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Neizrazito, evolucijsko i neuroračunarstvo

## PROJEKTNI ZADATAK 6

### ANFIS

## Zadatak 1

Izvodi postupka učenja neuronske mreže ANFIS.

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## Projektni zadatak 6 ANFIS

$$E_i = \frac{1}{2} (t_i - o_i)^2$$

$$o_i = \frac{\sum_{l=1}^N w_l f_l}{\sum_{l=1}^N w_l}$$

$$f_k = p_k x + q_k y + r$$

$$w_k = \mu_A(x_i) \cdot \mu_B(y_i)$$

$$\mu(x_i) = \frac{1}{1 + e^{b(x_i - a)}}$$

$$\mu(y_i) = \frac{1}{1 + e^{d(y_i - c)}}$$

Stohastički  
gradijentni spust

$$a_k(t+1) = a_k(t) - \eta \frac{\partial E_i}{\partial a_k(t)}$$

$$b_k(t+1) = b_k(t) - \eta \frac{\partial E_i}{\partial b_k(t)}$$

$$c_k(t+1) = c_k(t) - \eta \frac{\partial E_i}{\partial c_k(t)}$$

$$d_k(t+1) = d_k(t) - \eta \frac{\partial E_i}{\partial d_k(t)}$$

$$p_k(t+1) = p_k(t) - \eta \frac{\partial E_i}{\partial p_k(t)}$$

$$q_k(t+1) = q_k(t) - \eta \frac{\partial E_i}{\partial q_k(t)}$$

$$r_k(t+1) = r_k(t) - \eta \frac{\partial E_i}{\partial r_k(t)}$$

Gradijentni spust

$$a_k(t+1) = a_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial a_k(t)}$$

$$b_k(t+1) = b_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial b_k(t)}$$

$$c_k(t+1) = c_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial c_k(t)}$$

$$d_k(t+1) = d_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial d_k(t)}$$

$$p_k(t+1) = p_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial p_k(t)}$$

$$q_k(t+1) = q_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial q_k(t)}$$

$$r_k(t+1) = r_k(t) - \eta \sum_i^N \frac{\partial E_i}{\partial r_k(t)}$$

često korišteni gradijenti:

$$\frac{\partial E_i}{\partial o_i} = -(t_i - o_i) \quad \frac{\partial o_i}{\partial f_k} = \frac{w_k}{\sum_j w_j} \quad \frac{\partial o_i}{\partial w_k} = \frac{f_k \sum_j w_j - \sum_j w_j f_j}{(\sum_j w_j)^2}$$

$$\frac{\partial w_k}{\partial \mu(x_i)} = \mu_B(y_i) \quad \frac{\partial w_k}{\partial \mu(y_i)} = \mu_A(x_i)$$

Postupak za gradijent po "a" analogan je postupku gradijenta po "c"

Lanac utjecaja za a:

$$a_k \rightarrow \mu(x_i) \rightarrow w_k \rightarrow o_i \rightarrow E_i$$

$$\Rightarrow \frac{\partial E_i}{\partial a_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial w_k} \frac{\partial w_k}{\partial \mu(x_i)}}_{\text{često korišteni gradijenti}} \frac{\partial \mu(x_i)}{\partial a_k}$$

$$\frac{\partial \mu(x_i)}{\partial a_k} = \frac{e^{b_k(x-a_k)}}{b_k(1+e^{b_k(x-a_k)})^2} = b_k \mu_A(x_i)(1-\mu_A(x_i))$$

Lanac utjecaja za b:

$$b_k \rightarrow \mu(x_i) \rightarrow w_k \rightarrow o_i \rightarrow E_i$$

$$\Rightarrow \frac{\partial E_i}{\partial b_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial w_k} \frac{\partial w_k}{\partial \mu(x_i)}}_{\text{često korišteni gradijenti}} \frac{\partial \mu(x_i)}{\partial b_k}$$

$$\frac{\partial \mu(x_i)}{\partial b_k} = \frac{(x-a_k) e^{b_k(x-a_k)}}{(1+e^{b_k(x-a_k)})^2} =$$

$$= (a-x) \mu_A(x_i)(1-\mu_A(x_i))$$



Lanac utjecaja za  $c$ :

$$c_k \rightarrow p(y_i) \rightarrow w_k \rightarrow o_i \rightarrow E_i$$

$$\Rightarrow \frac{\partial E_i}{\partial c_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial w_k} \frac{\partial w_k}{\partial p(y_i)}}_{\text{često korišteni gradijenti}} \frac{\partial p(y_i)}{\partial c_k}$$

$$d_k p_B(y_i) (1 - p_B(y_i))$$

Lanac utjecaja za  $d$ :

$$d_k \rightarrow p(y_i) \rightarrow w_k \rightarrow o_i \rightarrow E_i$$

$$\frac{\partial E_i}{\partial d_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial w_k} \frac{\partial w_k}{\partial p(y_i)}}_{\text{često korišteni gradijenti}} \frac{\partial p(y_i)}{\partial d_k}$$

$$(c - y) p_B(y_i) (1 - p_B(y_i))$$

Lanac utjecaja za  $p$ :

$$p_k \rightarrow f_k \rightarrow o_i \rightarrow E_i$$

$$\frac{\partial E_i}{\partial p_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial f_k} \frac{\partial f_k}{\partial p_k}}_{\text{često korišteni gradijenti}}$$

često korišteni gradijenti

Lanac utjecaja za  $q$ :

$$q_k \rightarrow f_k \rightarrow o_i \rightarrow E_i$$

$$\frac{\partial E_i}{\partial q_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial f_k} \frac{\partial f_k}{\partial q_k}}_{\text{često korišteni gradijenti}}$$

često korišteni gradijenti

Lanac utjecaja za  $r$ :

$$r_k \rightarrow f_k \rightarrow o_i \rightarrow E_i$$

$$\frac{\partial E_i}{\partial r_k} = \underbrace{\frac{\partial E_i}{\partial o_i} \frac{\partial o_i}{\partial f_k} \frac{\partial f_k}{\partial r_k}}_{\text{često korišteni gradijenti}}$$

često korišteni gradijenti

Cijeli izraz za gradijent:

→ izraz koji se ponavlja

$$* \equiv (t_i - o_i) \frac{f_k \sum_j w_j - \sum_j w_j f_j}{(\sum_j w_j)^2}$$

$$*_A \equiv * \cdot \mu_B(y_i)$$

$$*_B \equiv * \cdot \mu_A(x_i)$$

$$a_k(t+1) = a_k(t) + \eta \cdot *_A \cdot b_k \mu_A(x_i) (1 - \mu_A(x_i))$$

$$b_k(t+1) = b_k(t) + \eta \cdot *_A \cdot (a_k - x_i) \mu_A(x_i) (1 - \mu_A(x_i))$$

$$c_k(t+1) = c_k(t) + \eta \cdot *_B \cdot d_k \mu_B(y_i) (1 - \mu_B(y_i))$$

$$d_k(t+1) = d_k(t) + \eta \cdot *_B \cdot (c_k - y_i) \mu_B(y_i) (1 - \mu_B(y_i))$$

$$\sigma \equiv (t_i - o_i) \cdot \frac{w_k}{\sum_j w_j}$$

$$p_k(t+1) = p_k(t) + \eta \cdot \sigma \cdot x_i$$

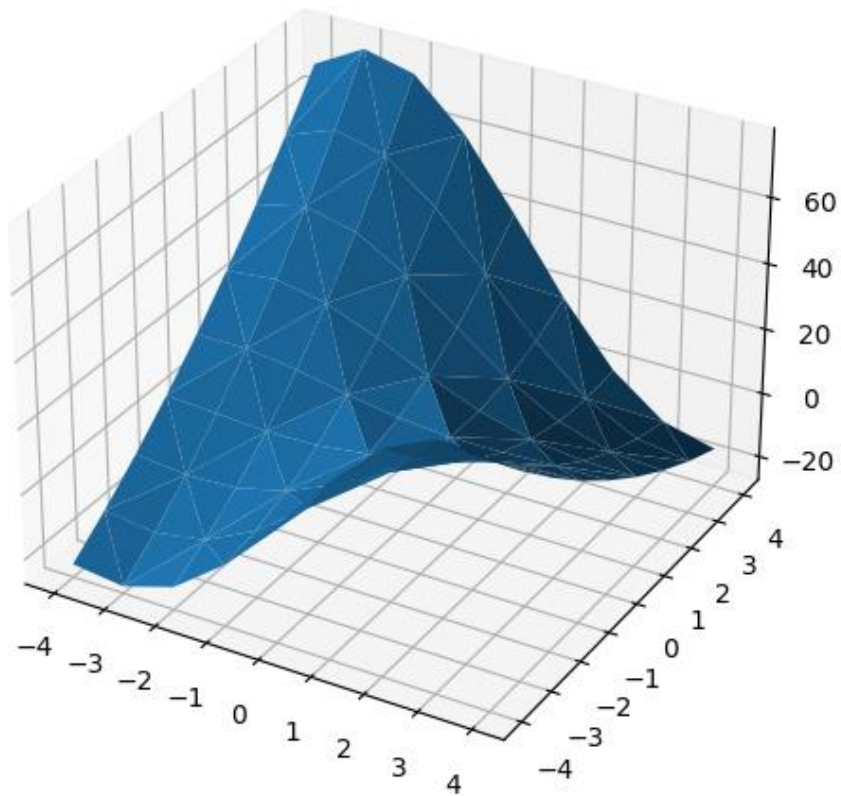
$$q_k(t+1) = q_k(t) + \eta \cdot \sigma \cdot y_i$$

$$r_k(t+1) = r_k(t) + \eta \cdot \sigma$$



Zadatak 3:

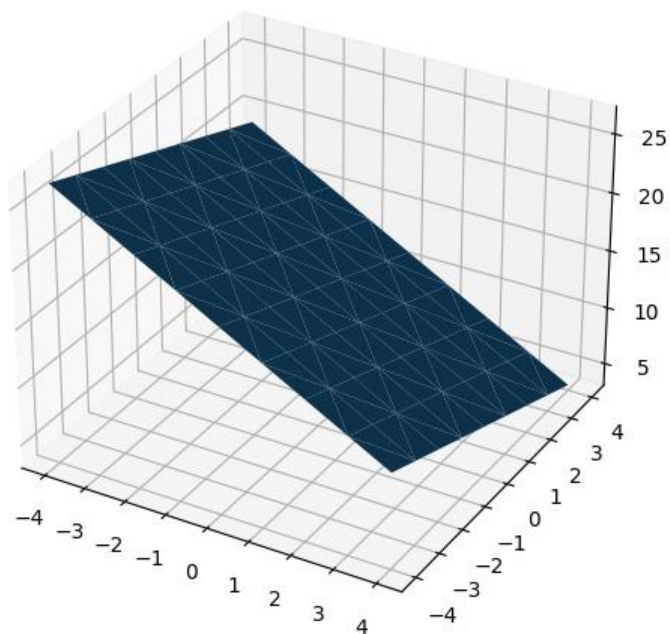
Graf koji prikazuje kako izgleda zadana funkcija nad zadanom domenom.



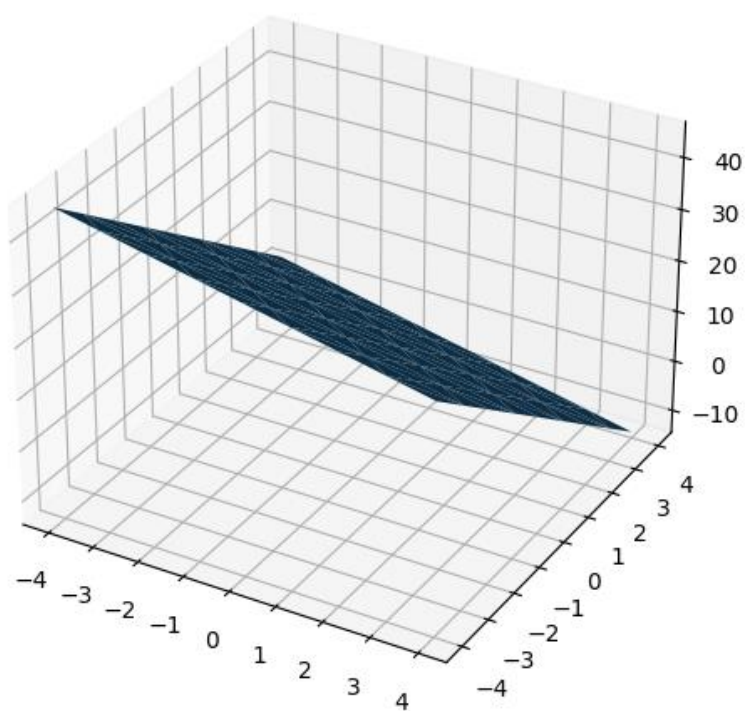
Zadatok 4:

Jedno pravilo

SGD

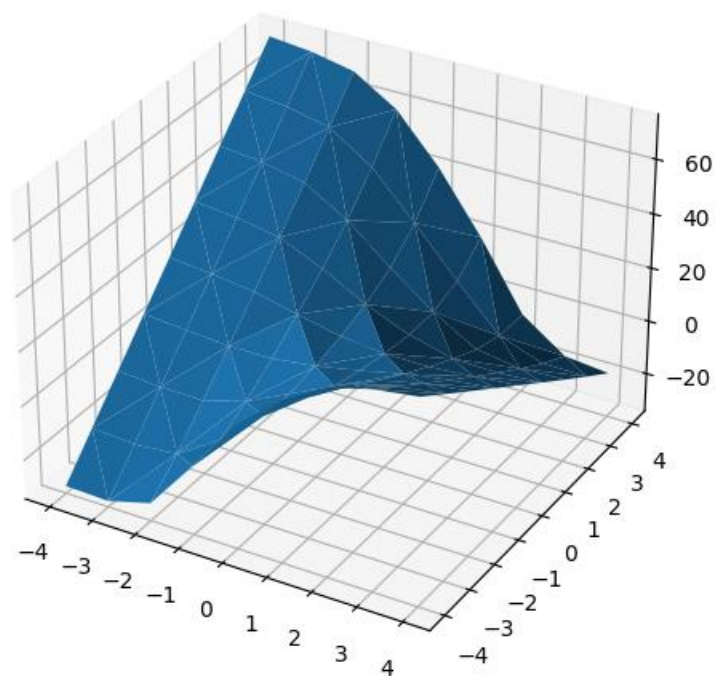


BGD

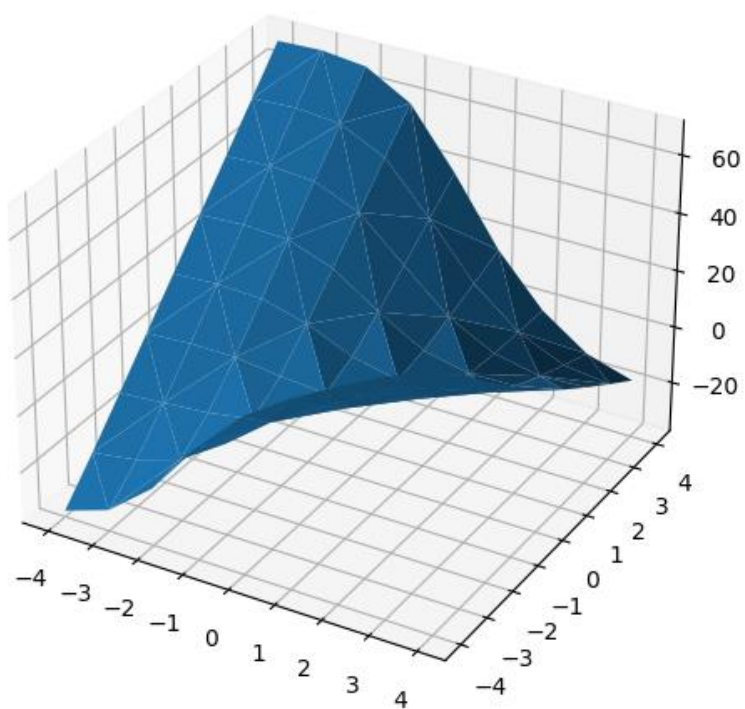


Dva pravila

SGD



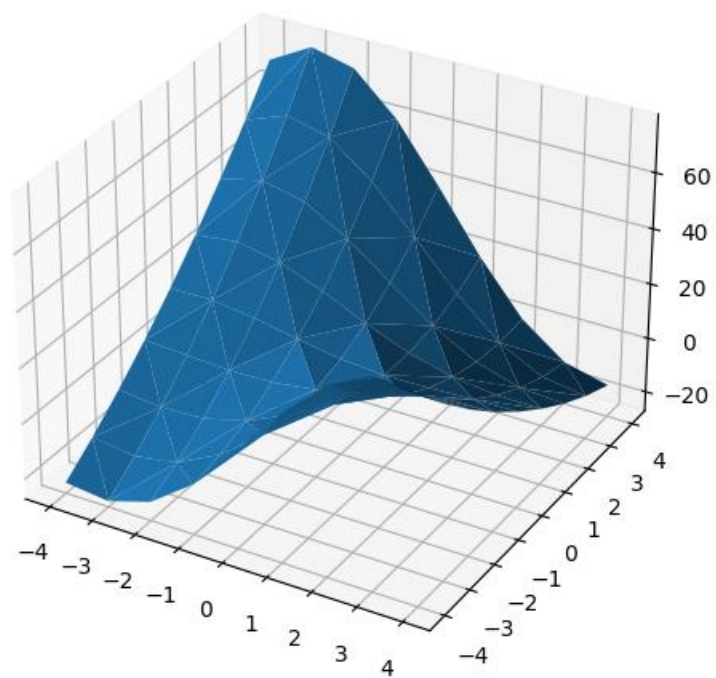
BGD



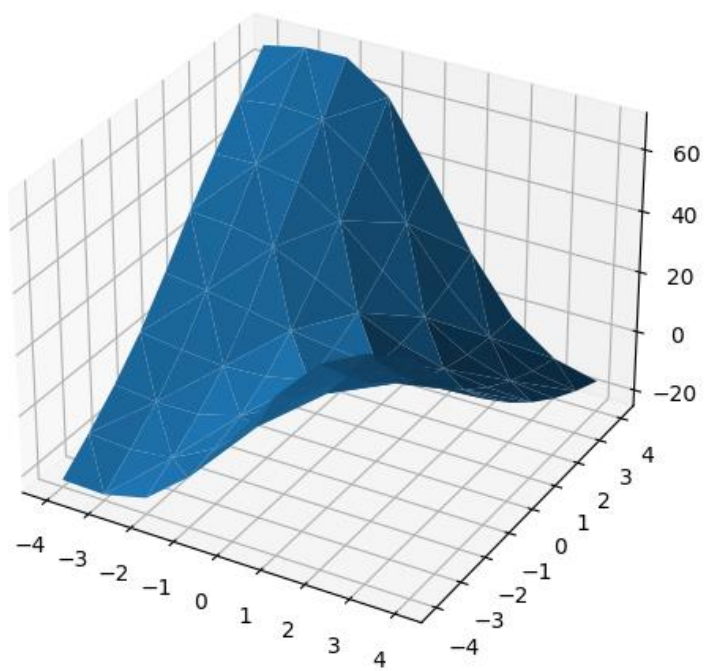


Optimalni broj pravila

SGD



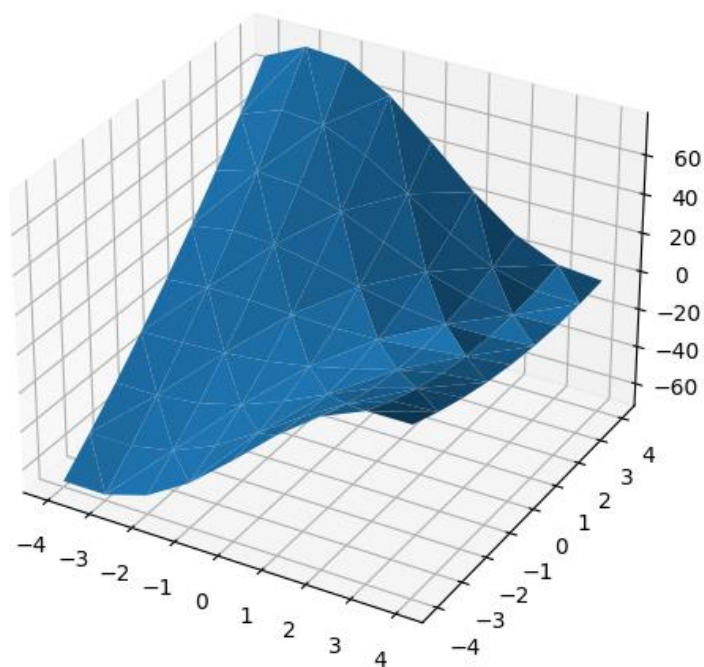
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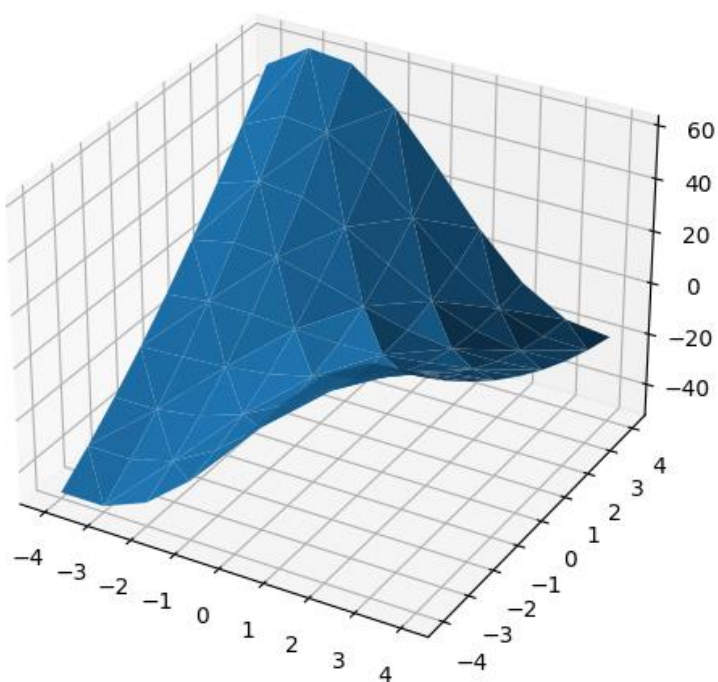
Graf odstupanja naučene funkcije (prava vrijednost – naučena vrijednost)

Jedno pravilo

SGD



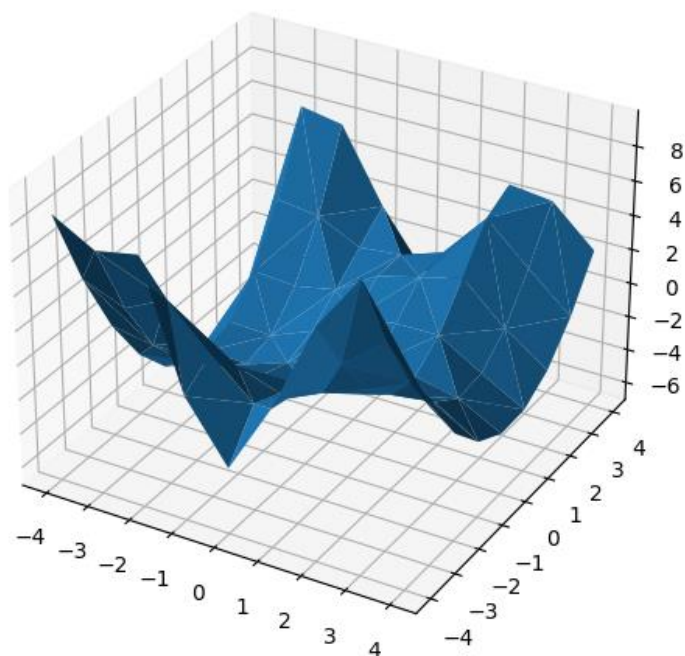
BGD



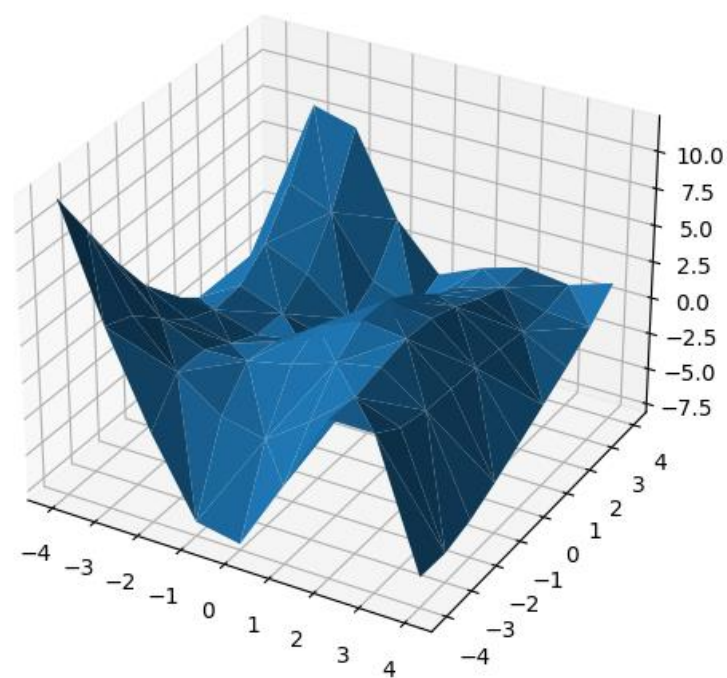
Graf odstupanja naučene funkcije (prava vrijednost – naučena vrijednost)

Dva pravila

SGD



BGD

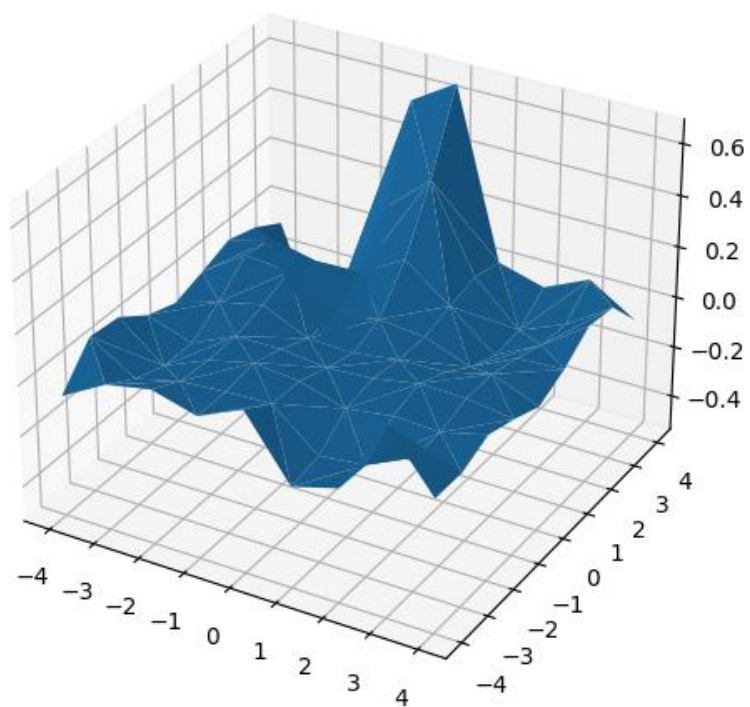




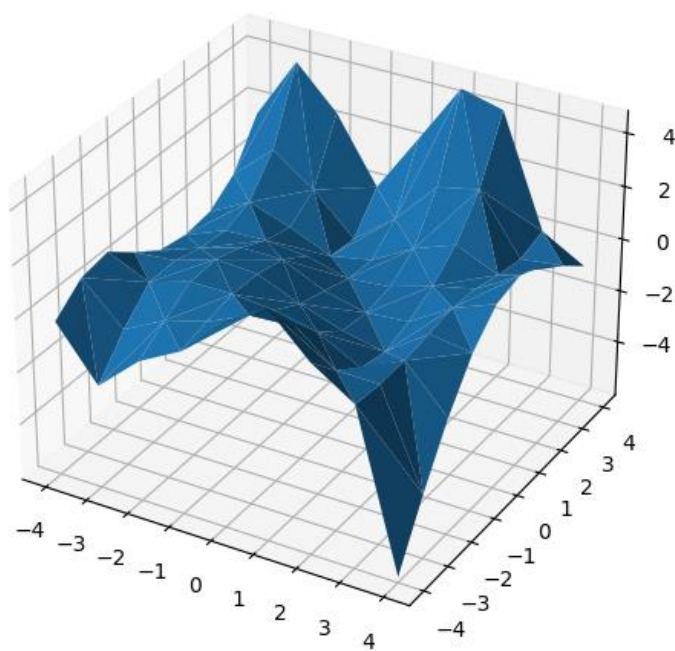
Graf odstupanja naučene funkcije (prava vrijednost – naučena vrijednost)

Optimalni broj pravila

SGD



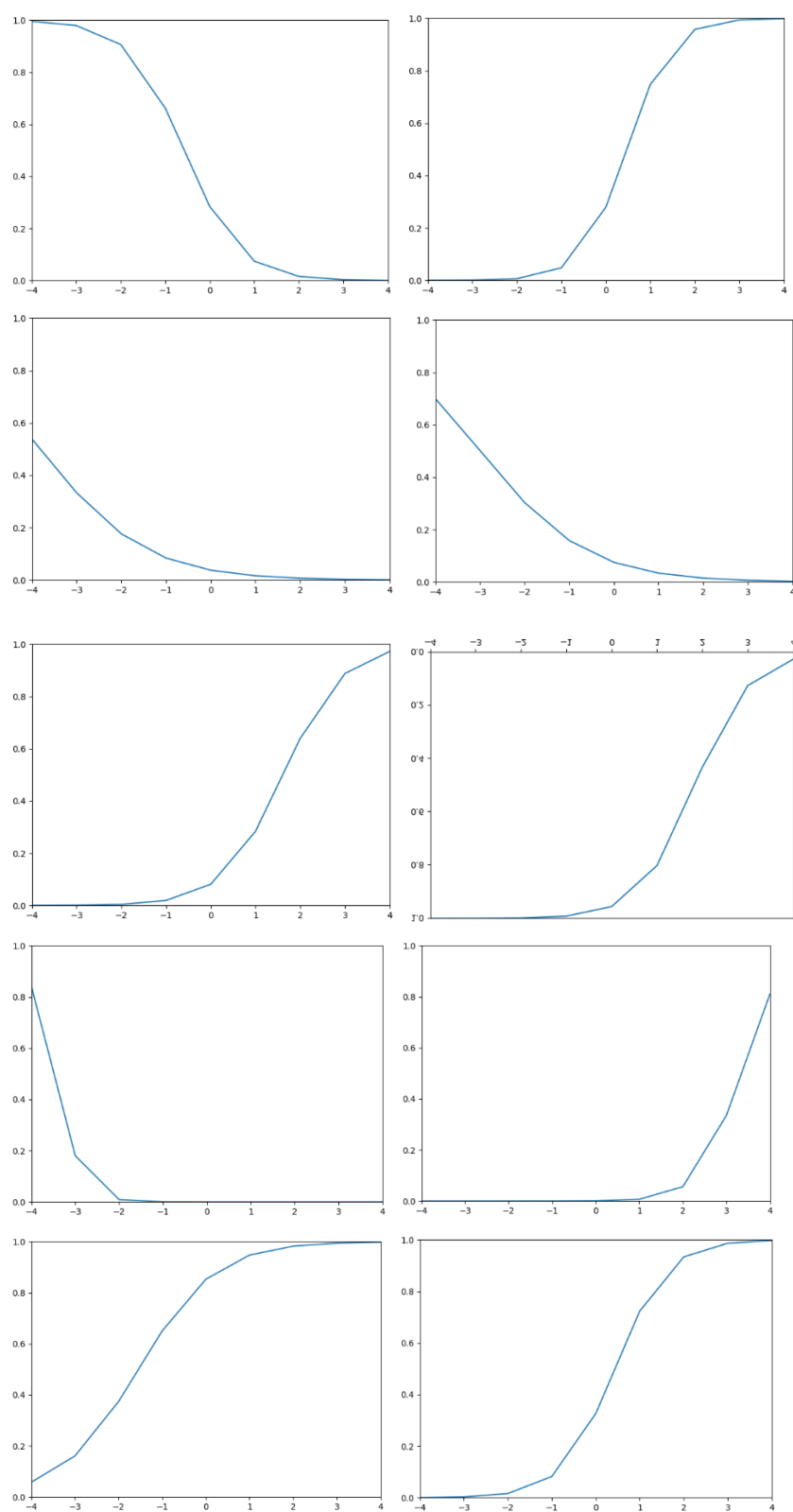
BGD



## Zadatak 5

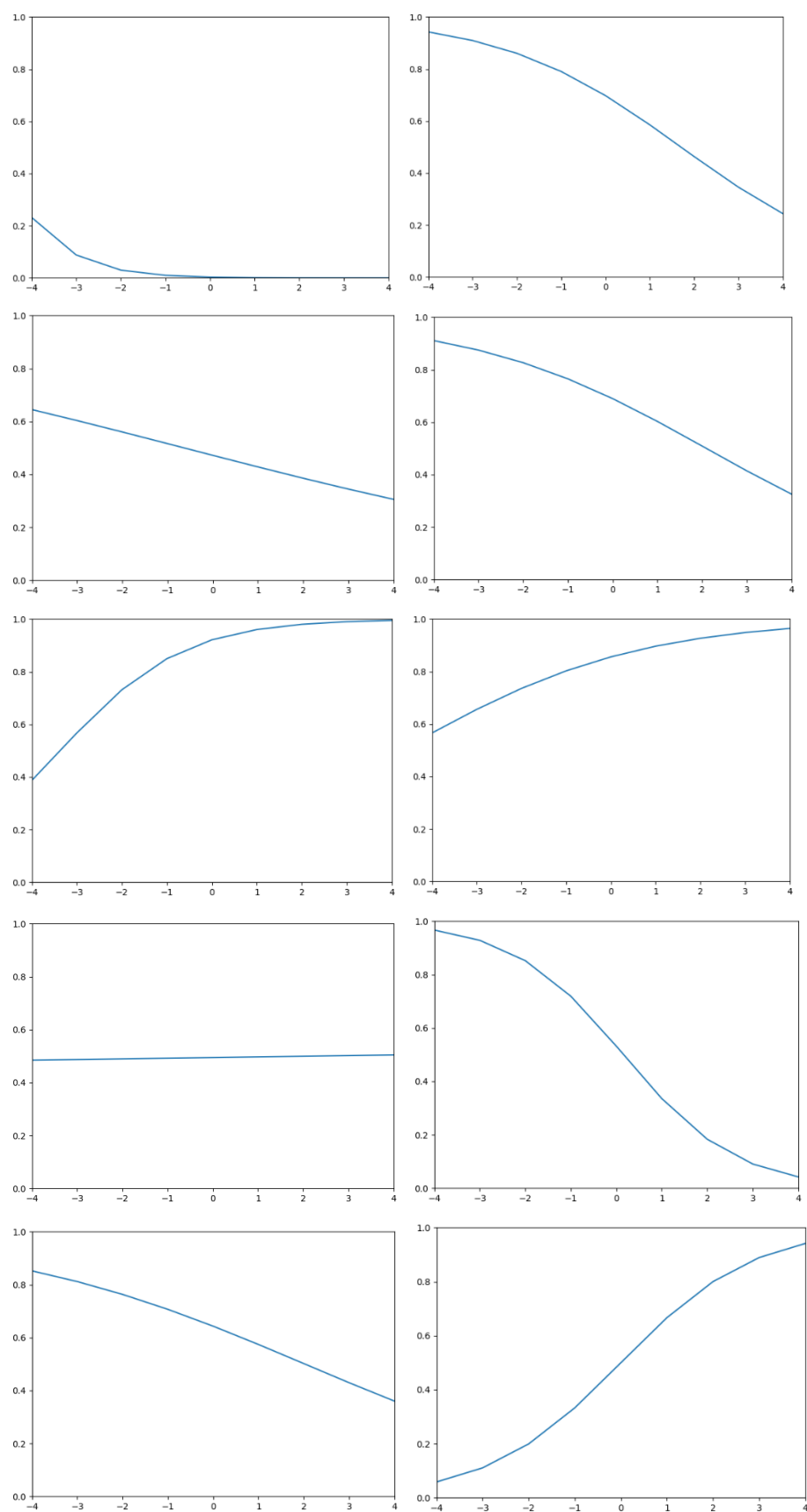
### Optimalni broj pravila

### Grafovi mjera pripadnosti za čvor A



## Optimalni broj pravila

### Grafovi mjera pripadnosti za čvor B

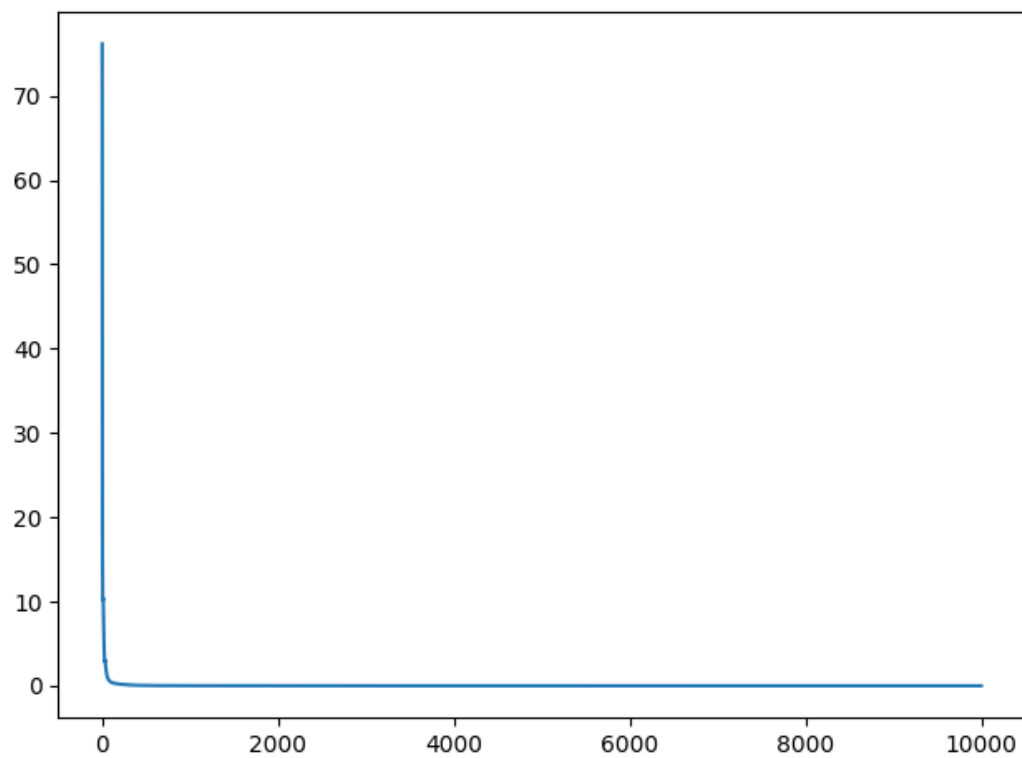




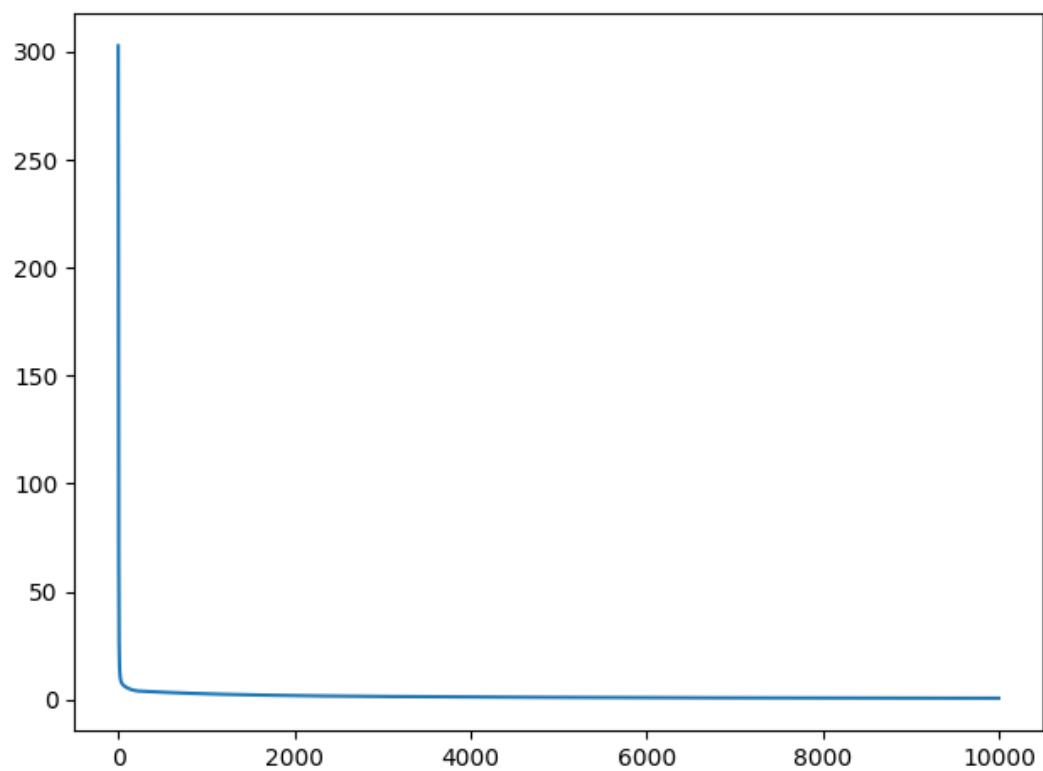
### Zadatak 7

Graf kretanja pogreške ovisno o broju epohe

SGD



BGD

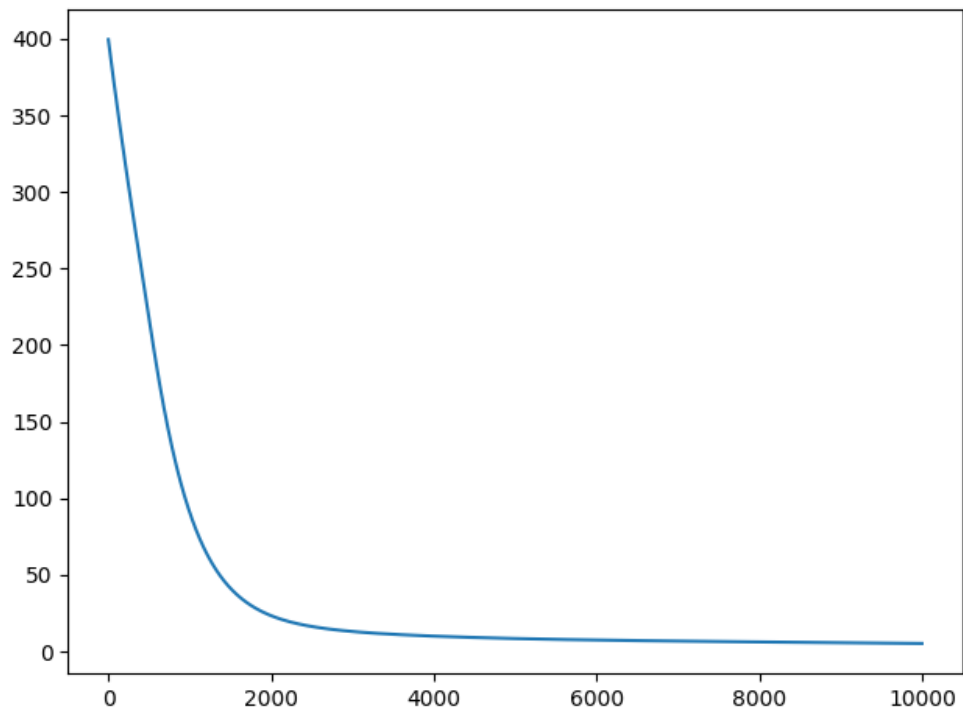


## Zadatak 8

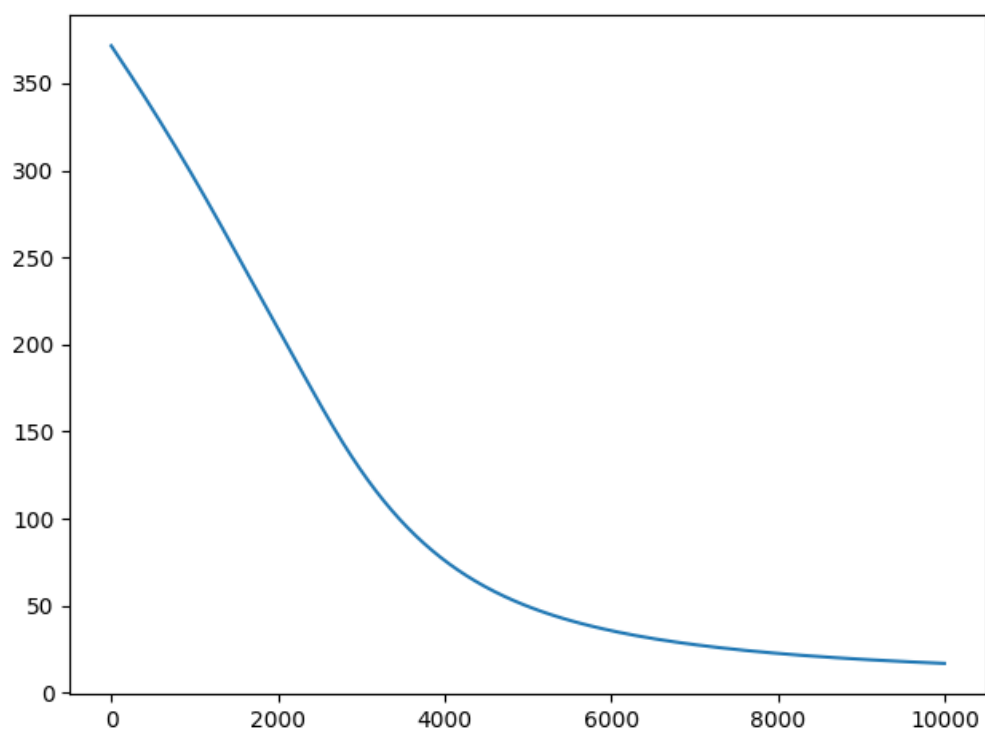
Grafovi za različite vrijednosti stope učenje eta.

Eta – vrlo mala

SGD

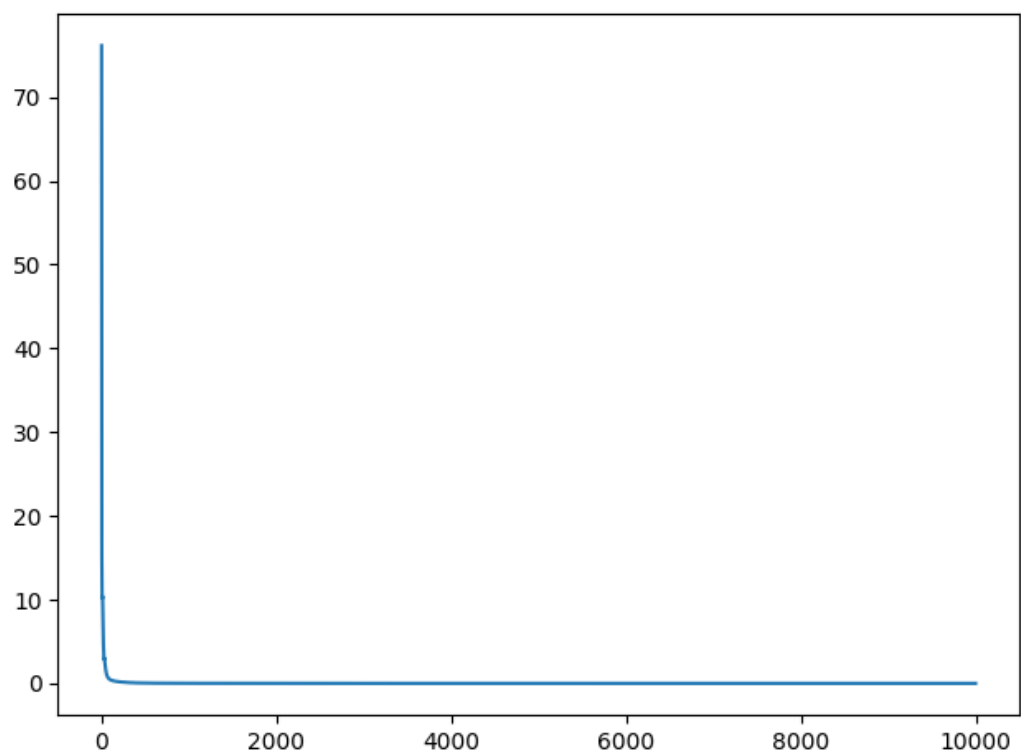


BGD

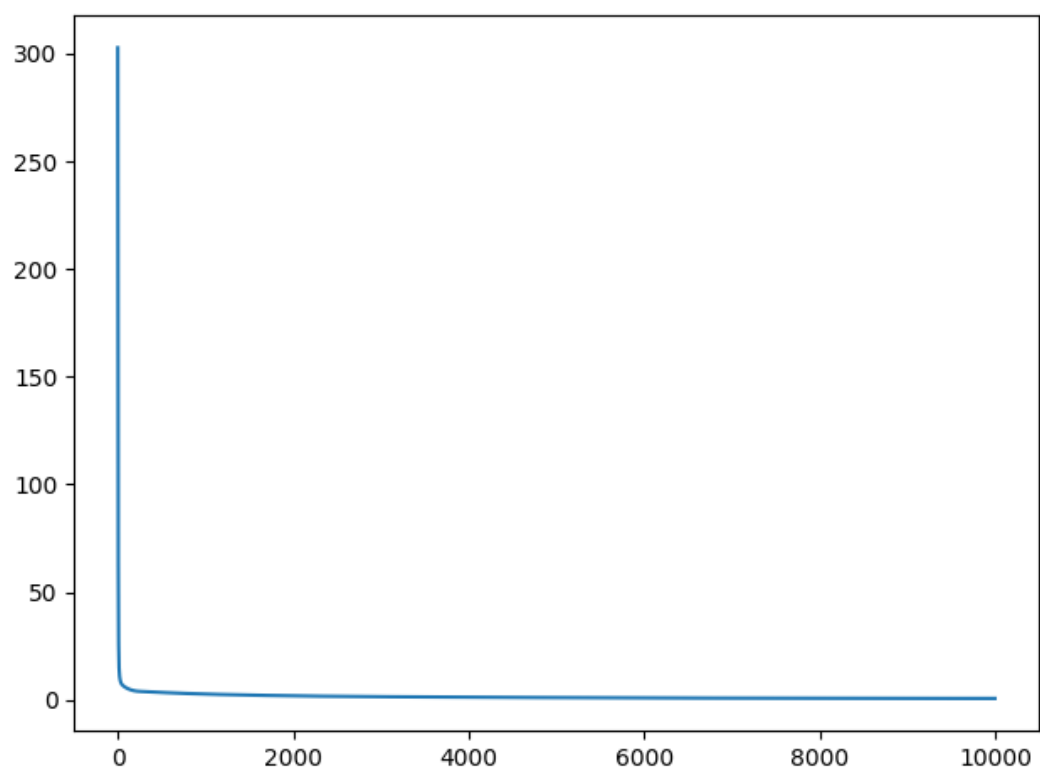


Eta – baš prikladna

SGD



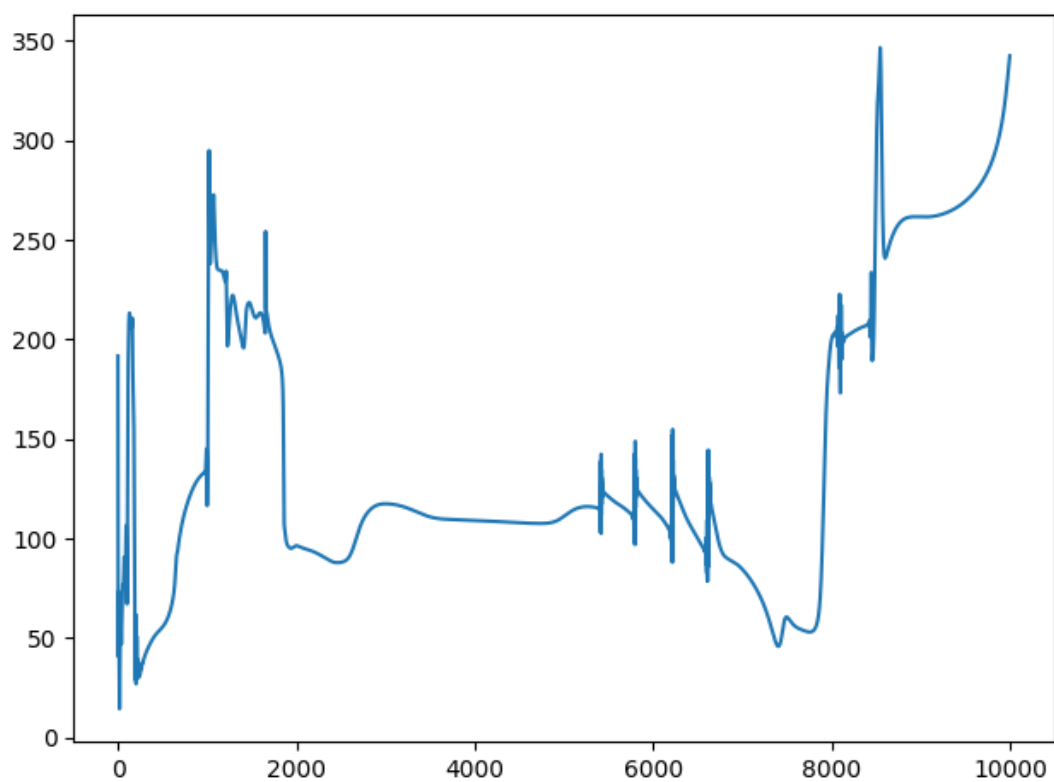
BGD





Eta – vrlo velik (možda i odviše velik)

SGD



BGD

