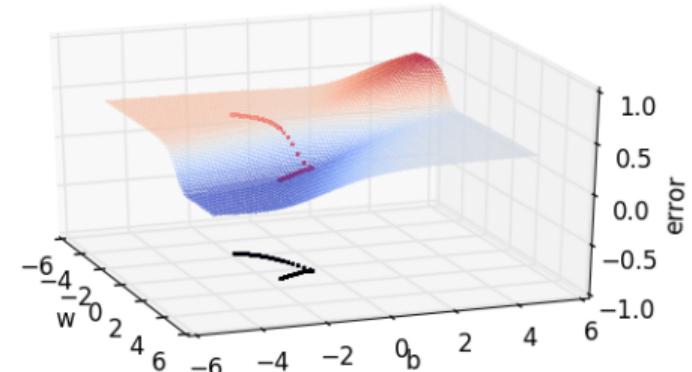
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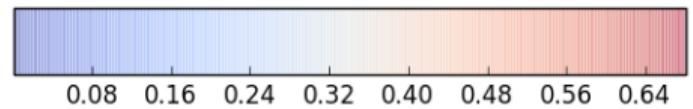
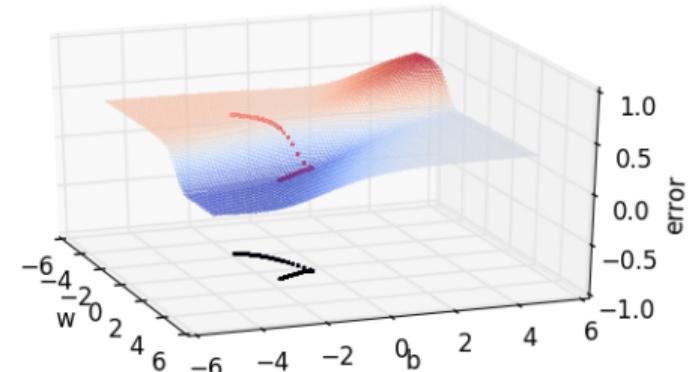
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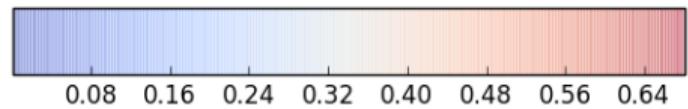
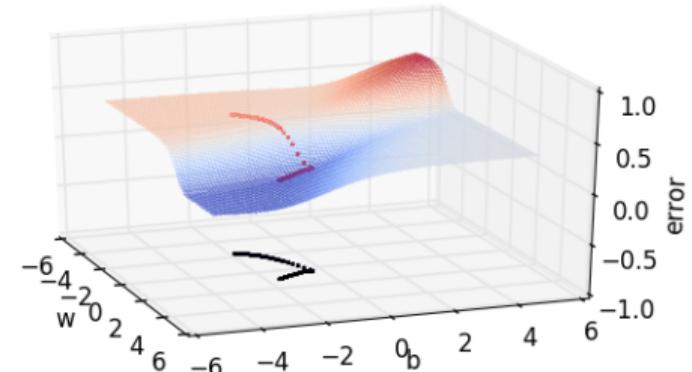
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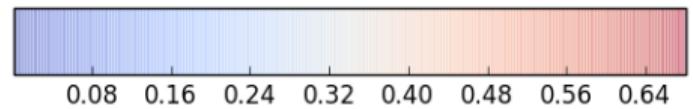
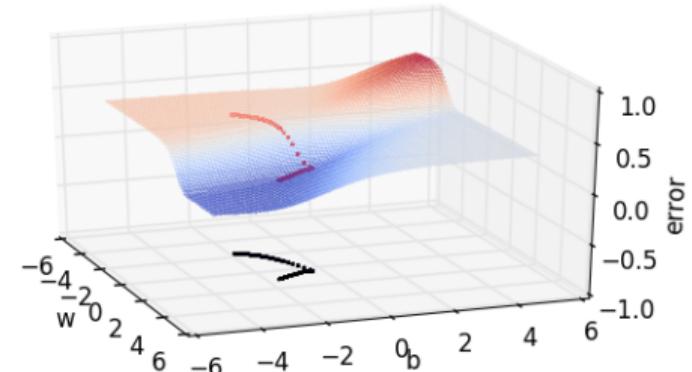
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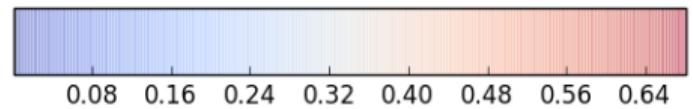
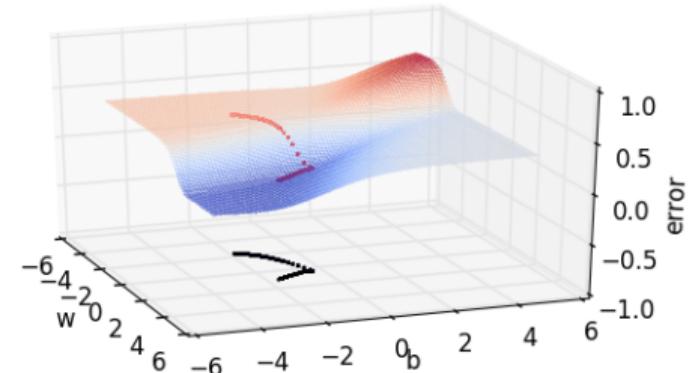
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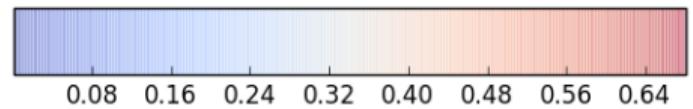
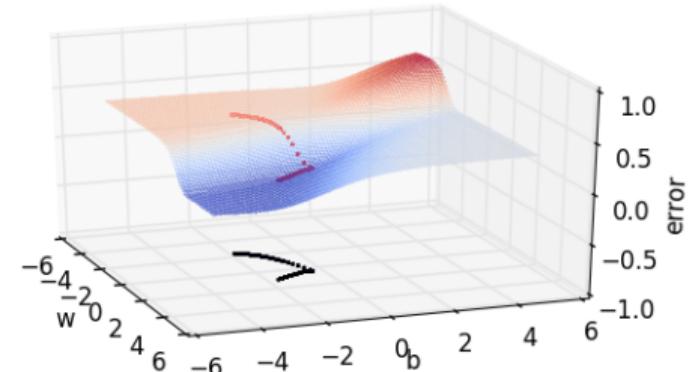
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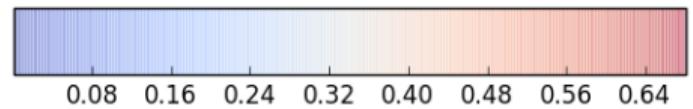
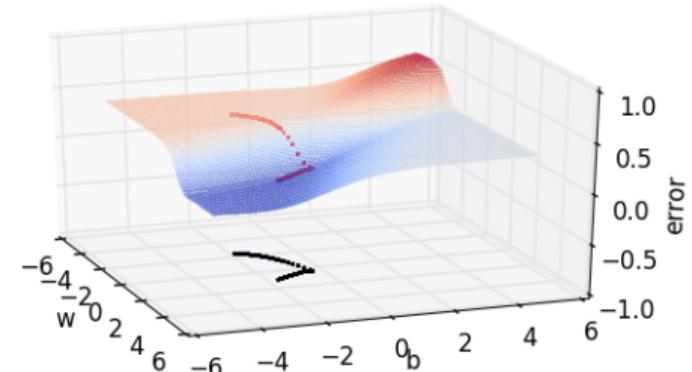
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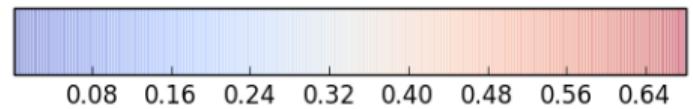
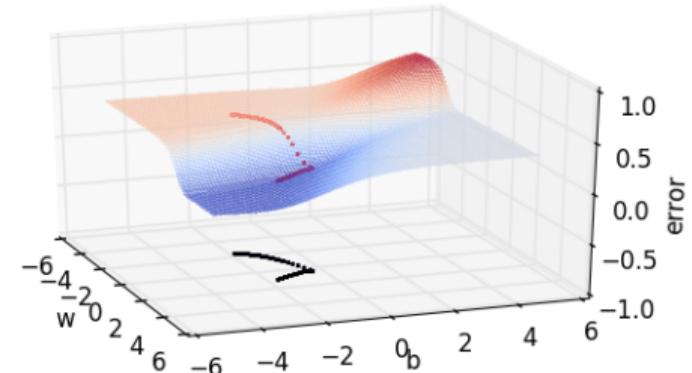
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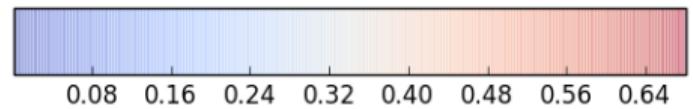
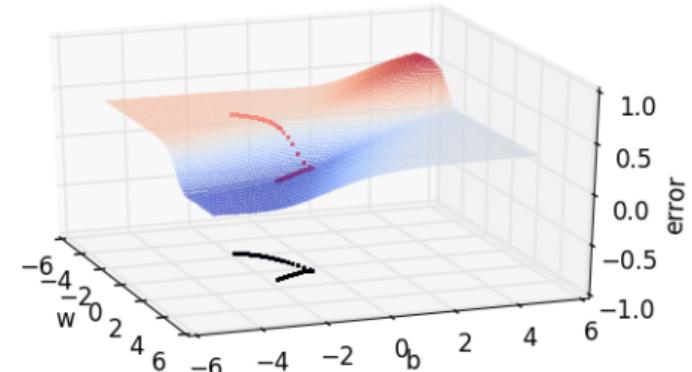
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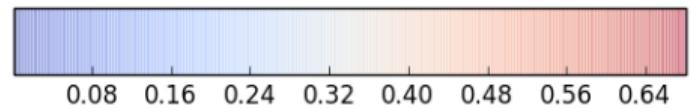
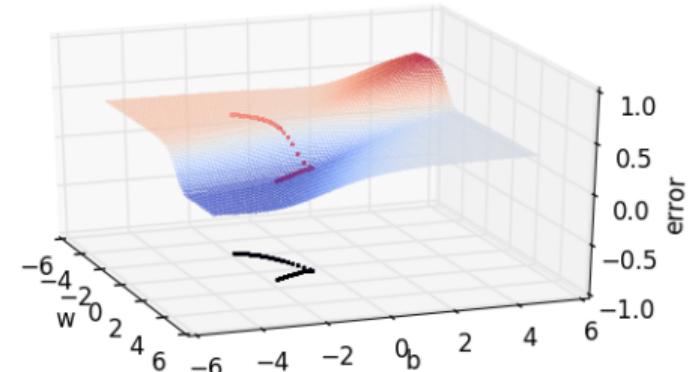
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## Gradient descent on the error surface



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Y = [0.2, 0.9]

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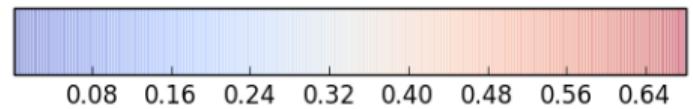
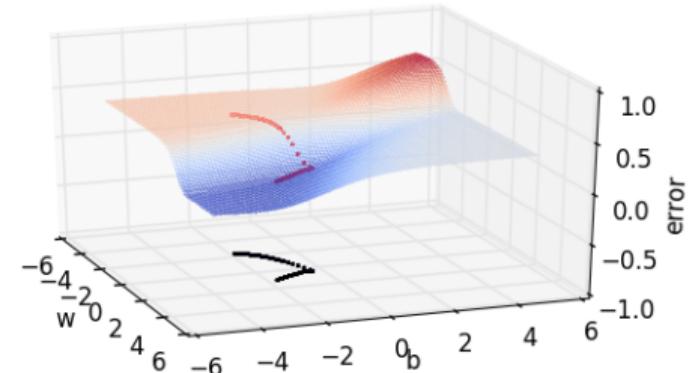
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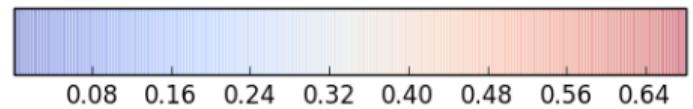
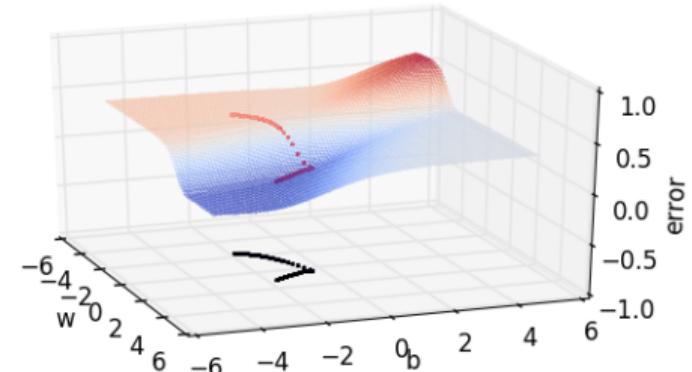
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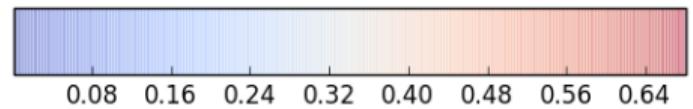
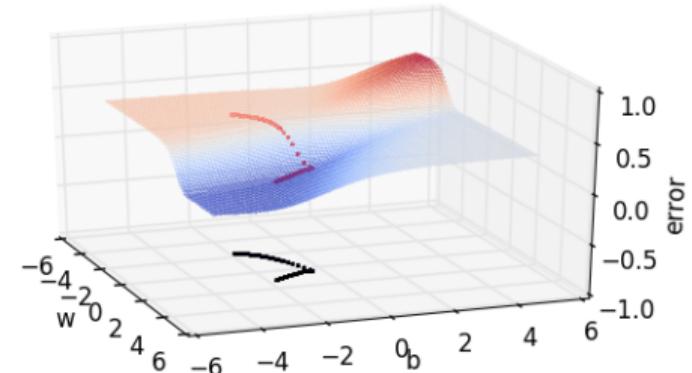
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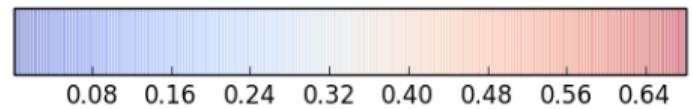
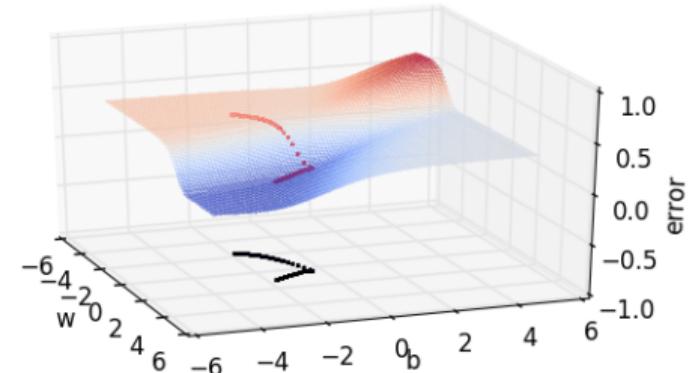
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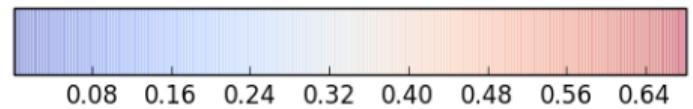
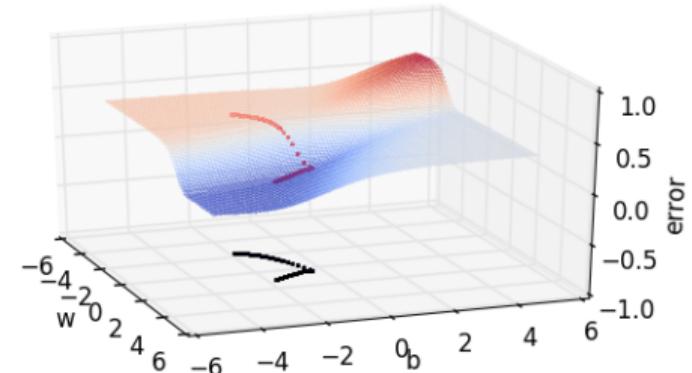
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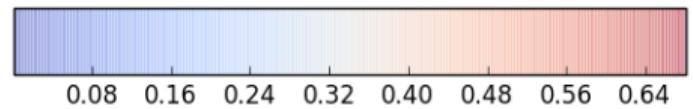
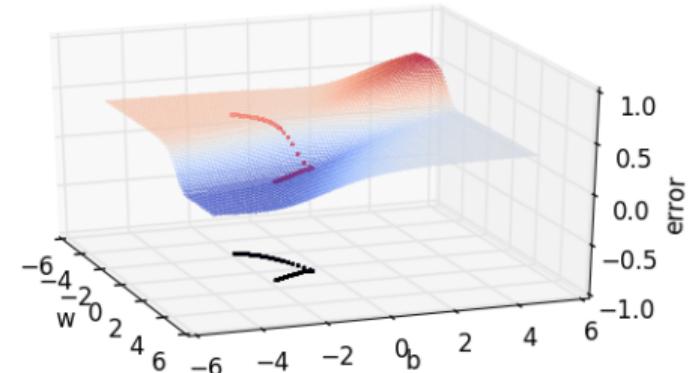
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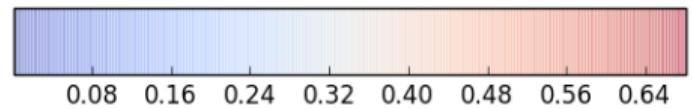
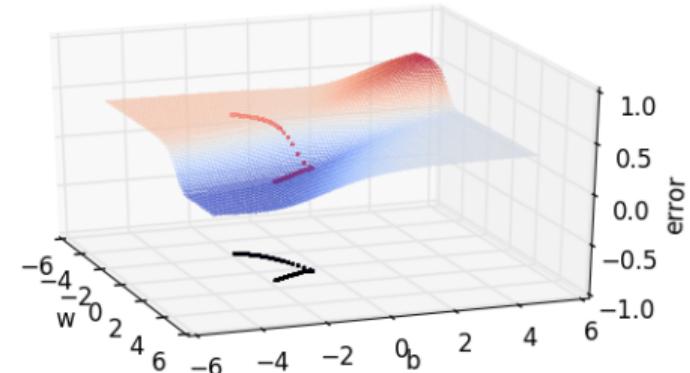
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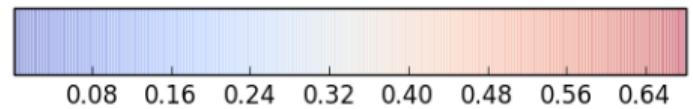
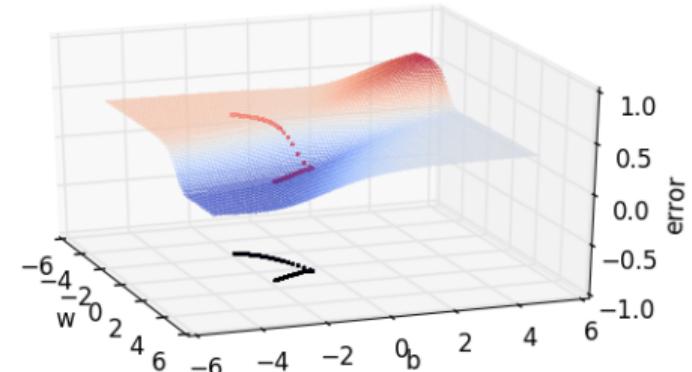
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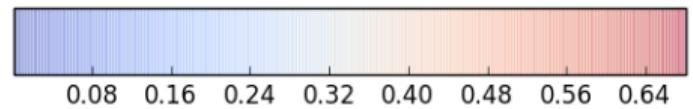
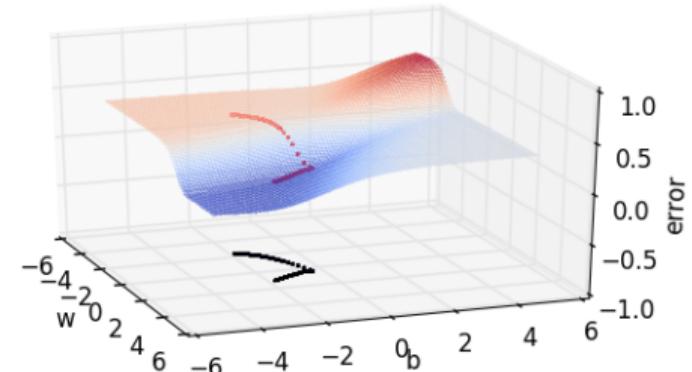
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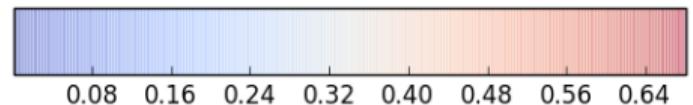
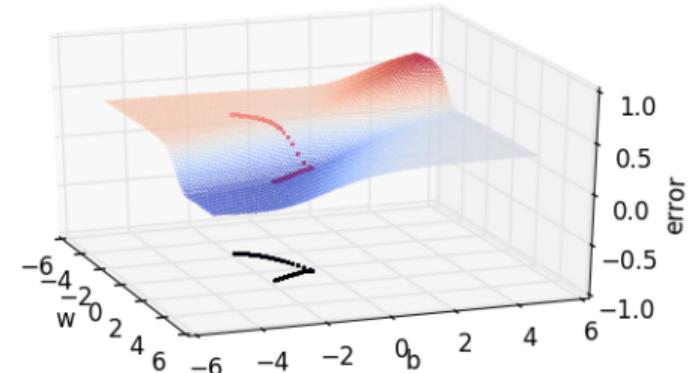
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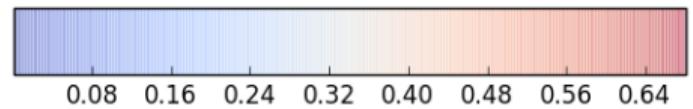
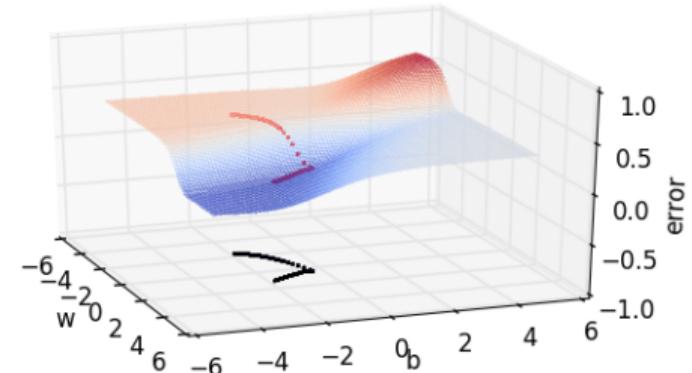
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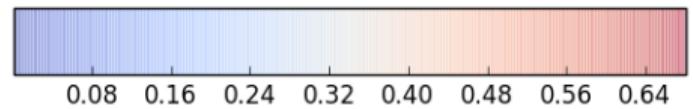
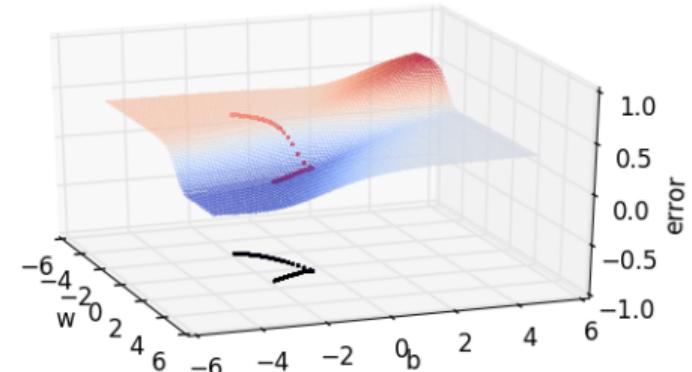
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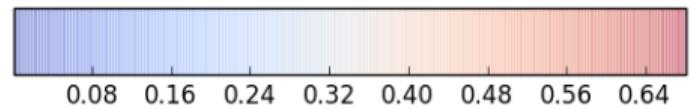
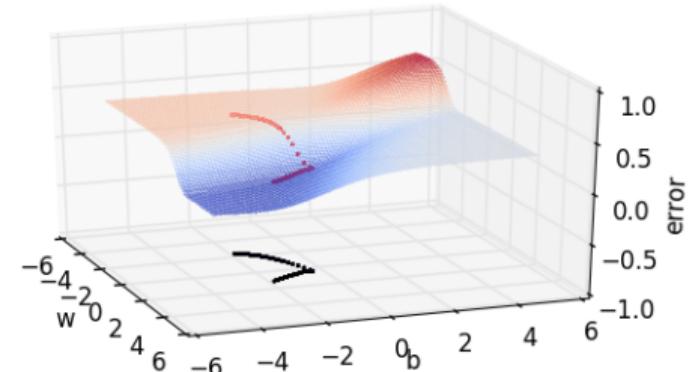
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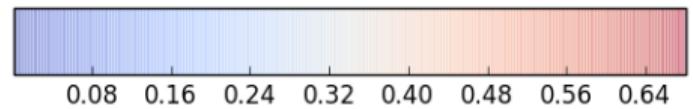
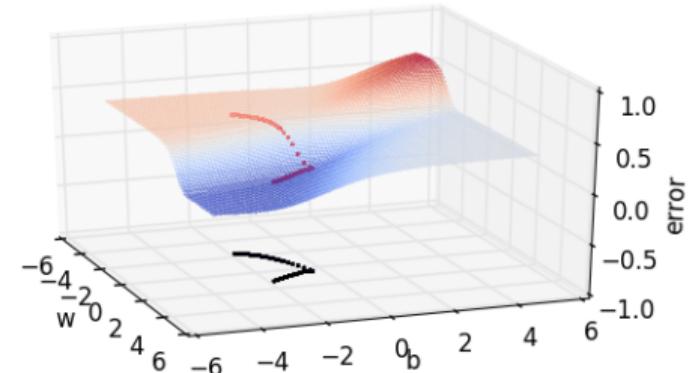
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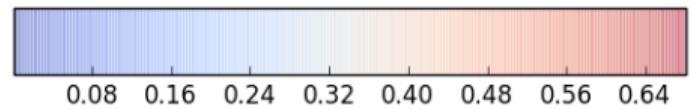
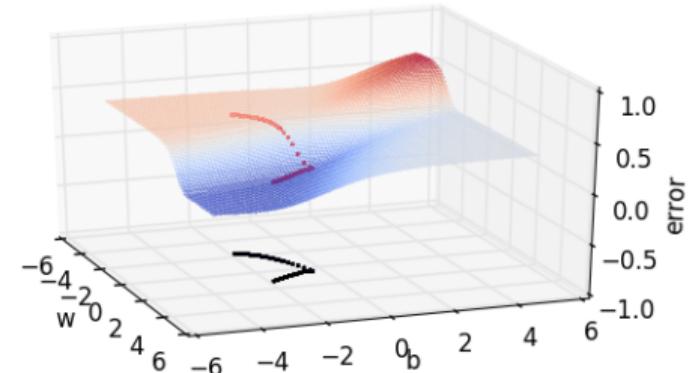
def grad_b(w,b,x,y) :
    fx = f(w,b,x)
    return (fx - y) * fx * (1 - fx)

def grad_w(w,b,x,y) :
    fx = f(w,b,x)
    return (fx - y) * fx * (1 - fx) * x

def do_gradient_descent() :
    w, b, eta, max_epochs = -2, -2, 1.0, 1000
    for i in range(max_epochs) :
        dw, db = 0, 0
        for x,y in zip(X, Y) :
            dw += grad_w(w, b, x, y)
            db += grad_b(w, b, x, y)
        w = w - eta * dw
        b = b - eta * db

```

## Gradient descent on the error surface



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- So where do we head from here ?