

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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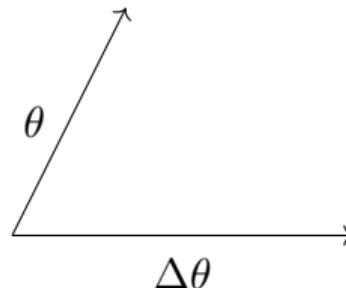
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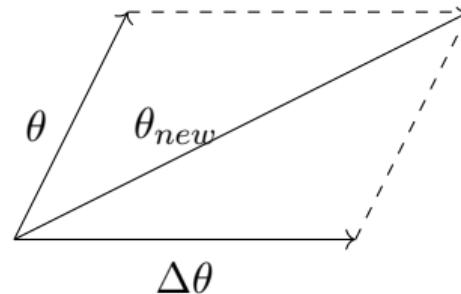


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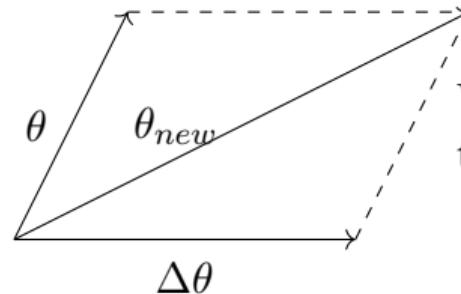


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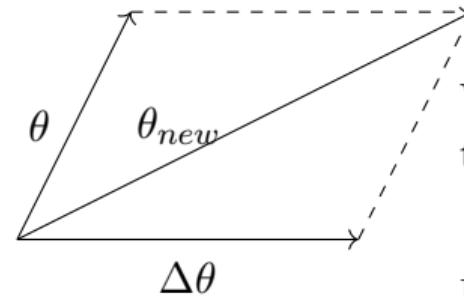


We moved in the direction of $\Delta\theta$

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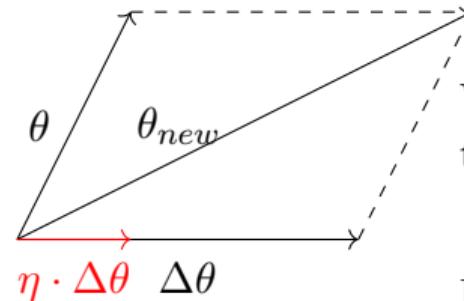
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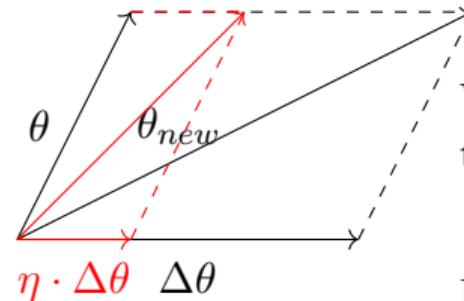
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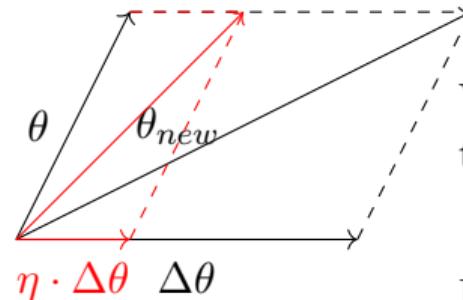
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$$\theta_{new} = \theta + \eta \cdot \Delta\theta$$



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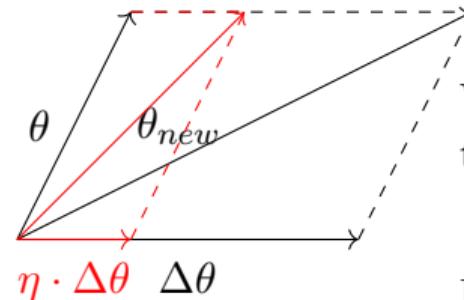
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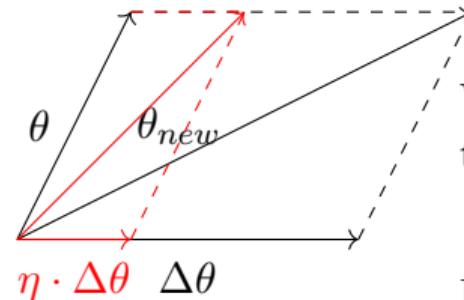
Question: What is the right $\Delta\theta$ to use?
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The answer comes from Taylor series

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

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Note that the move (ηu) 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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$$-1 \leq \cos(\beta) = \frac{u^T \nabla \mathcal{L}(\theta)}{\|u\| * \|\nabla \mathcal{L}(\theta)\|} \leq 1$$

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

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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 β is 180°

Gradient Descent Rule

- The direction u that we intend to move in should be at 180° 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

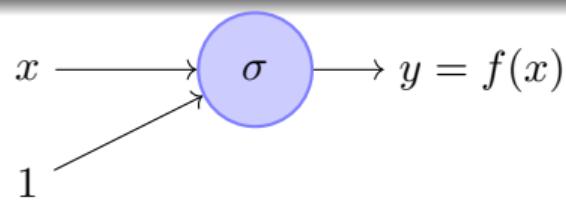
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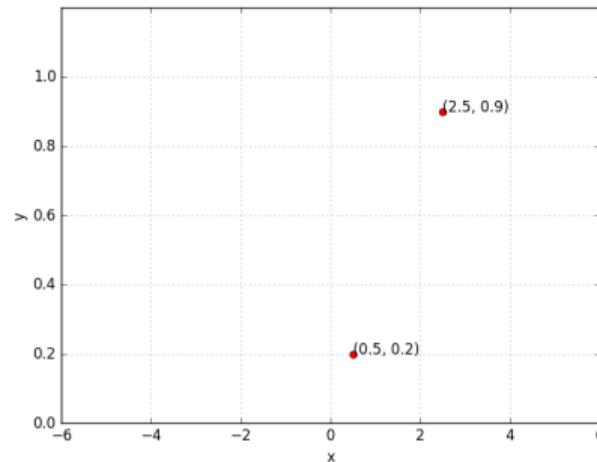
Algorithm: gradient_descent()

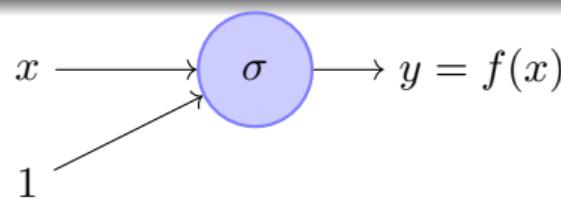
```
t ← 0;  
max_iterations ← 1000;  
while  $t < max\_iterations$  do  
    |  $w_{t+1} \leftarrow w_t - \eta \nabla w_t;$   
    |  $b_{t+1} \leftarrow b_t - \eta \nabla b_t;$   
end
```

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



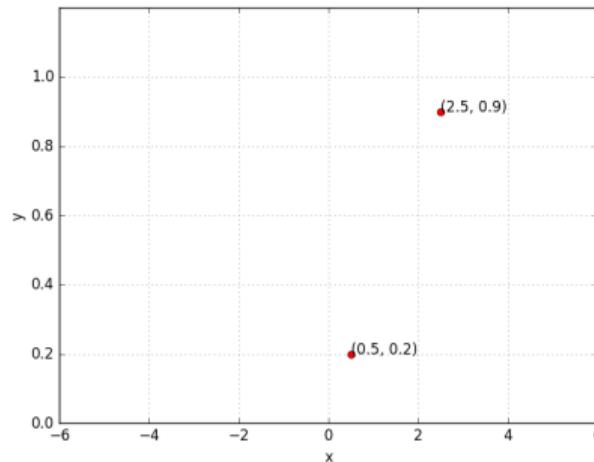
$$f(x) = \frac{1}{1+e^{-(w \cdot x + b)}}$$

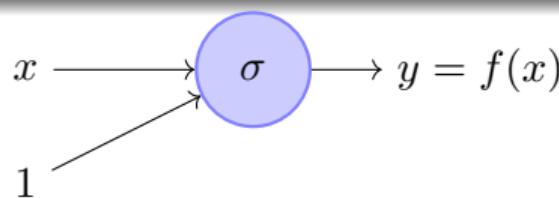




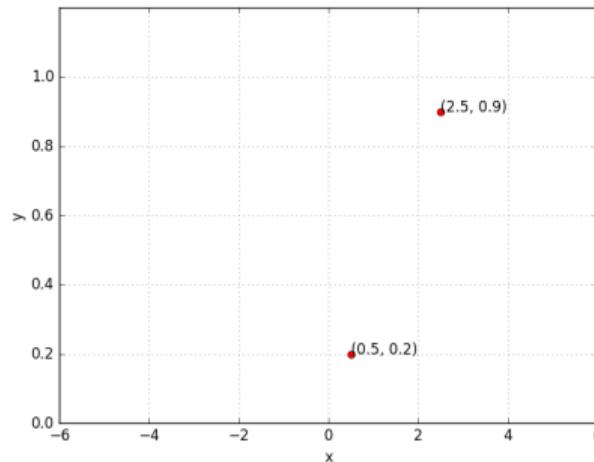
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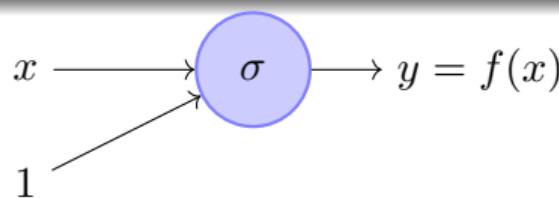


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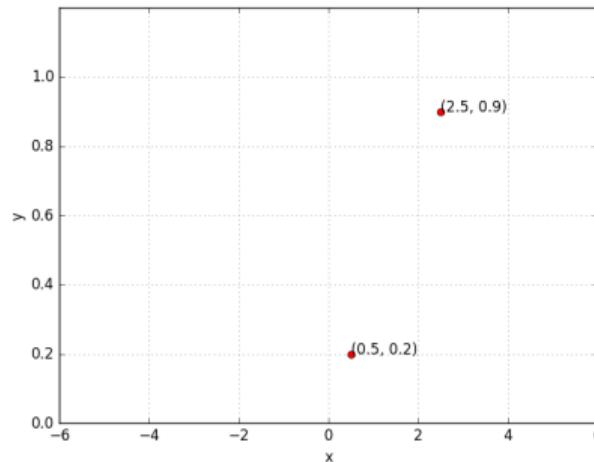


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$$\mathcal{L}(w, b) = \frac{1}{2} * (f(x) - y)^2$$



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

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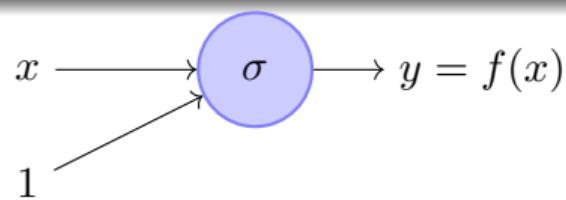
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 &= f(x) * (1 - f(x)) * x
 \end{aligned}$$

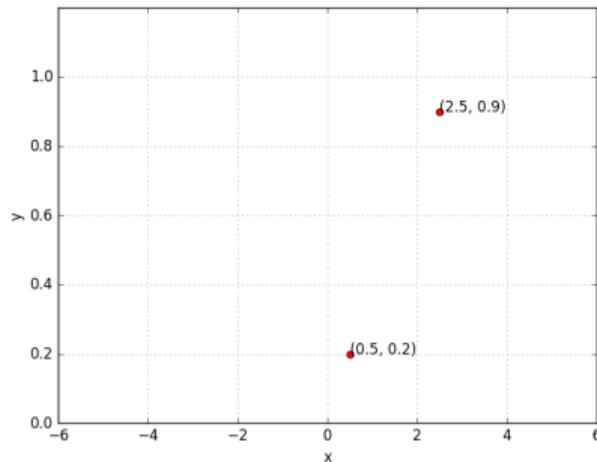
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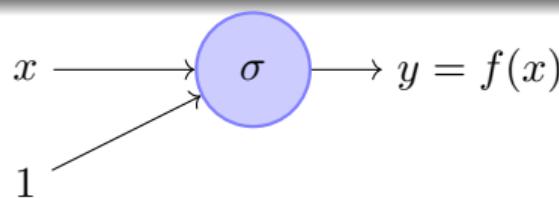
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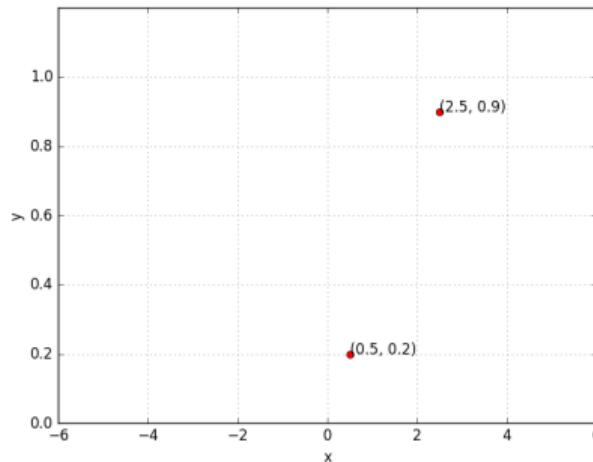
$$f(x) = \frac{1}{1+e^{-(w \cdot x + b)}}$$

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



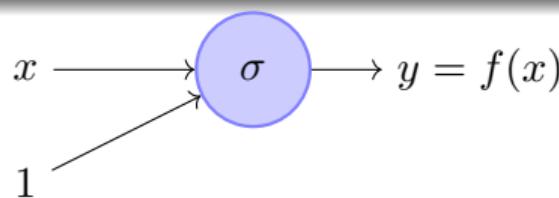


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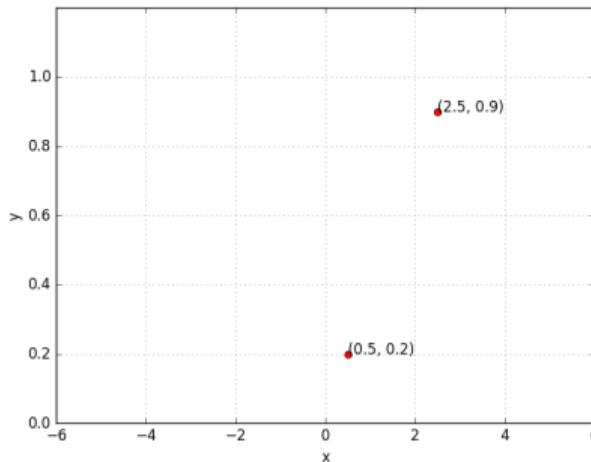


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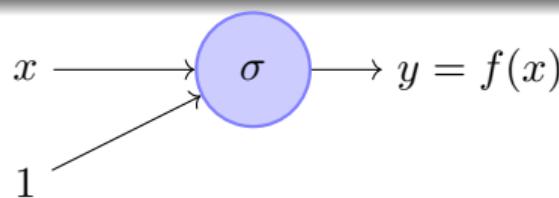
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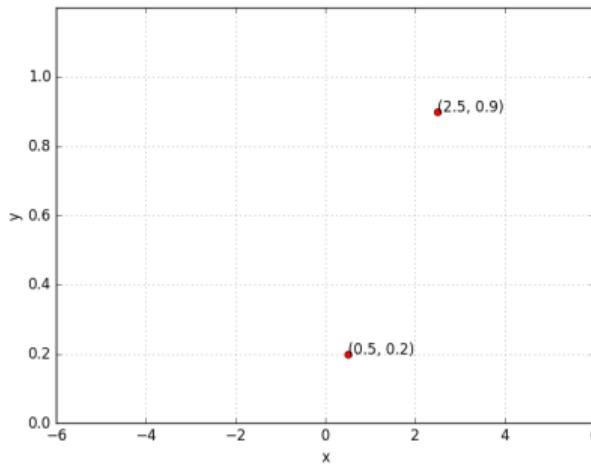
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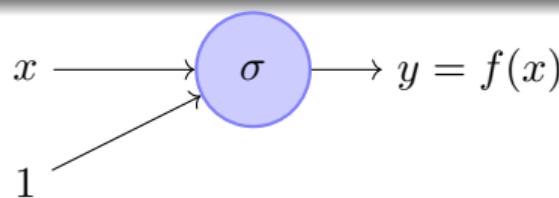


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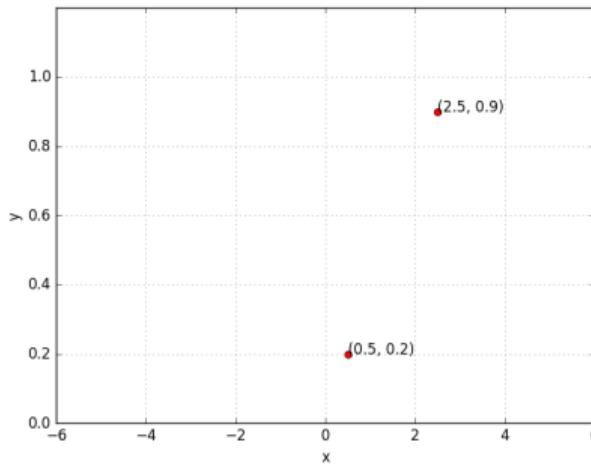
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$$\nabla w = \sum_{i=1}^2 (f(x_i) - y_i) * f(x_i) * (1 - f(x_i)) * x_i$$



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



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

$$\nabla w = (f(x) - y) * f(x) * (1 - f(x)) * x$$

For two points,

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

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

```
X = [0.5, 2.5]  
Y = [0.2, 0.9]
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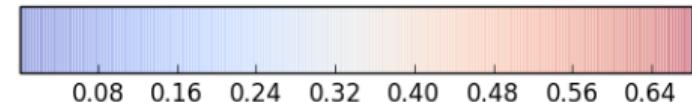
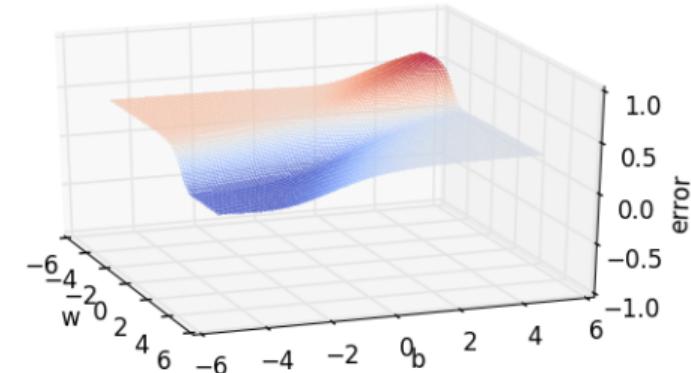
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Random search on error surface



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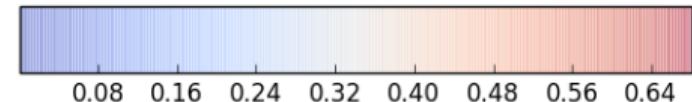
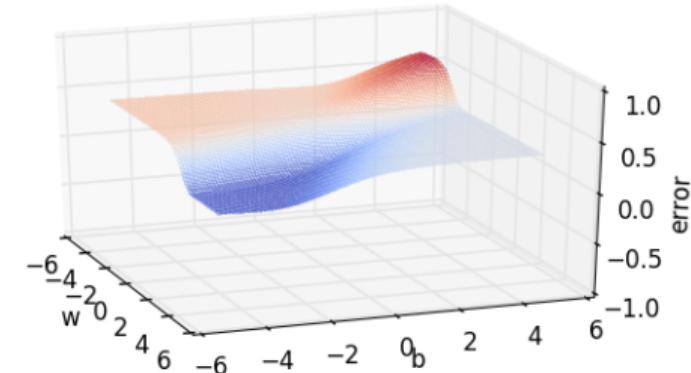
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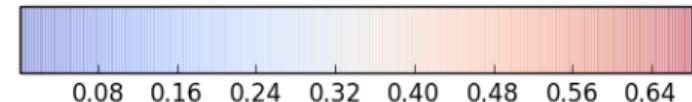
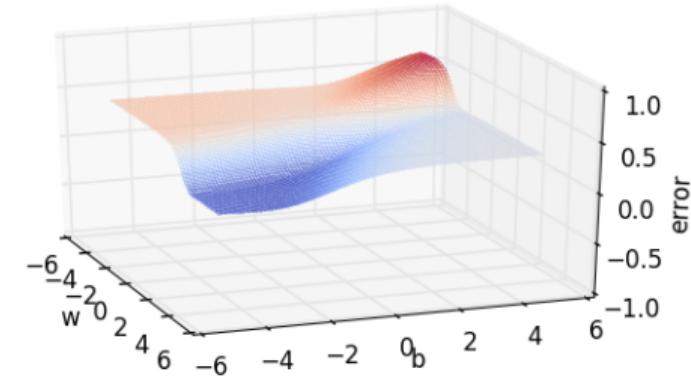
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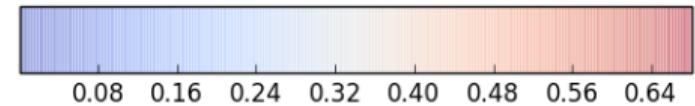
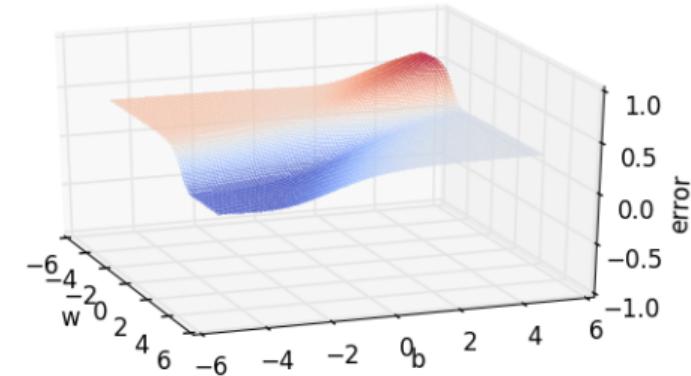
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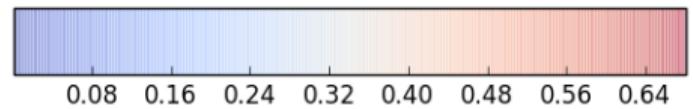
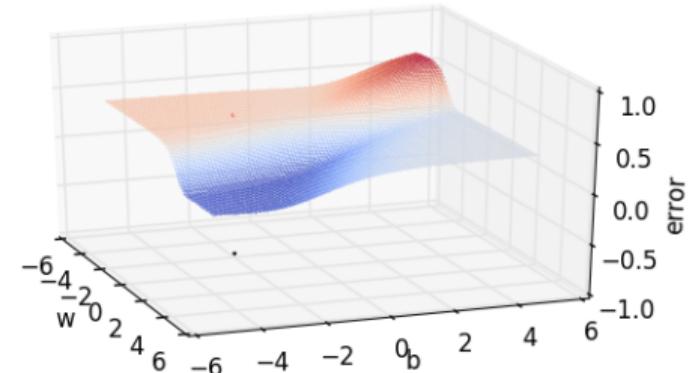
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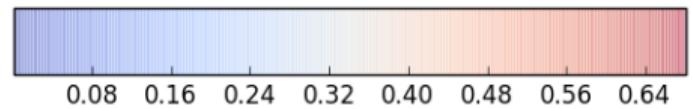
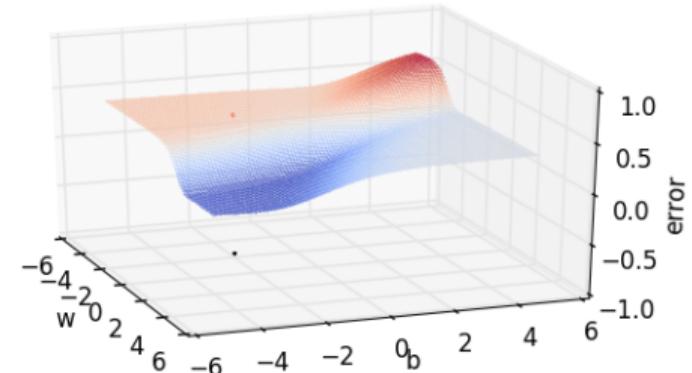
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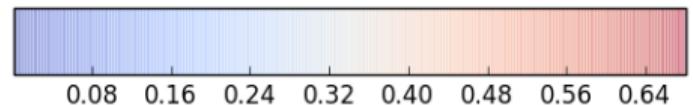
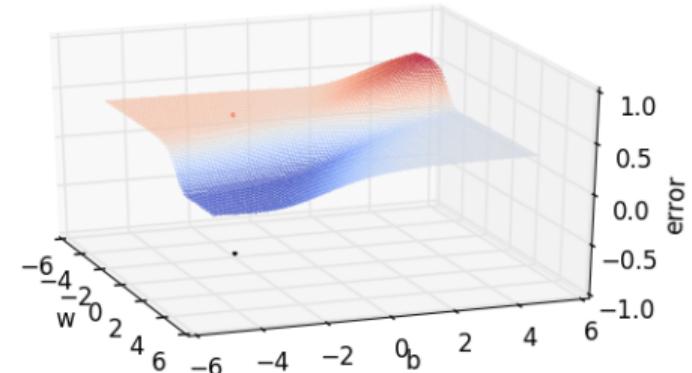
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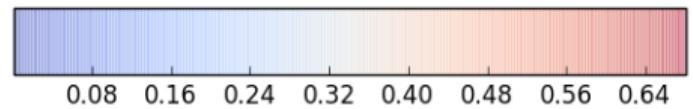
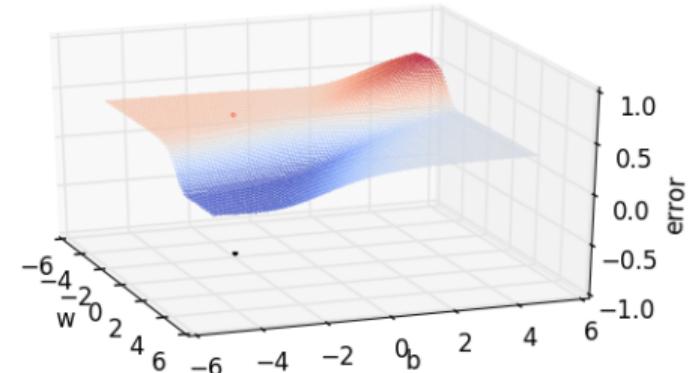
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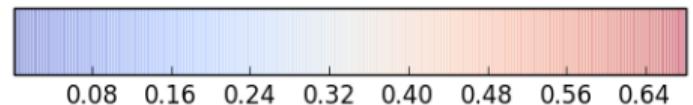
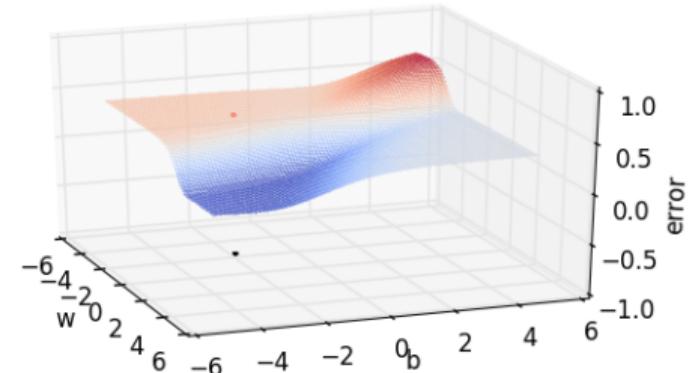
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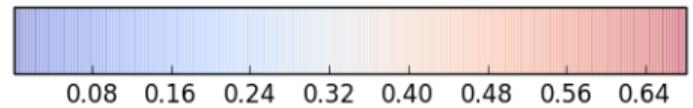
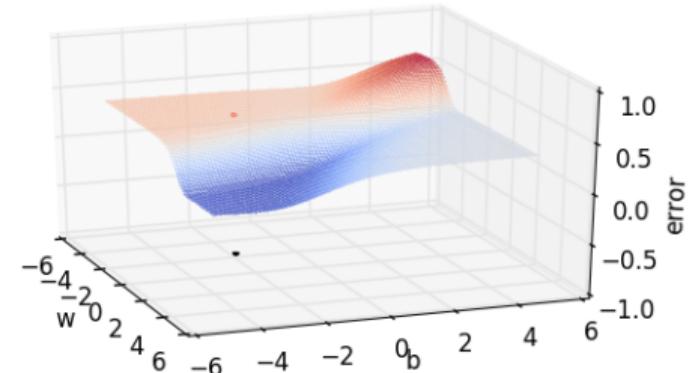
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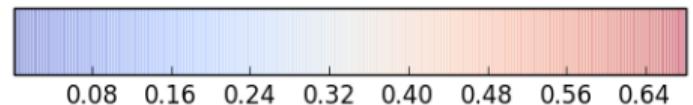
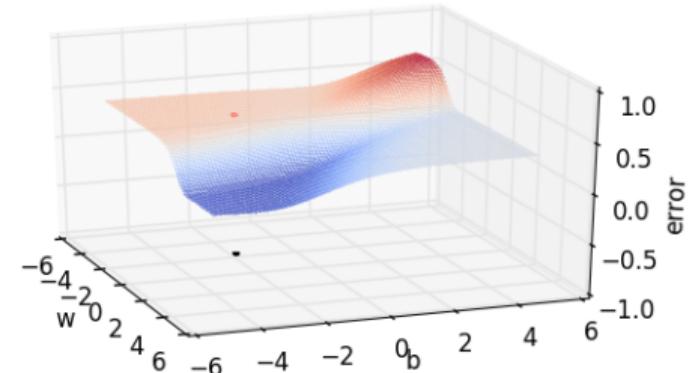
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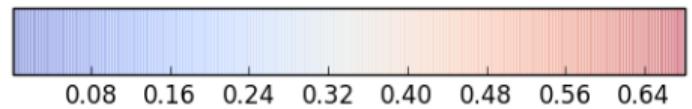
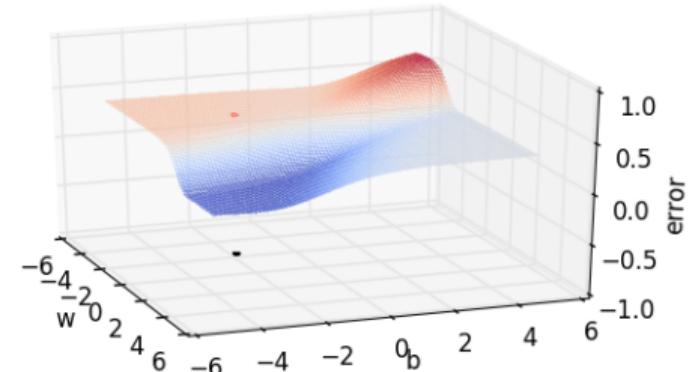
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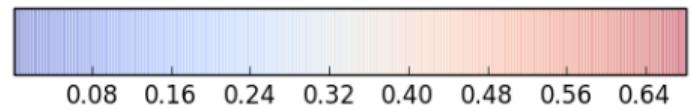
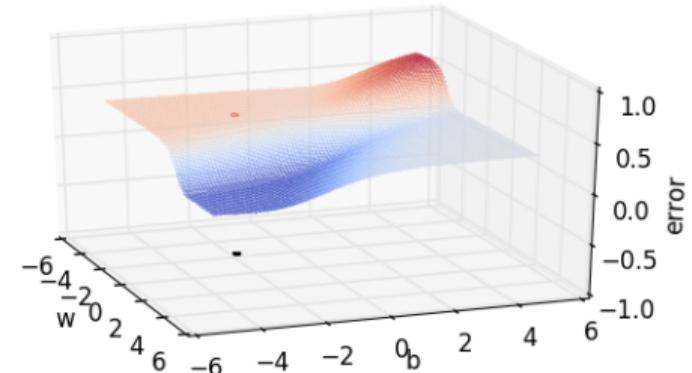
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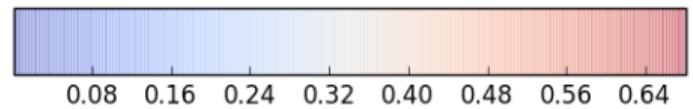
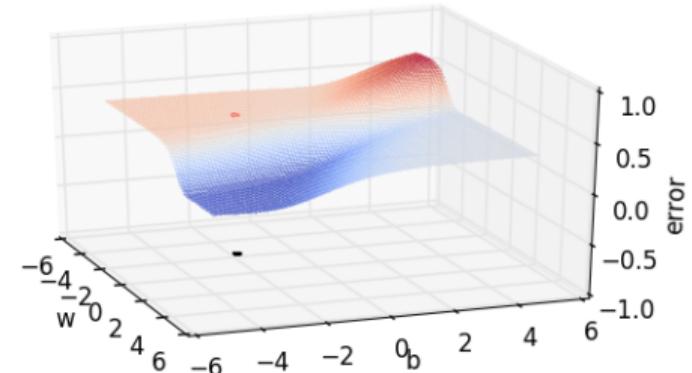
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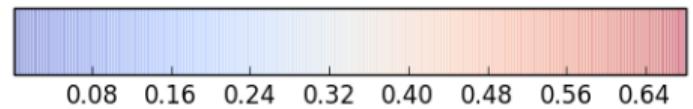
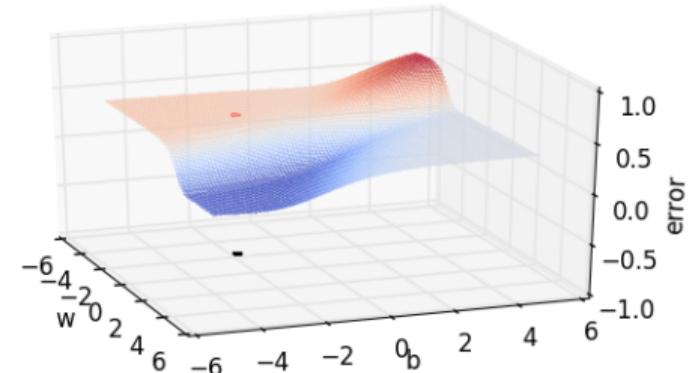
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Gradient descent on the error surface



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

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    return 1.0 / (1.0 + np.exp(-(w*x + b)))

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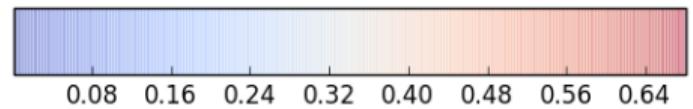
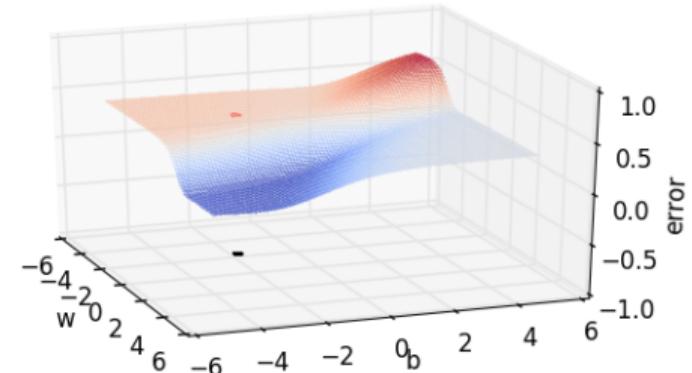
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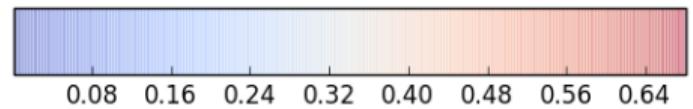
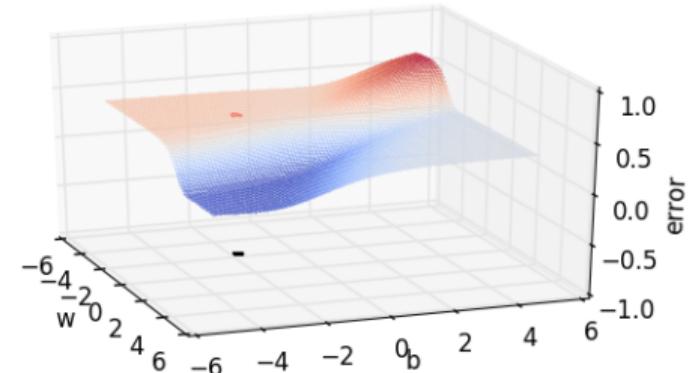
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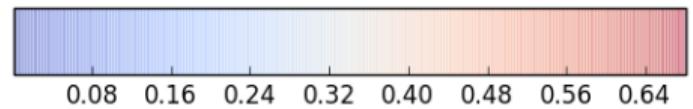
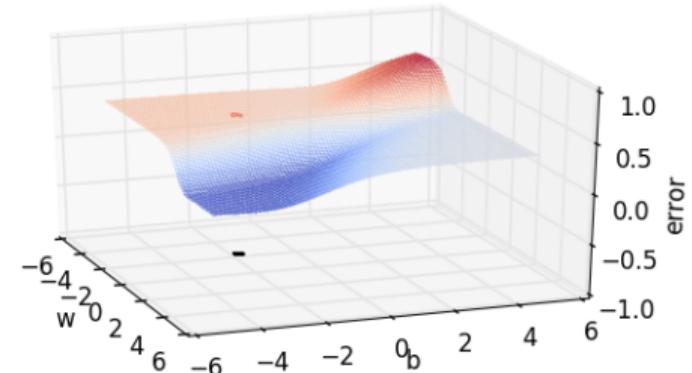
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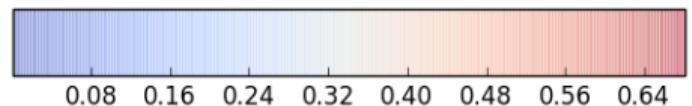
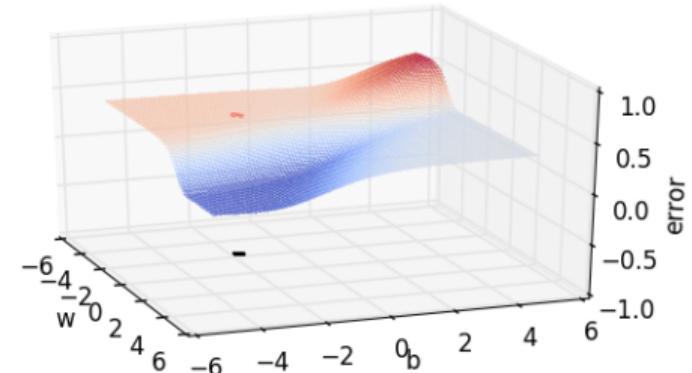
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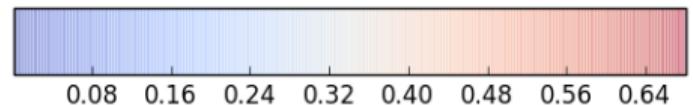
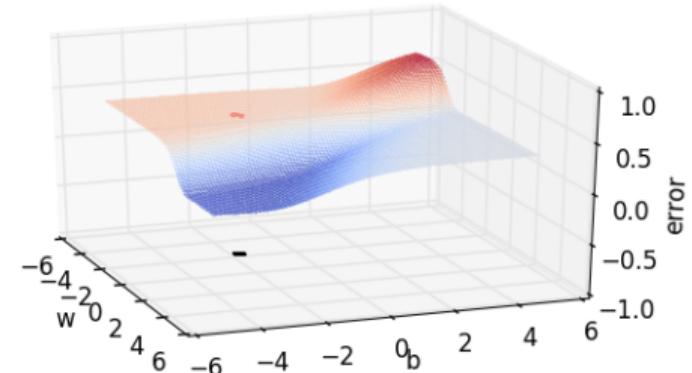
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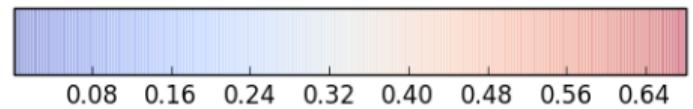
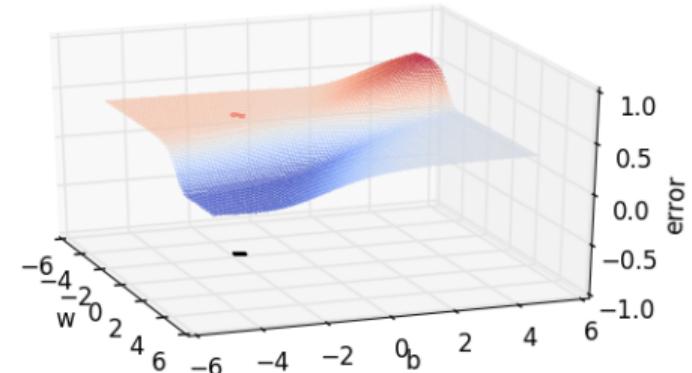
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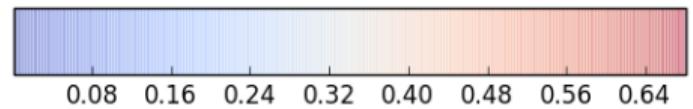
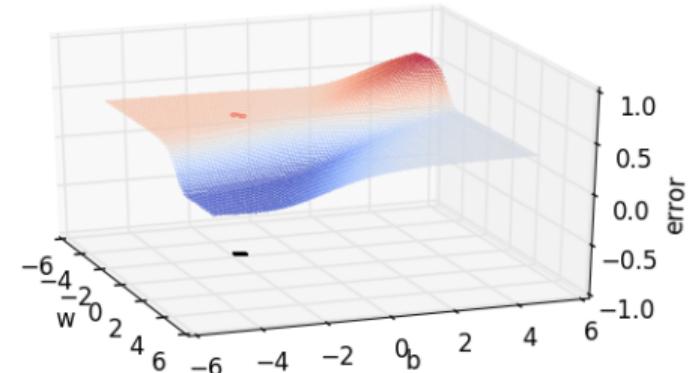
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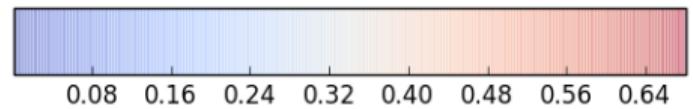
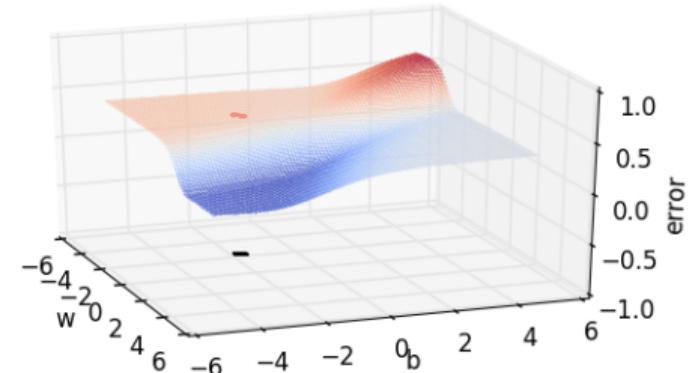
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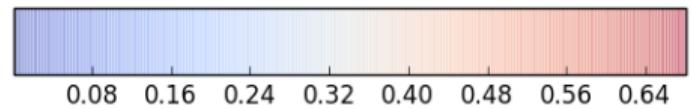
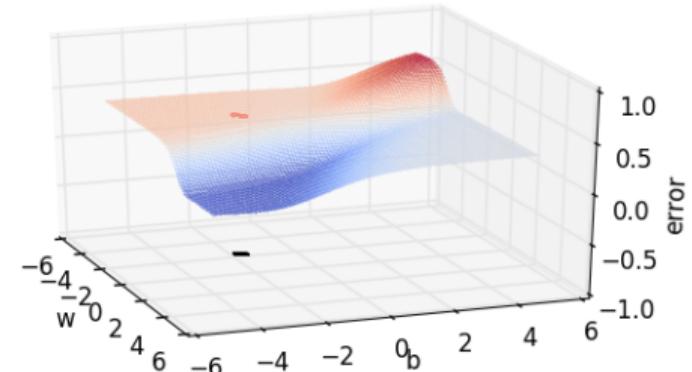
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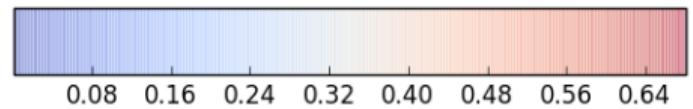
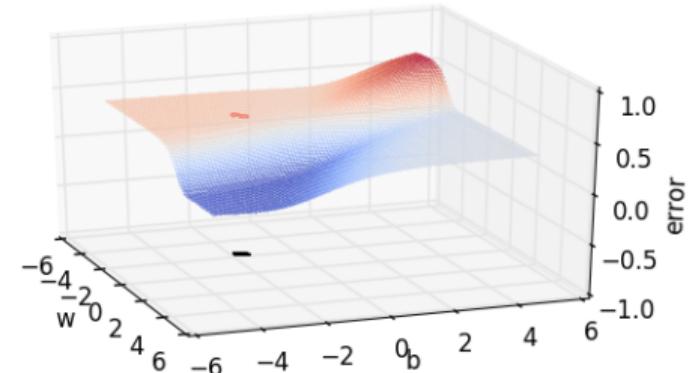
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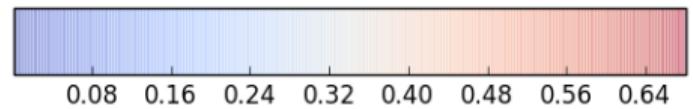
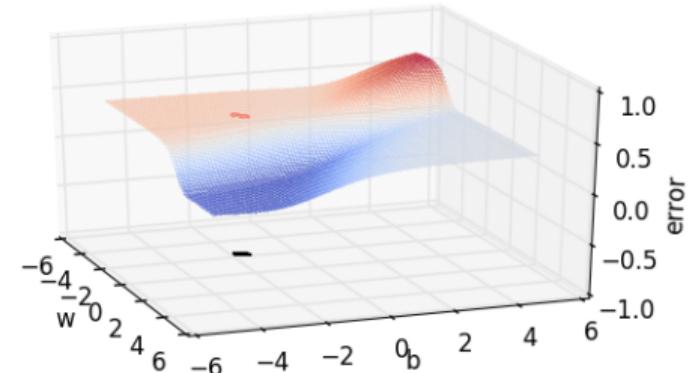
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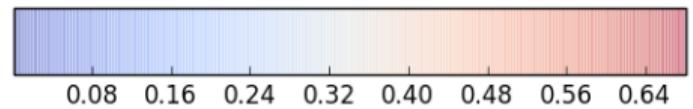
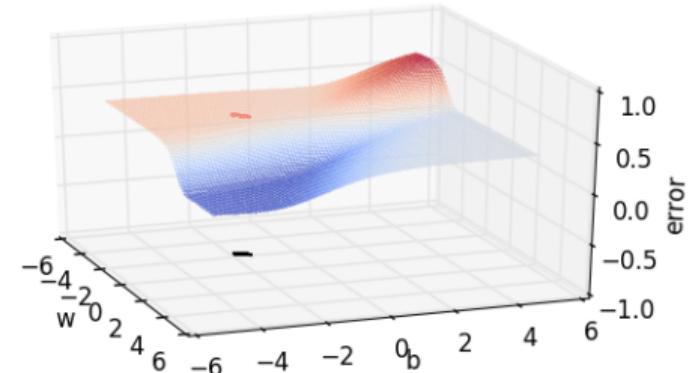
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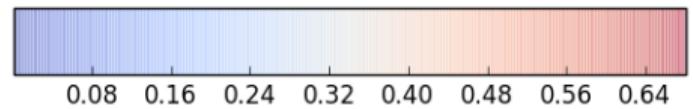
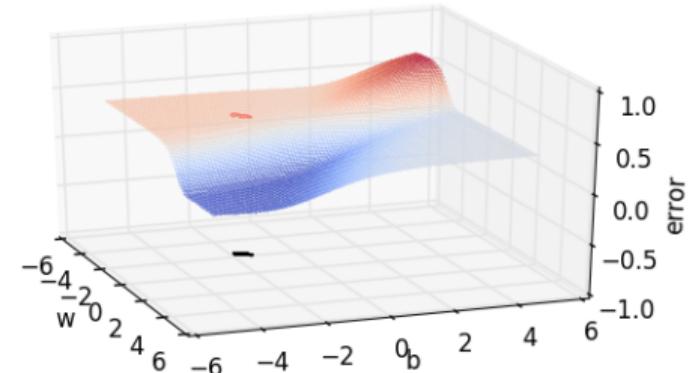
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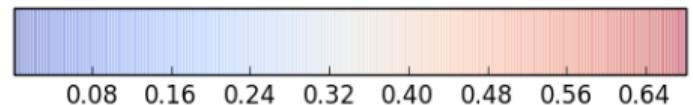
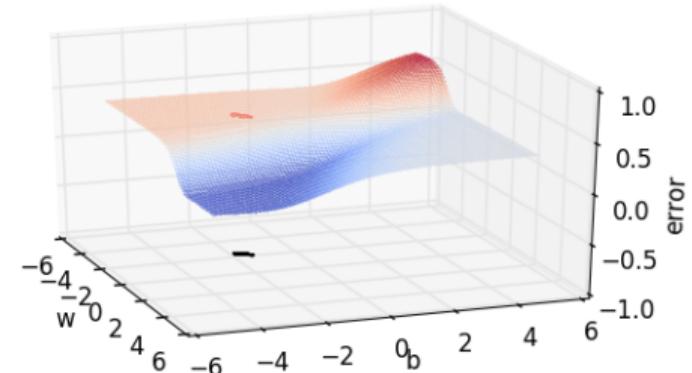
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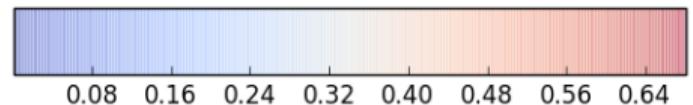
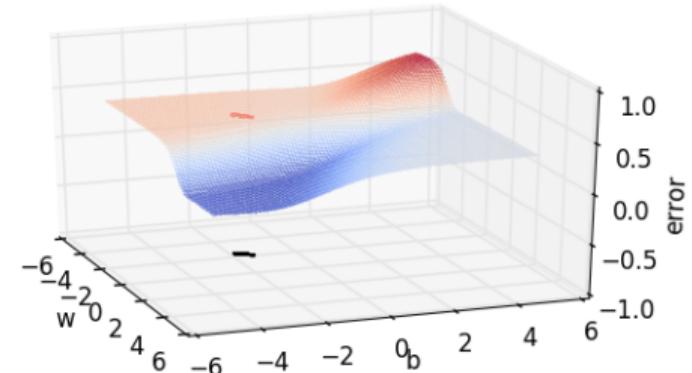
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Gradient descent on the error surface



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Y = [0.2, 0.9]

def f(w,b,x) : #sigmoid with parameters w,b
    return 1.0 / (1.0 + np.exp(-(w*x + b)))

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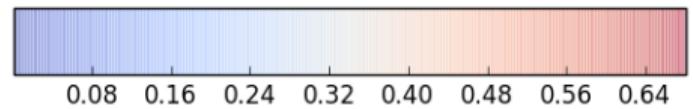
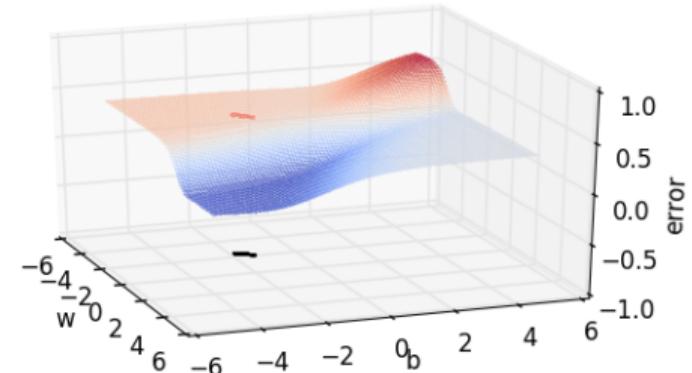
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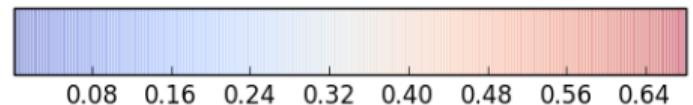
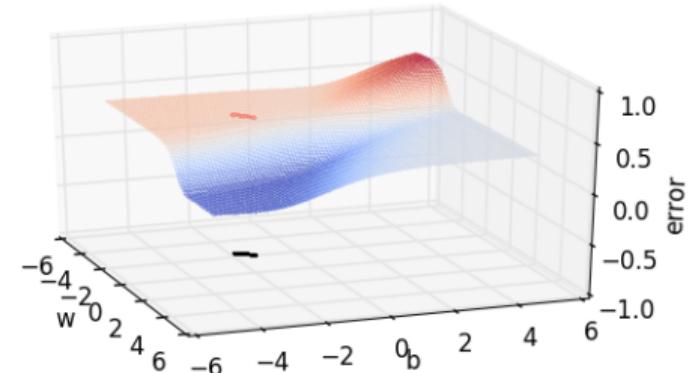
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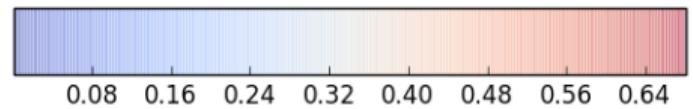
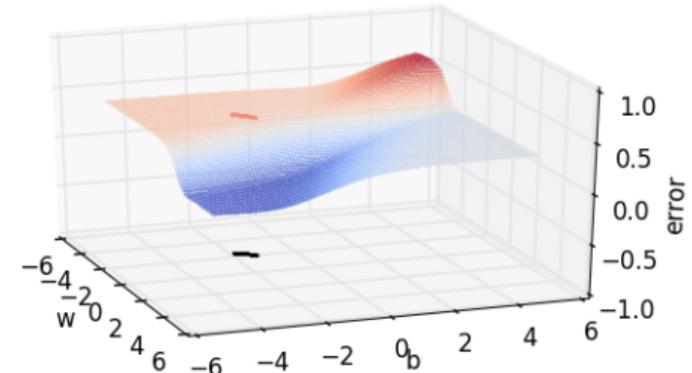
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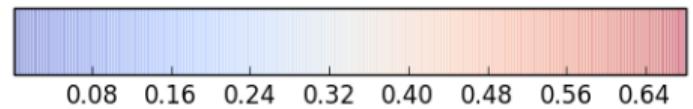
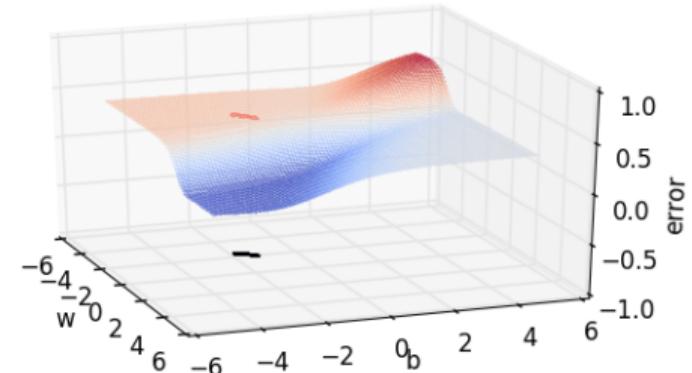
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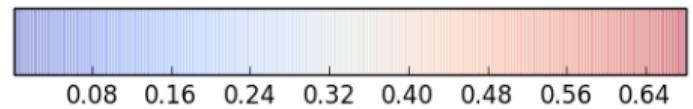
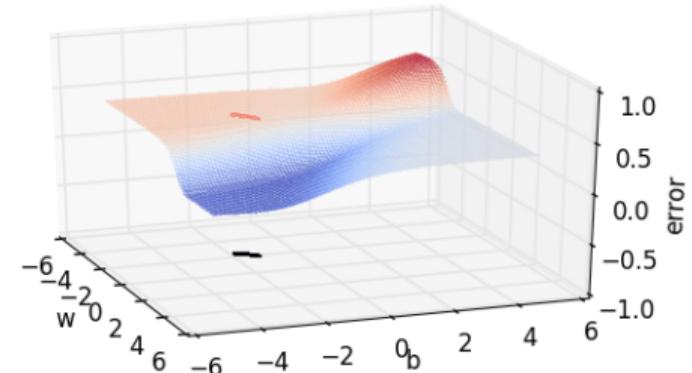
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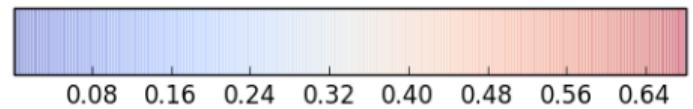
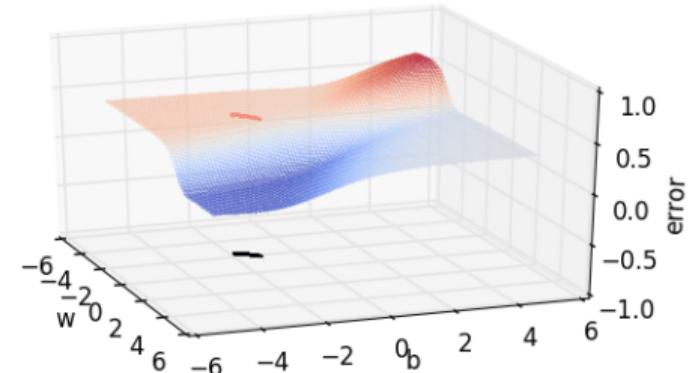
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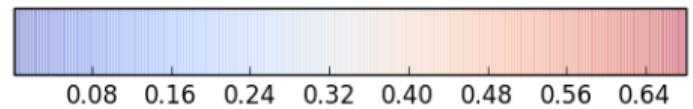
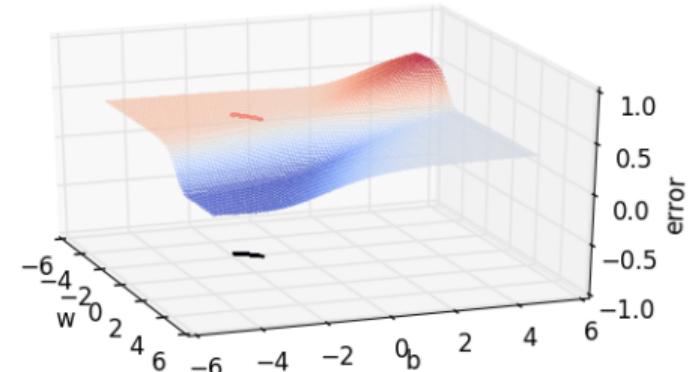
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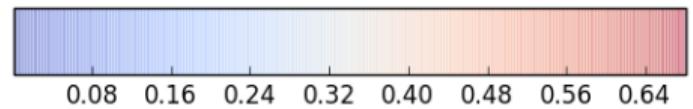
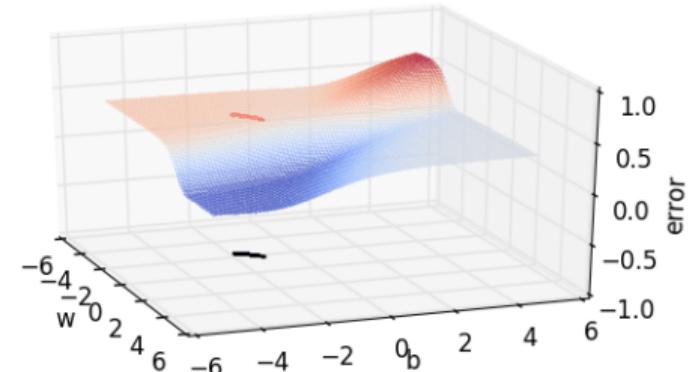
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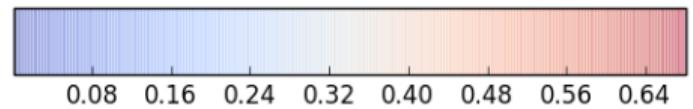
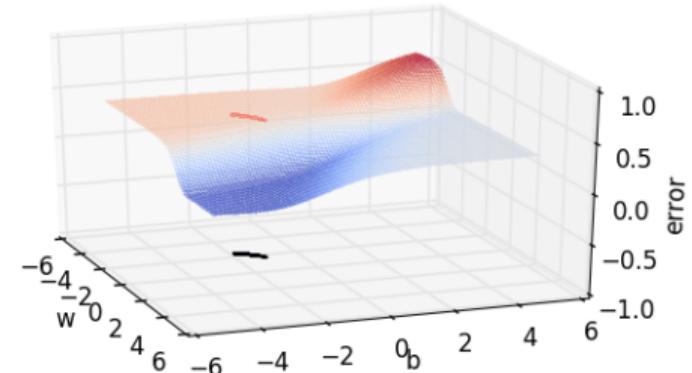
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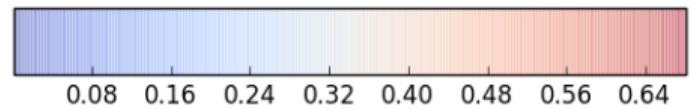
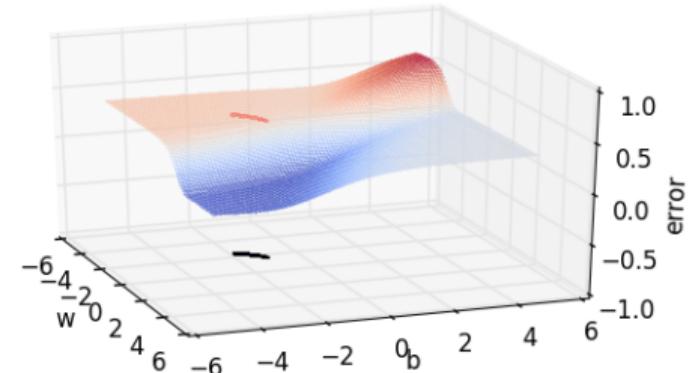
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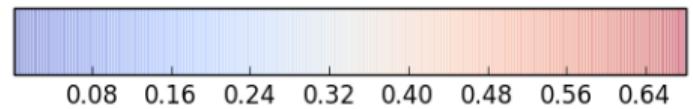
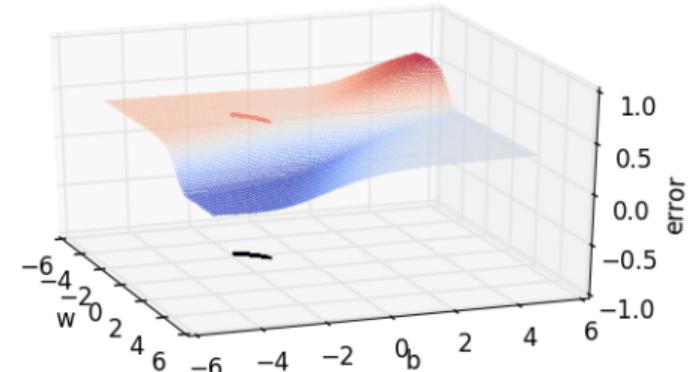
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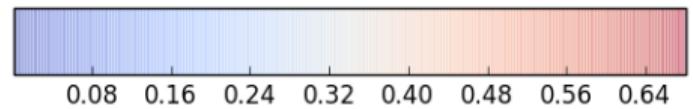
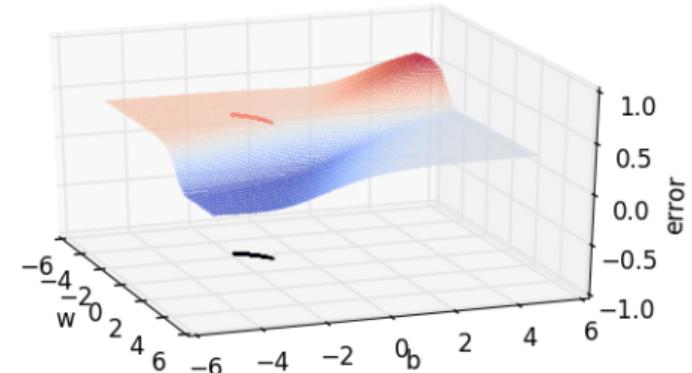
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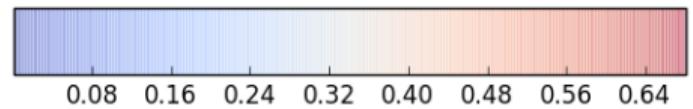
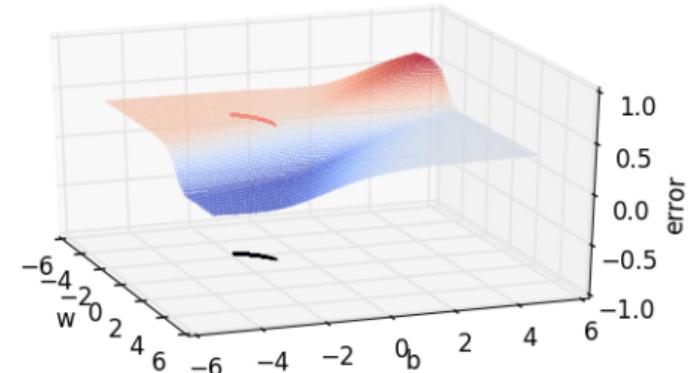
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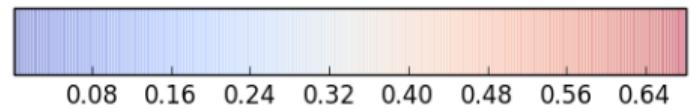
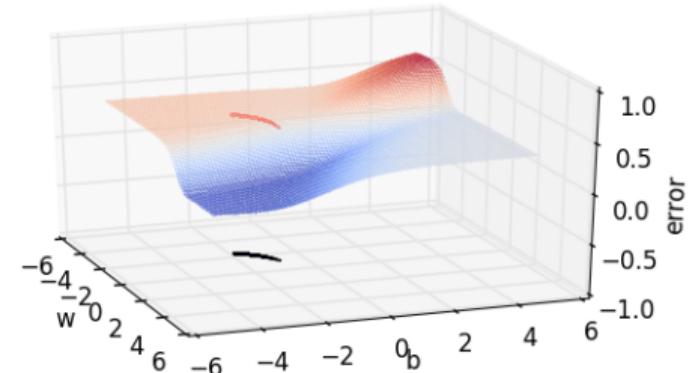
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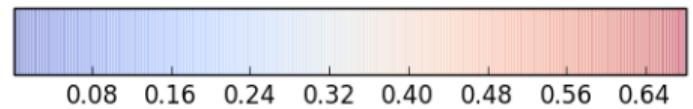
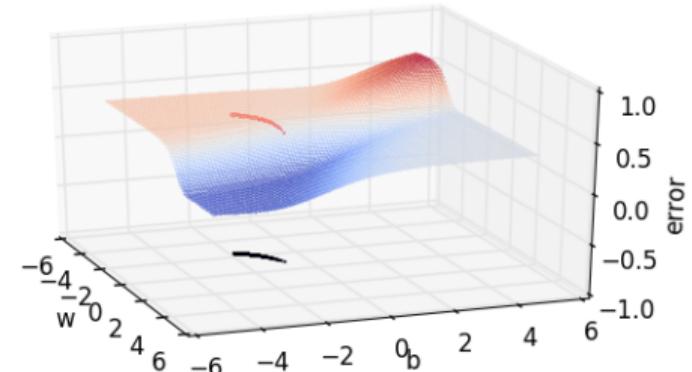
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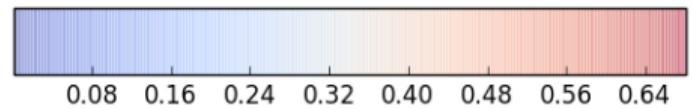
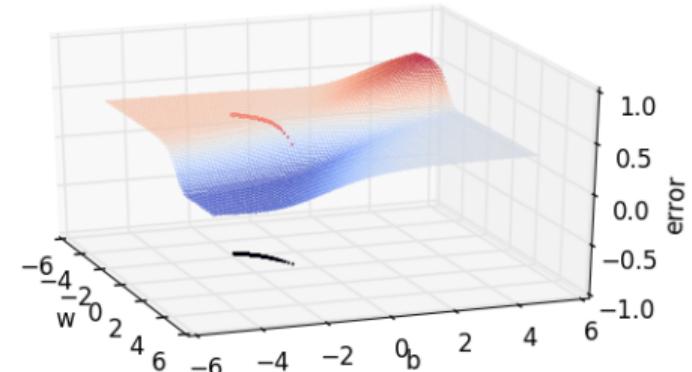
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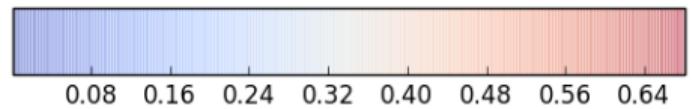
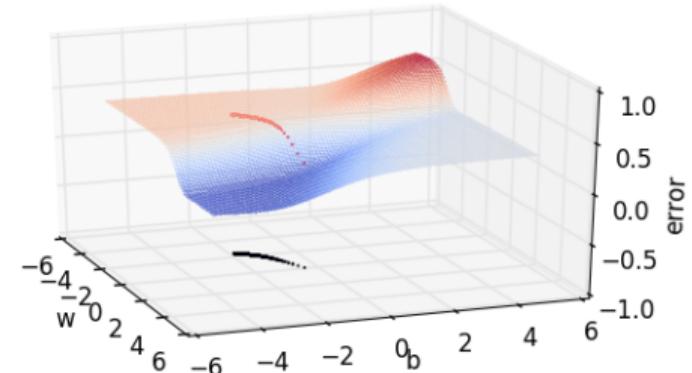
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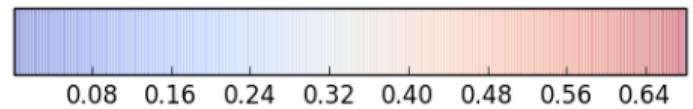
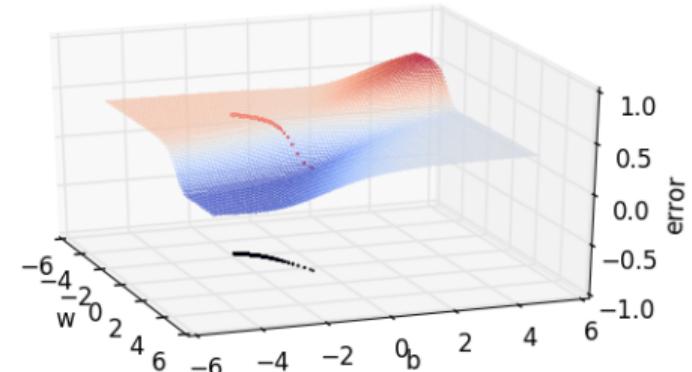
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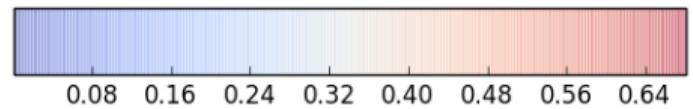
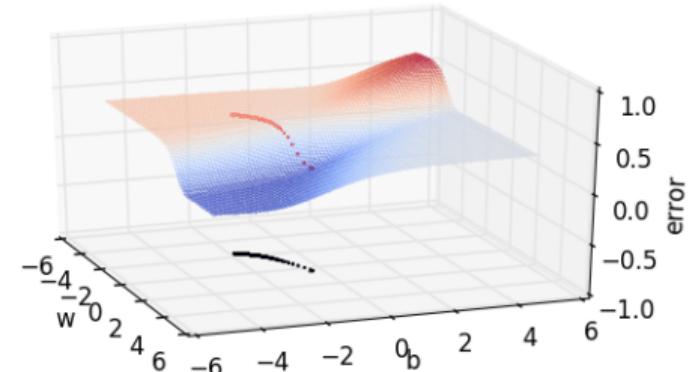
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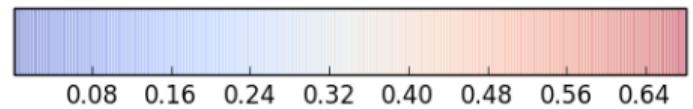
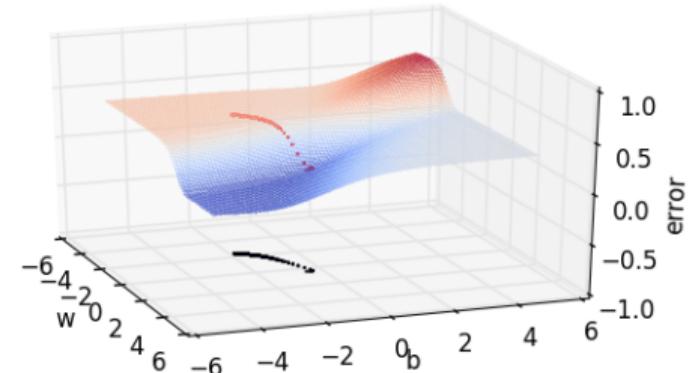
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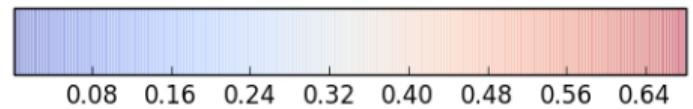
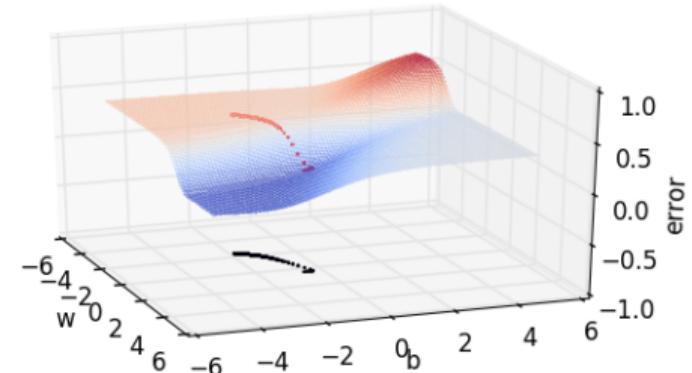
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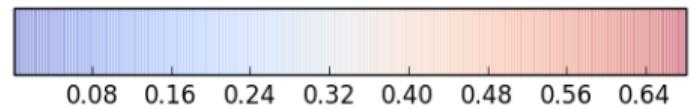
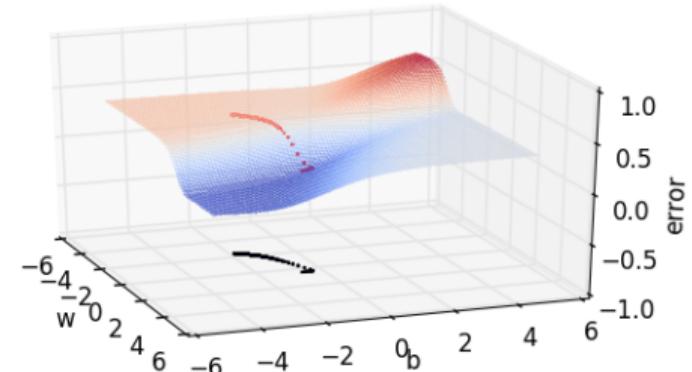
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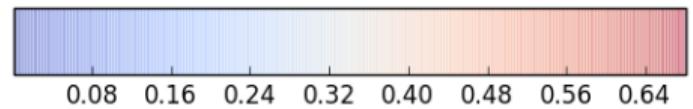
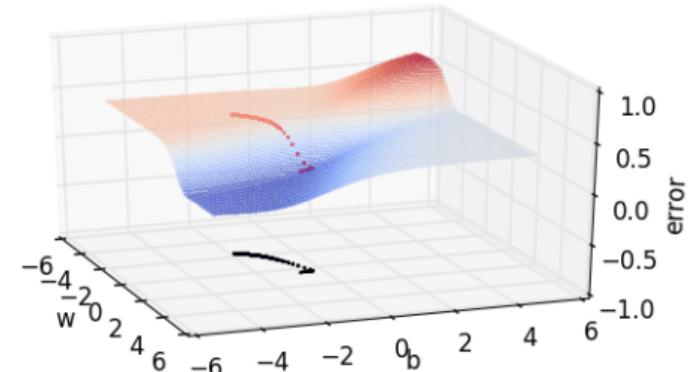
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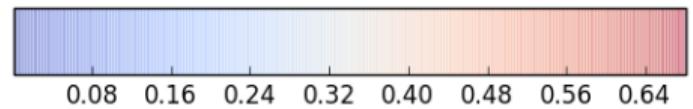
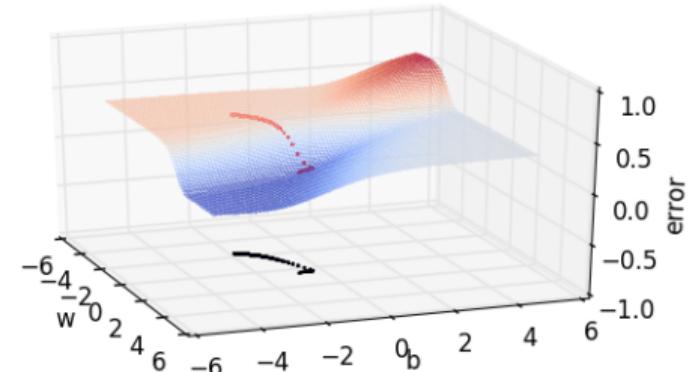
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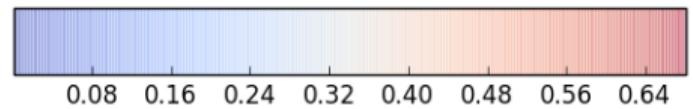
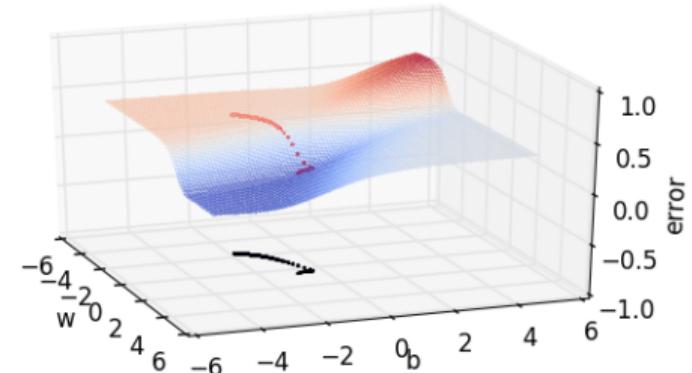
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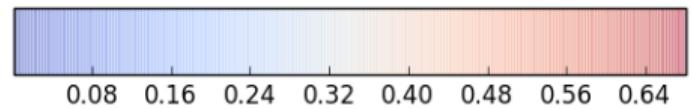
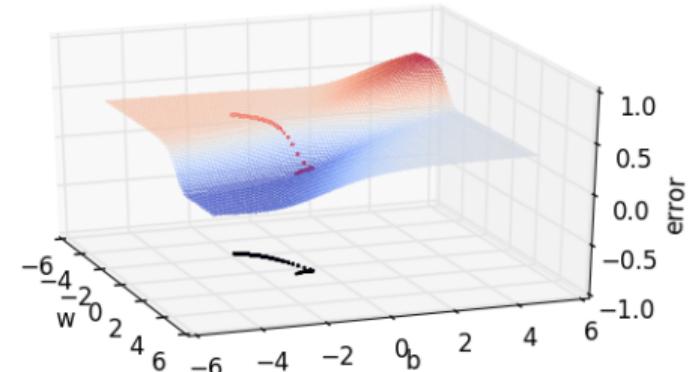
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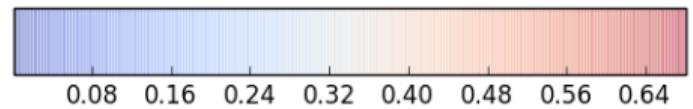
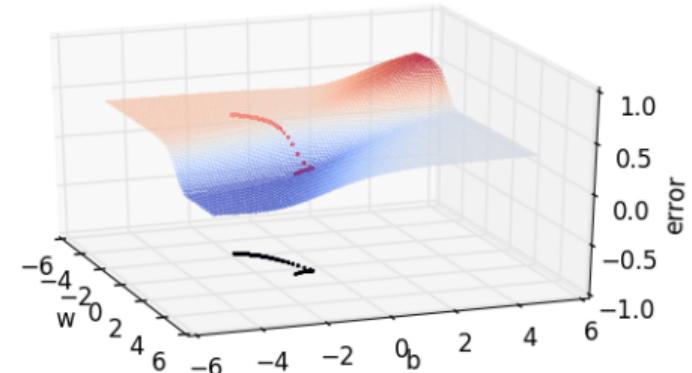
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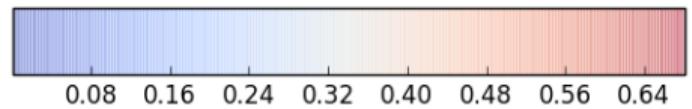
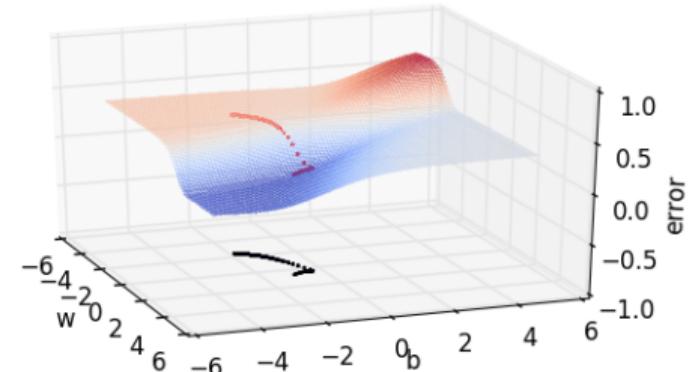
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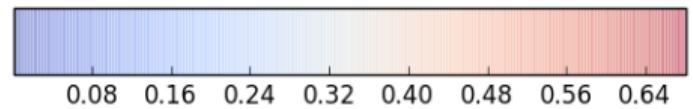
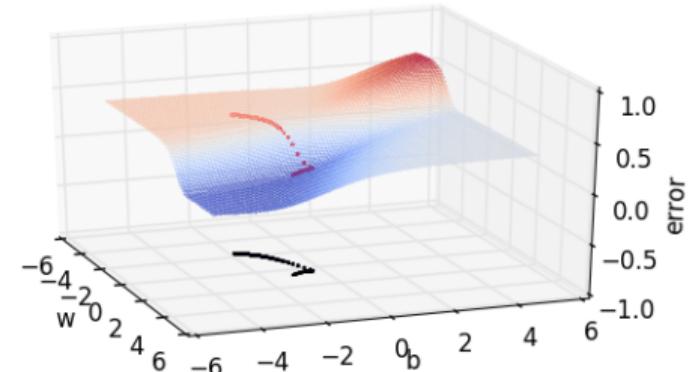
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Gradient descent on the error surface



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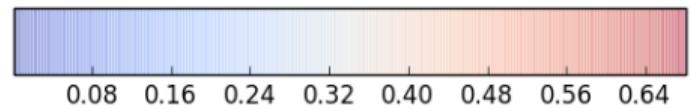
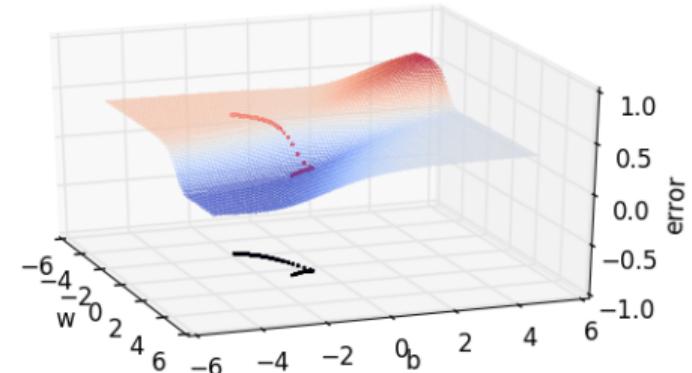
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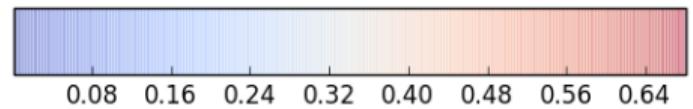
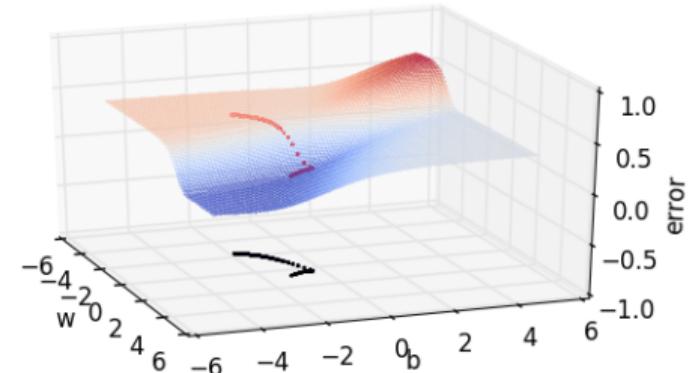
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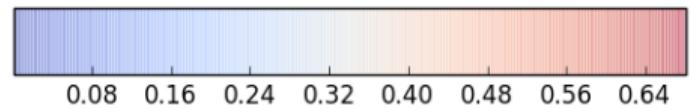
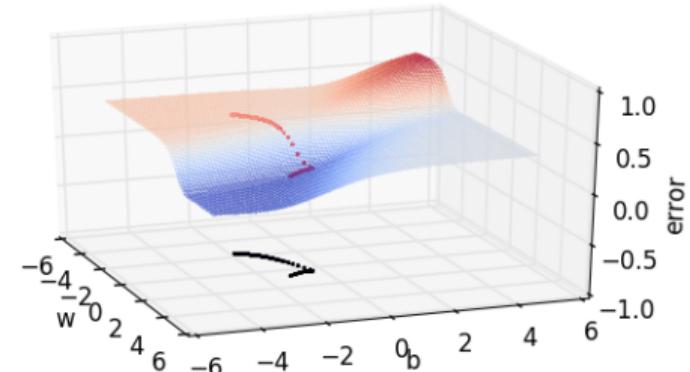
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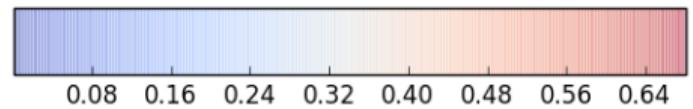
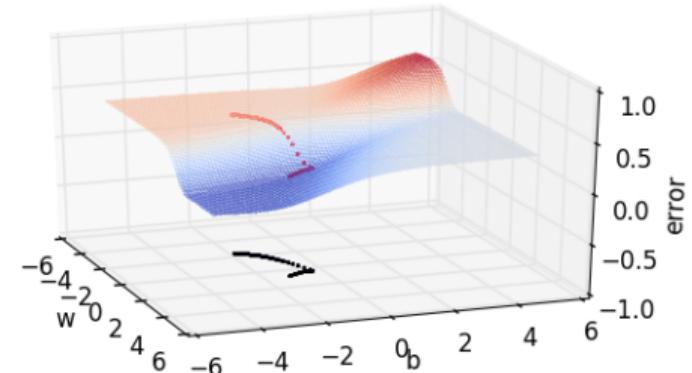
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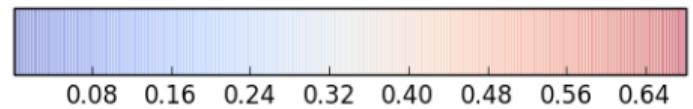
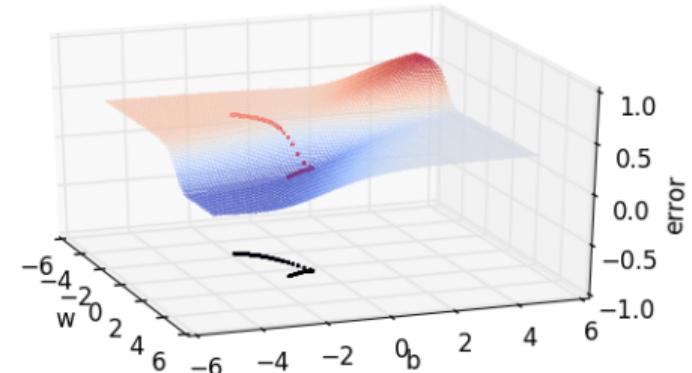
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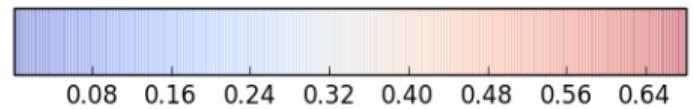
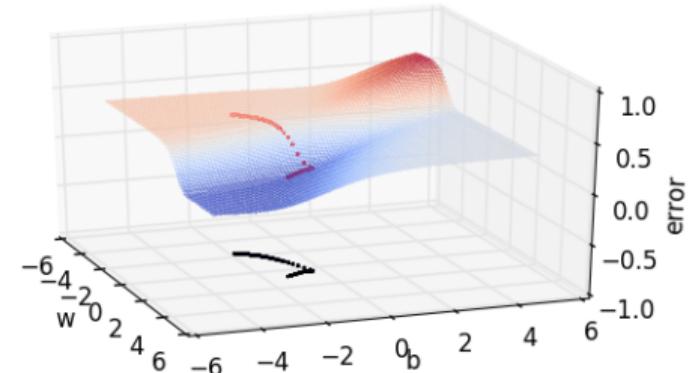
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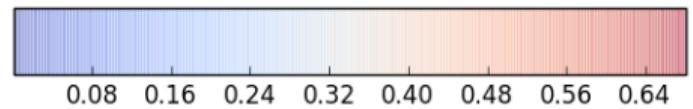
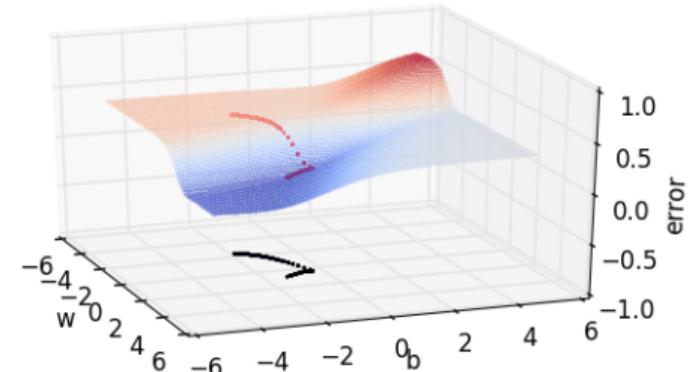
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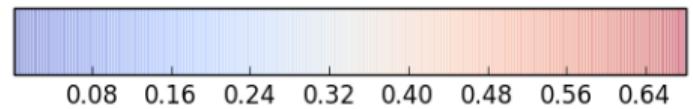
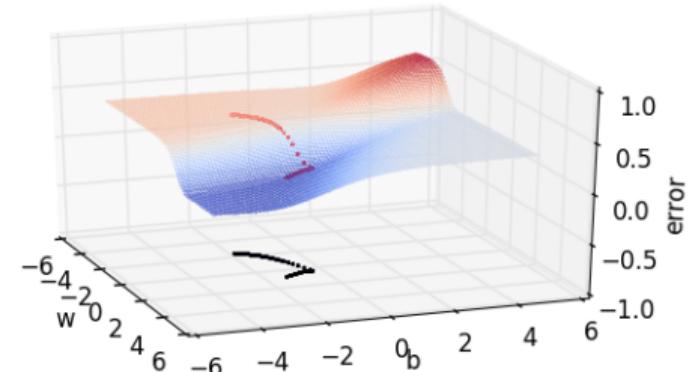
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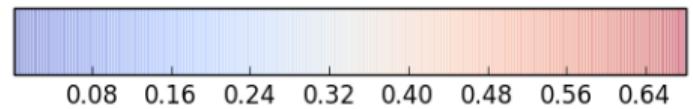
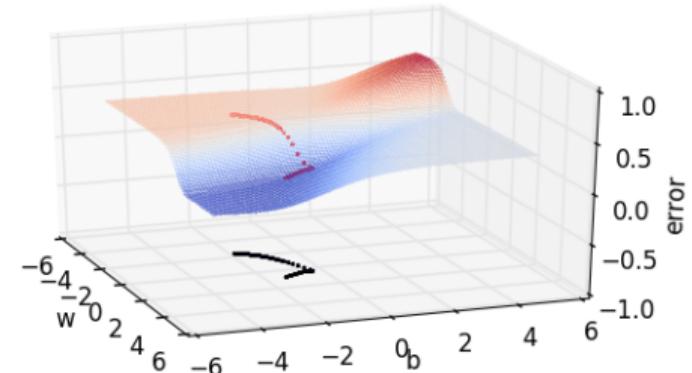
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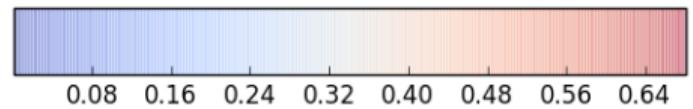
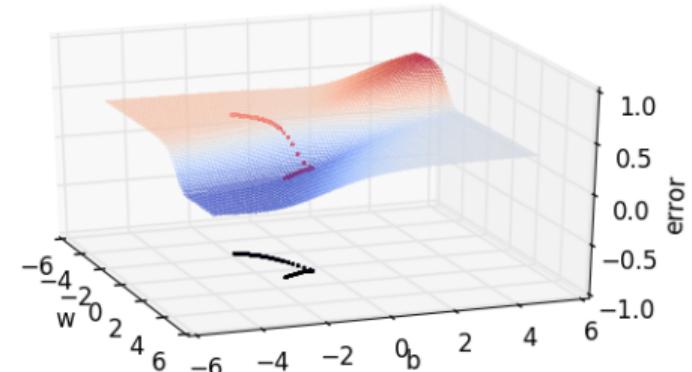
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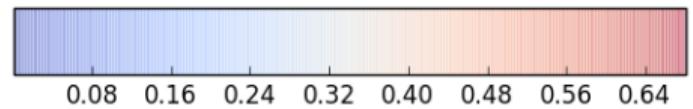
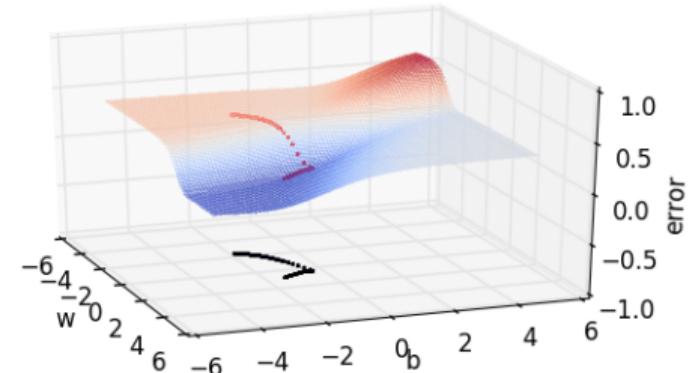
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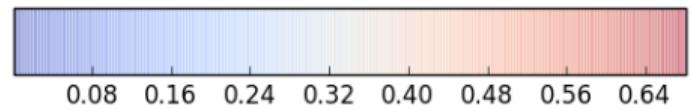
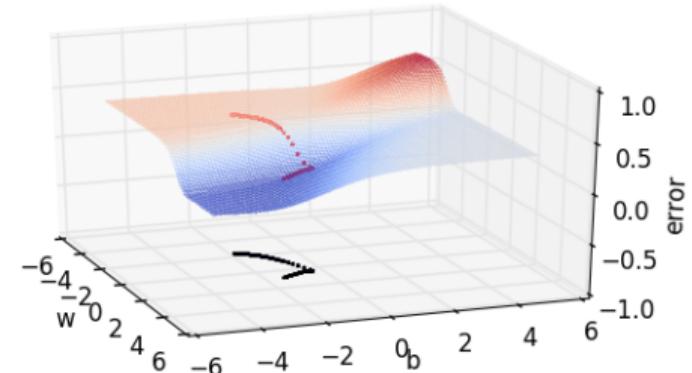
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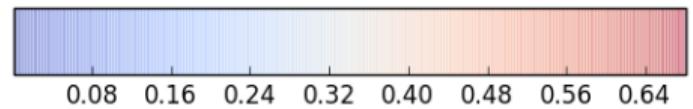
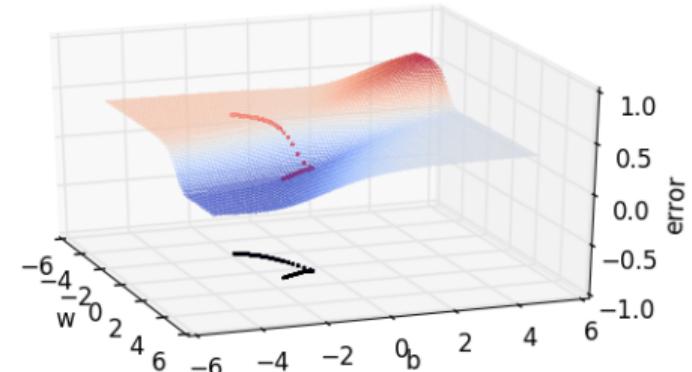
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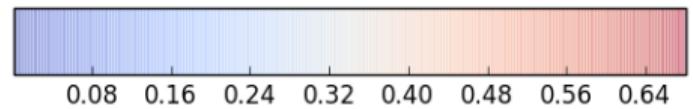
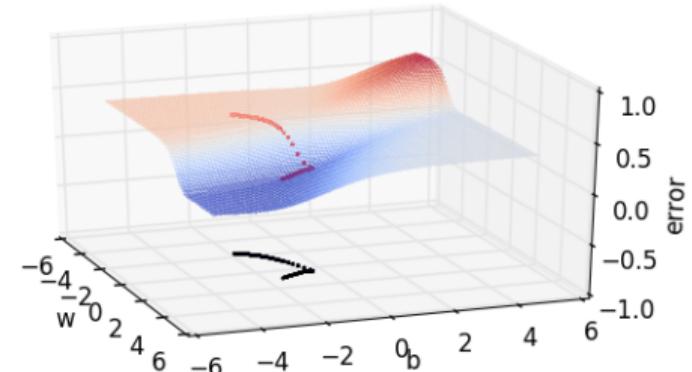
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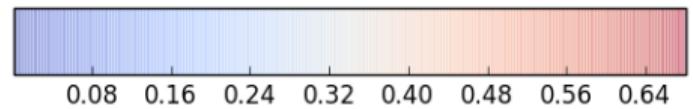
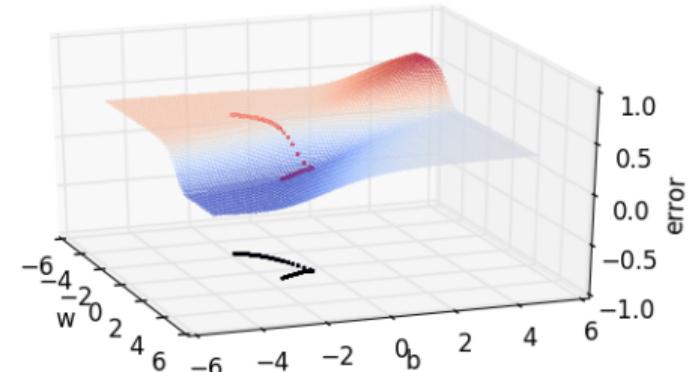
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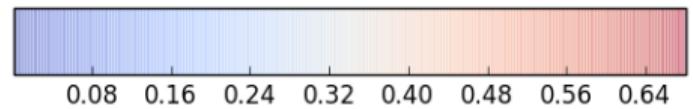
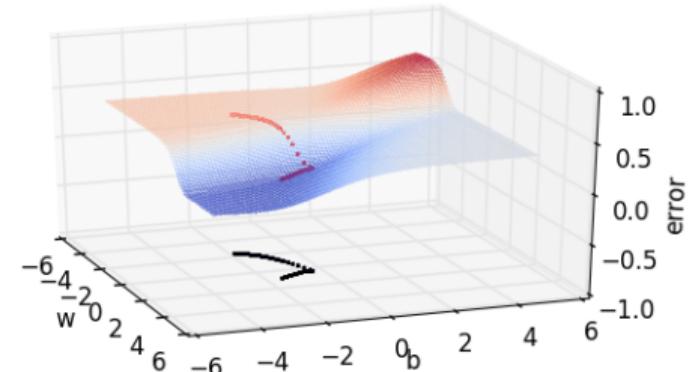
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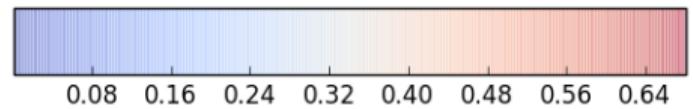
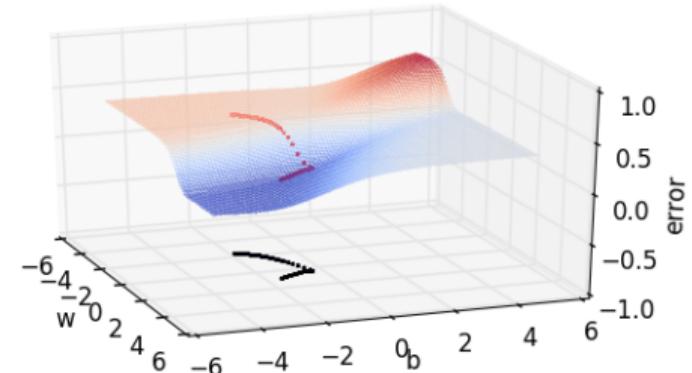
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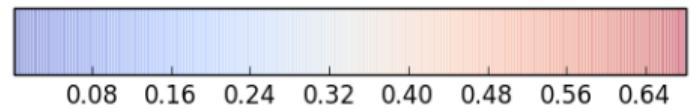
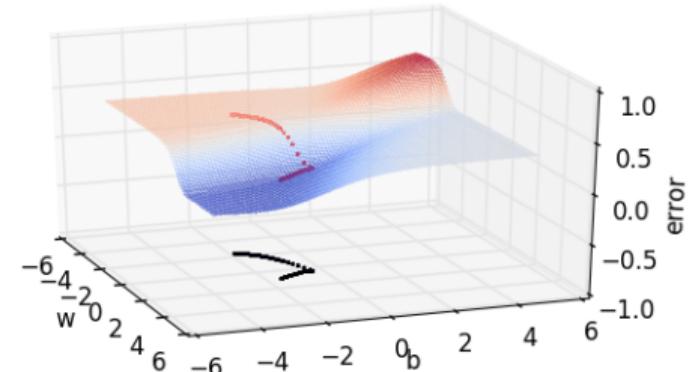
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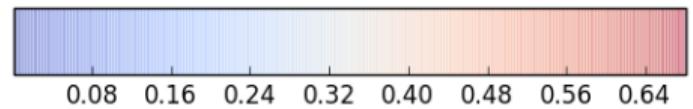
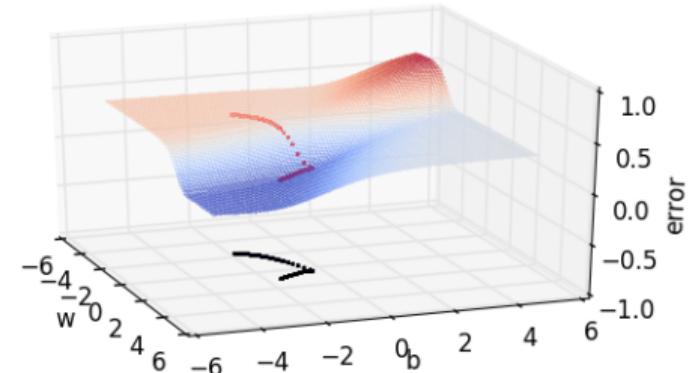
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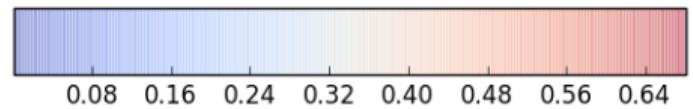
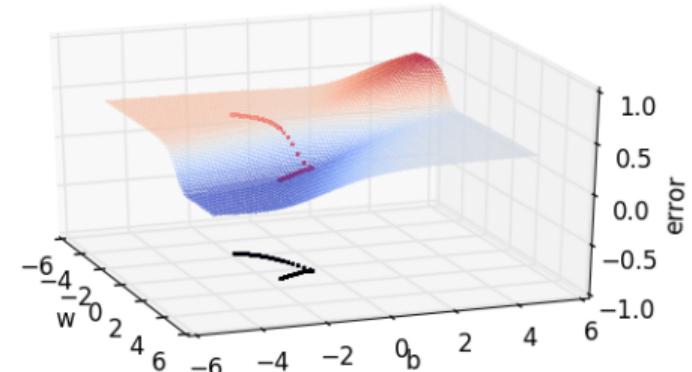
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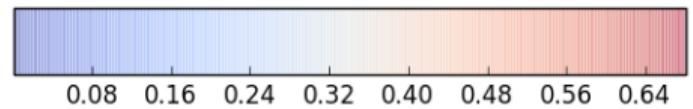
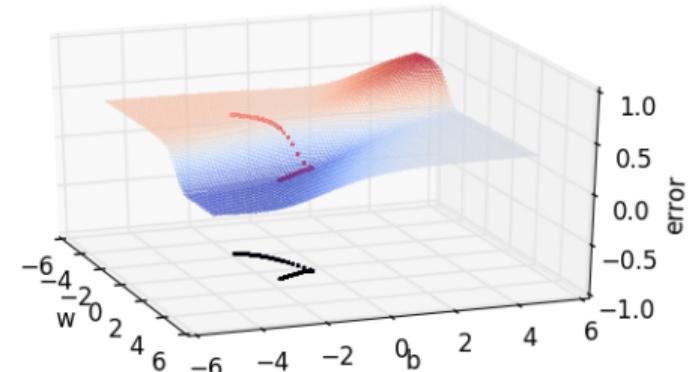
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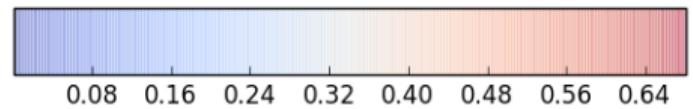
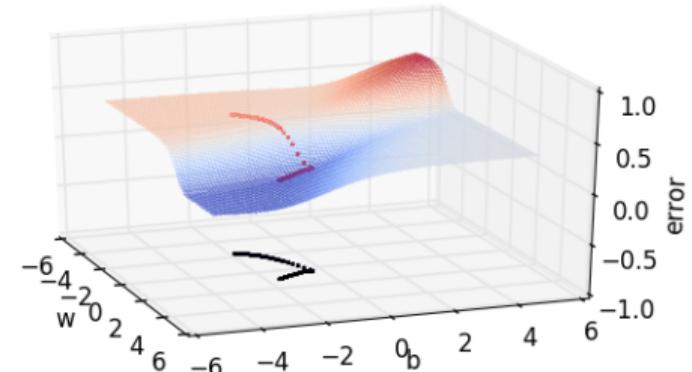
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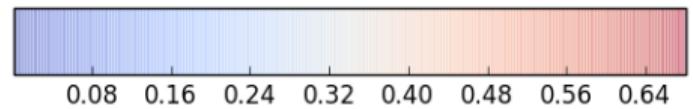
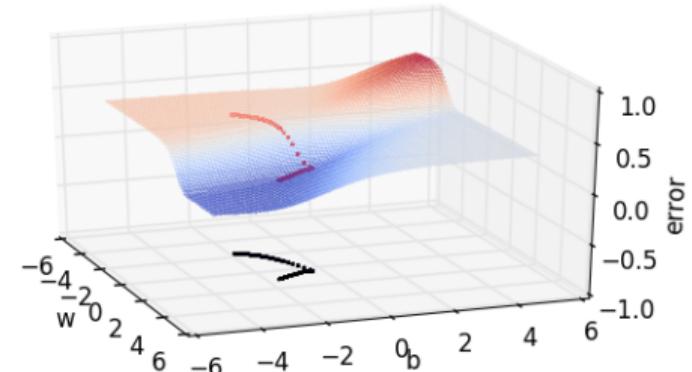
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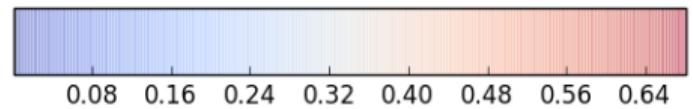
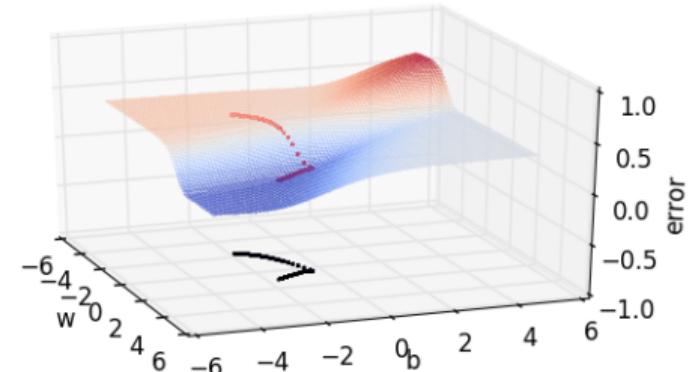
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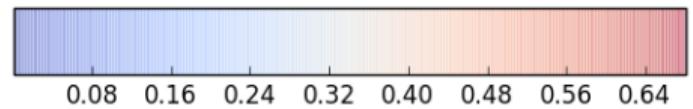
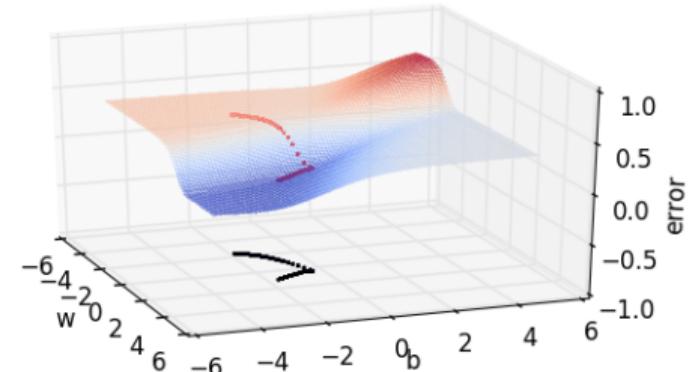
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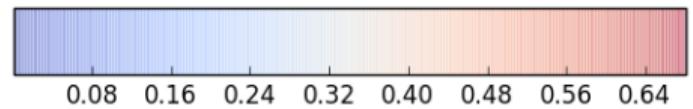
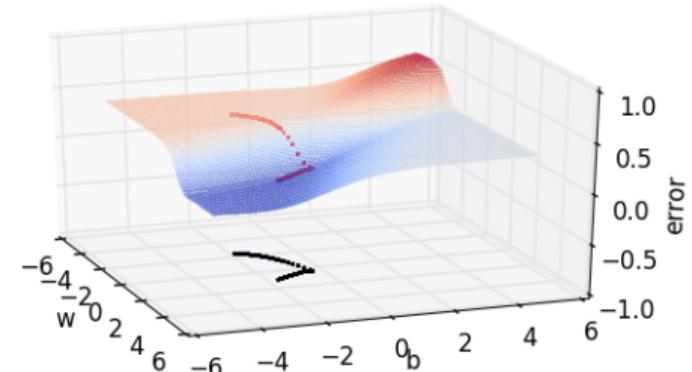
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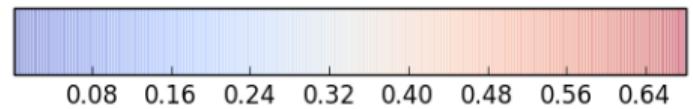
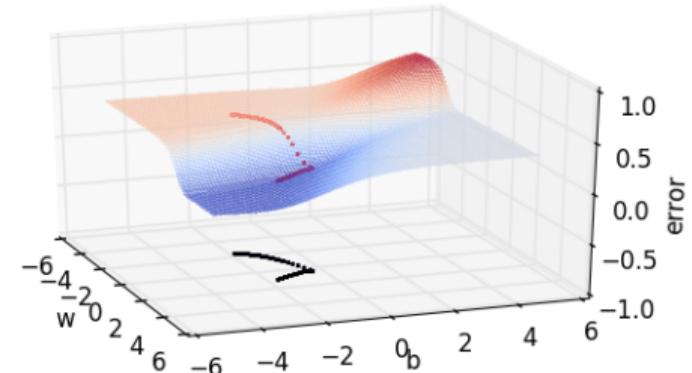
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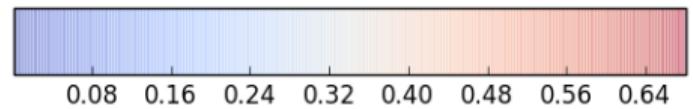
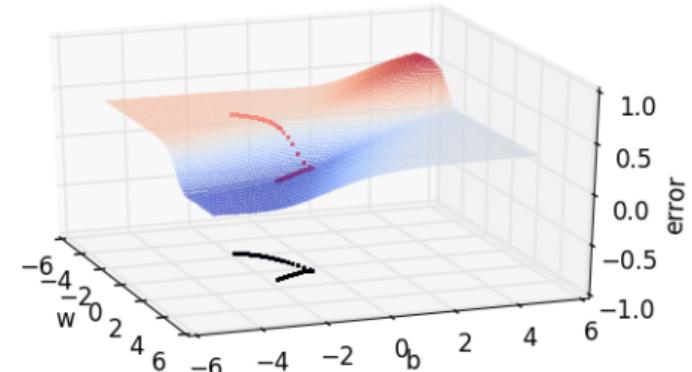
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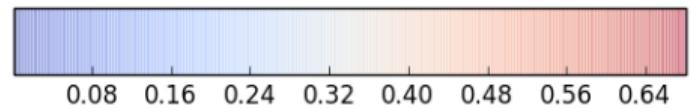
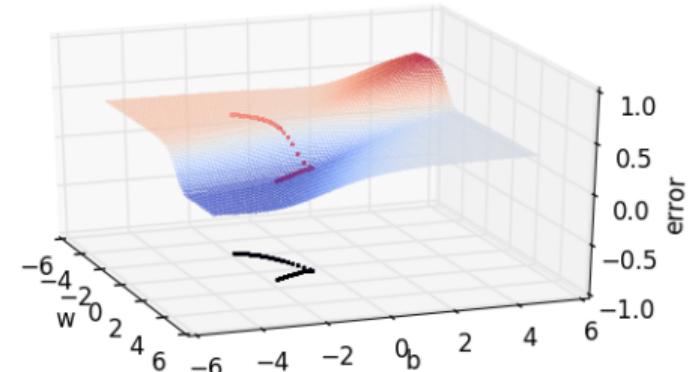
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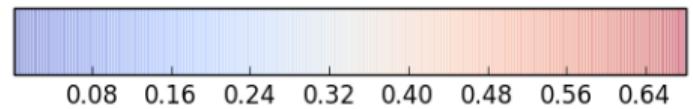
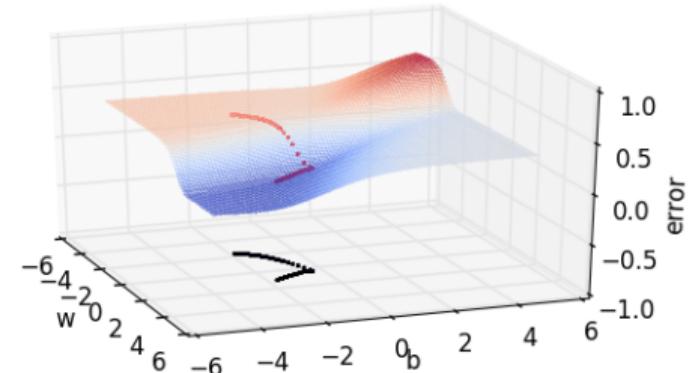
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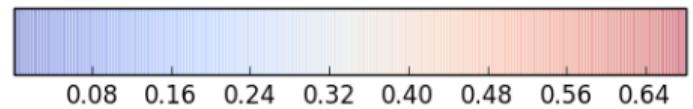
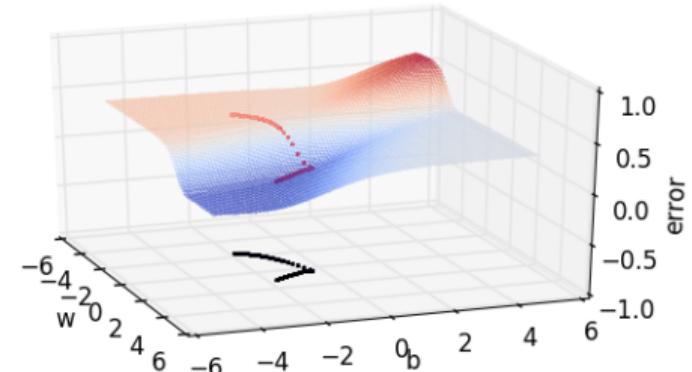
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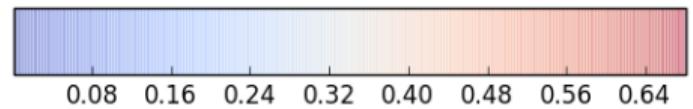
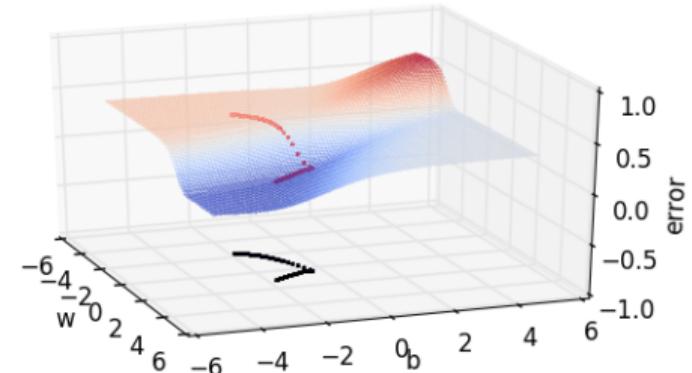
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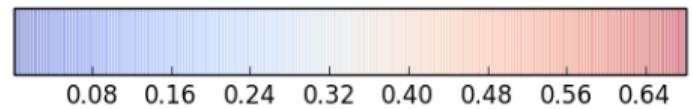
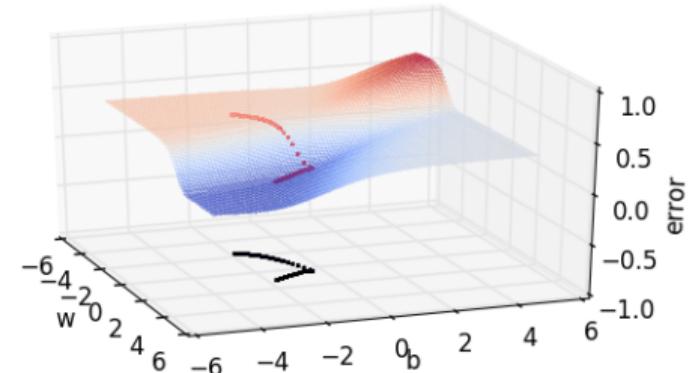
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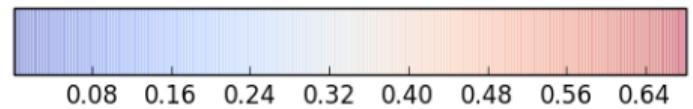
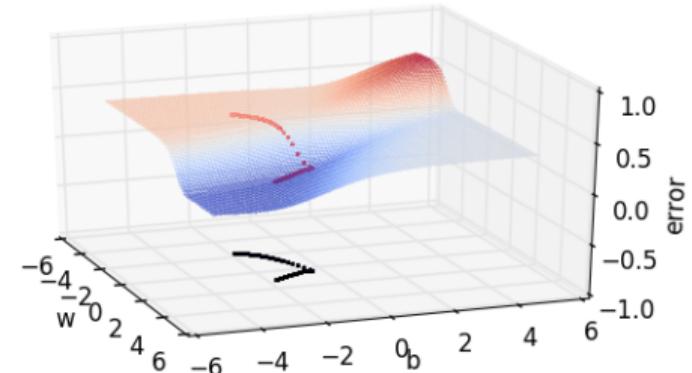
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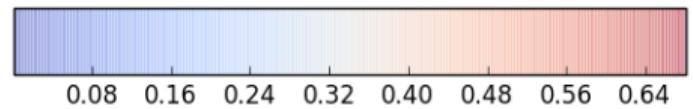
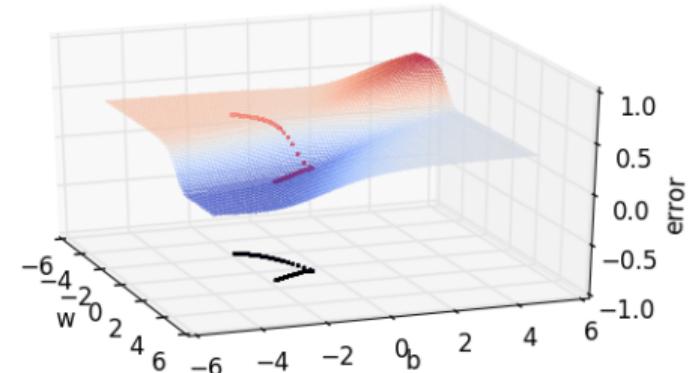
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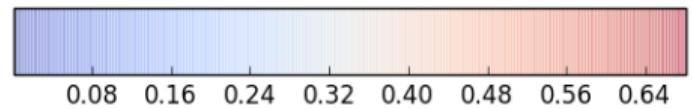
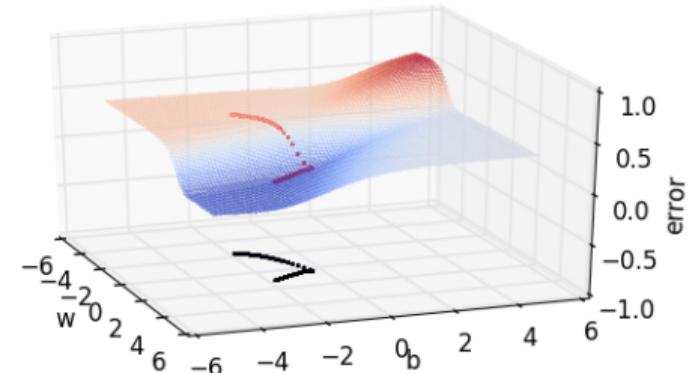
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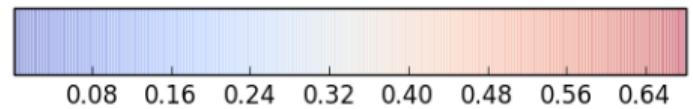
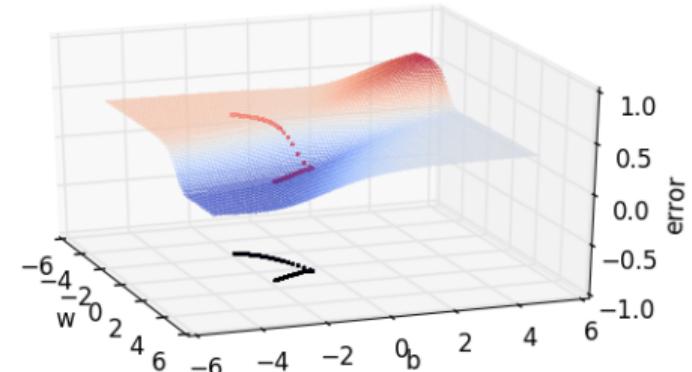
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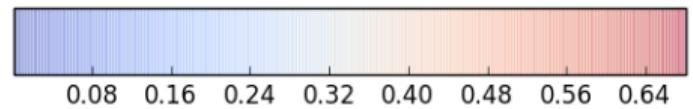
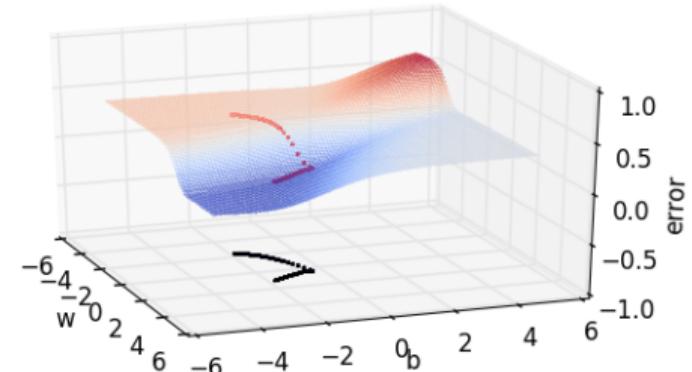
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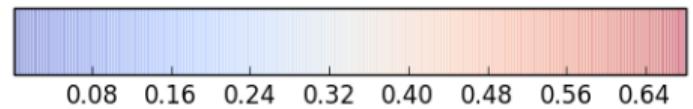
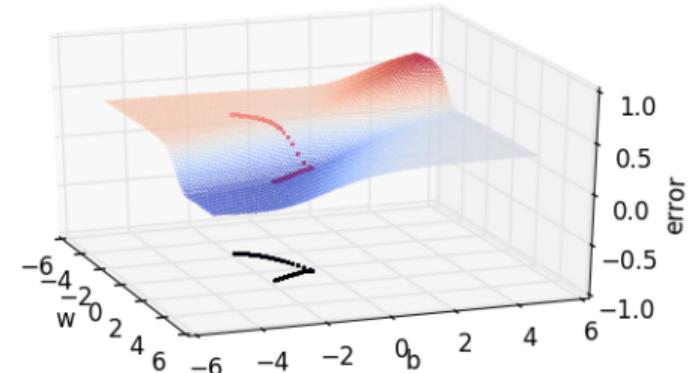
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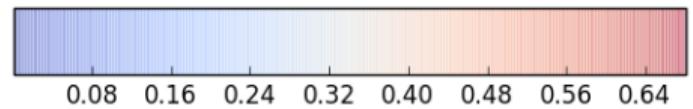
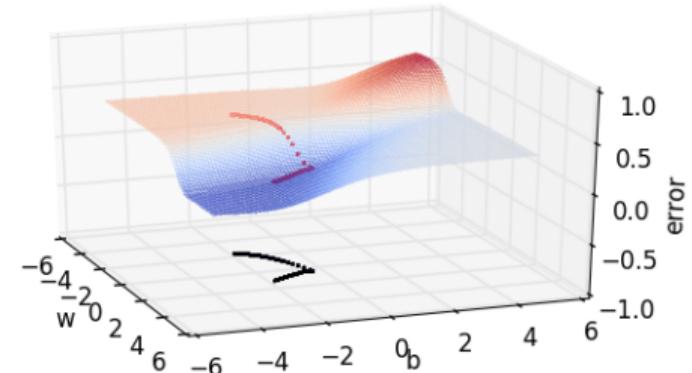
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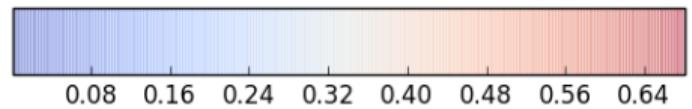
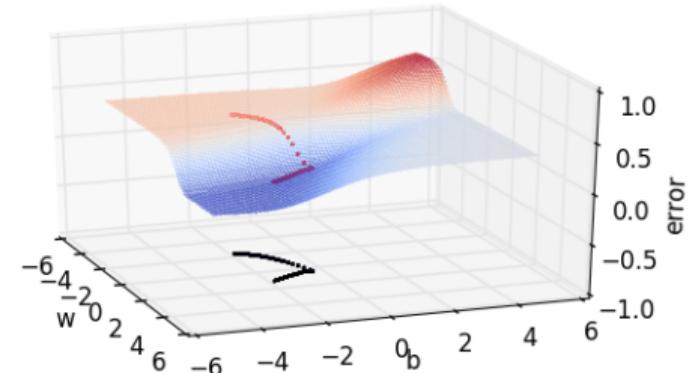
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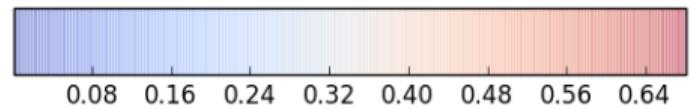
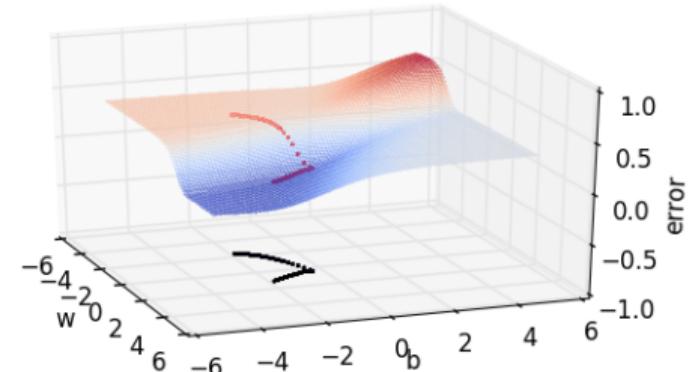
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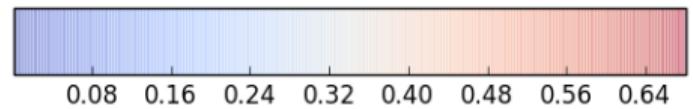
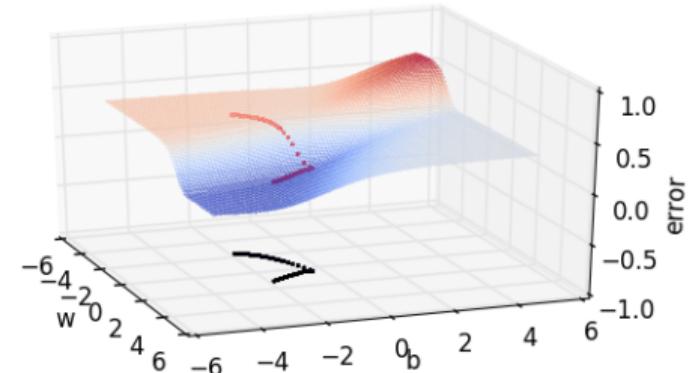
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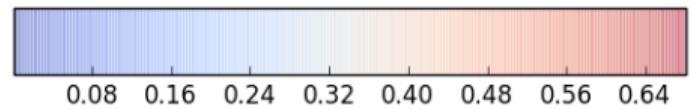
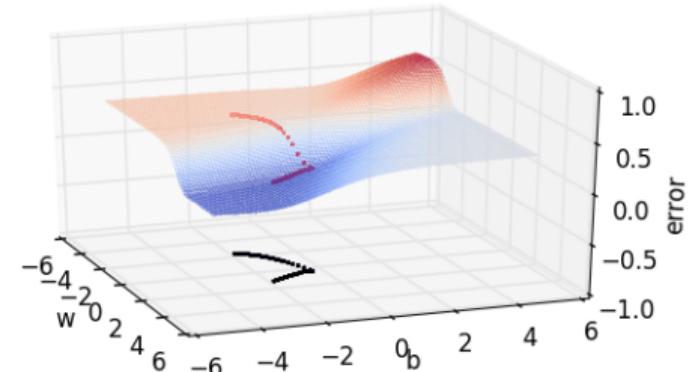
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def do_gradient_descent() :
    w, b, eta, max_epochs = -2, -2, 1.0, 1000
    for i in range(max_epochs) :
        dw, db = 0, 0
        for x,y in zip(X, Y) :
            dw += grad_w(w, b, x, y)
            db += grad_b(w, b, x, y)
        w = w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

```

Gradient descent on the error surface



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- So where do we head from here ?