

9주차(3/3)

XOR 신경망 구현

파이썬으로 배우는 기계학습

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김영섭 교수

XOR 신경망

- 학습 목표
 - 다층 신경망을 경사하강법과 역전파 알고리즘으로 구현한다.
 - **XOR**로 신경망을 학습하고 테스트한다.
- 학습 내용
 - 객체지향 다층 신경망 구현
 - **fit()** 메소드
 - **net_input()** 메소드
 - **predict()** 메소드
 - **XOR** 신경망 학습

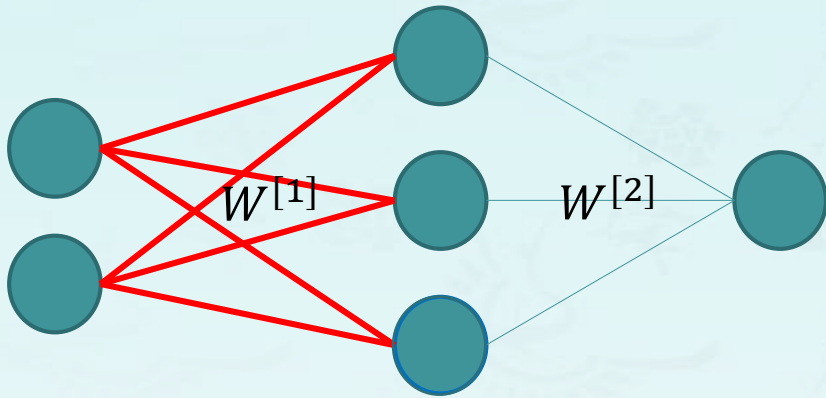
1. 지난 시간 복습

■ 클래스

- 이름: **NeuralNetwork**
- 생성자: **__init__()**
- 활성화 함수: **g()**
- 활성화 함수 미분 : **g_prime()**

```
1 class NeuralNetwork():
2     """ This class implements a multi-perceptron
3         with backpropagation. This handles a simple logics
4         such as OR, AND, NAND, and NOR gates, including XOR.
5     """
6     def __init__(self, net_arch, eta=0.1, epochs=10000,
7                 random_seed=1):
8         self.layers = len(net_arch)
9         self.net_arch = net_arch
10        self.eta = eta
11        self.epochs = epochs
12        self.random_seed = random_seed
13
14    def g(self, x):
15        return 1/(1 + np.exp((-x)))
16
17    def g_prime(self, x):
18        return self.g(x) * (1 - self.g(x))
19
20    def fit(self, X, Y):
```

2. fit() 메소드: 가중치 W_{ij}^T

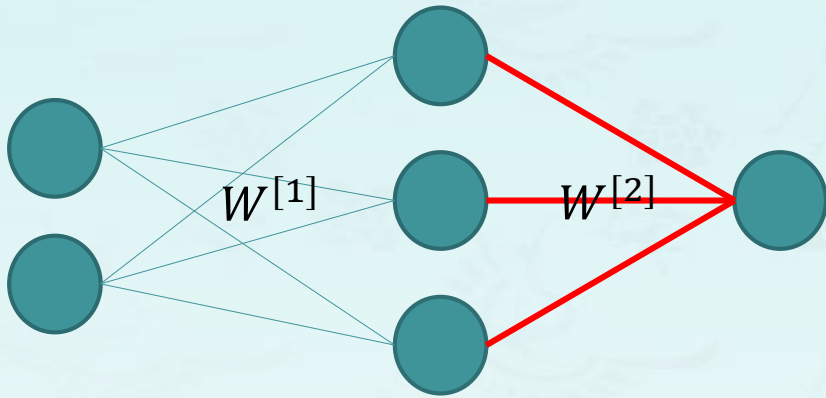


```
self.net_arch = [2, 3, 1]
```

```
W1_shape = (self.net_arch[1], self.net_arch[0])  
W2_shape = (self.net_arch[2], self.net_arch[1])  
self.W1 = 2*np.random.random(W1_shape) - 1  
self.W2 = 2*np.random.random(W2_shape) - 1
```

```
1 def fit(self, X, Y):  
2     np.random.seed(self.random_seed)  
3     W1_shape = (self.net_arch[1], self.net_arch[0])  
4     W2_shape = (self.net_arch[2], self.net_arch[1])  
5     self.W1 = 2*np.random.random(W1_shape) - 1  
6     self.W2 = 2*np.random.random(W2_shape) - 1  
7  
8     self.cost_ = []  
9  
10    for _ in range(self.epochs):  
11        A0 = X  
12        Z1 = np.dot(self.W1, A0)  
13        A1 = self.g(Z1)  
14        Z2 = np.dot(self.W2, A1)  
15        A2 = self.g(Z2)  
16  
17        E2 = Y - A2  
18        E1 = np.dot(self.W2.T, E2)  
19  
20        dZ2 = E2 * self.g_prime(Z2)  
21        dZ1 = E1 * self.g_prime(Z1)  
22  
23        self.W2 += np.dot(dZ2, A1.T)  
24        self.W1 += np.dot(dZ1, A0.T)  
25        self.cost_.append(np.sqrt(np.sum(E2 * E2)))  
26    return self
```

2. fit() 메소드: 가중치 W_{ij}^T

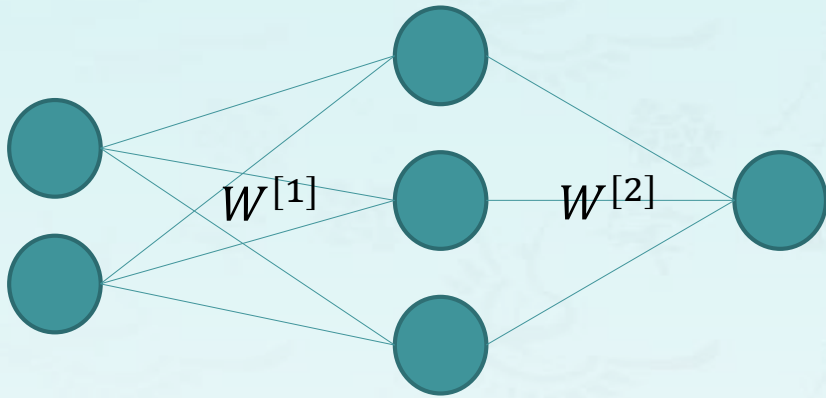


```
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```
W1_shape = (self.net_arch[1], self.net_arch[0])  
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```

```
1 def fit(self, X, Y):  
2     np.random.seed(self.random_seed)  
3     W1_shape = (self.net_arch[1], self.net_arch[0])  
4     W2_shape = (self.net_arch[2], self.net_arch[1])  
5     self.W1 = 2*np.random.random(W1_shape) - 1  
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8     self.cost_ = []  
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10    for _ in range(self.epochs):  
11        A0 = X  
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17        E2 = Y - A2  
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20        dZ2 = E2 * self.g_prime(Z2)  
21        dZ1 = E1 * self.g_prime(Z1)  
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23        self.W2 += np.dot(dZ2, A1.T)  
24        self.W1 += np.dot(dZ1, A0.T)  
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3. 오차 구하기

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1 def fit(self, X, Y):
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3. 오차 구하기 : 순전파

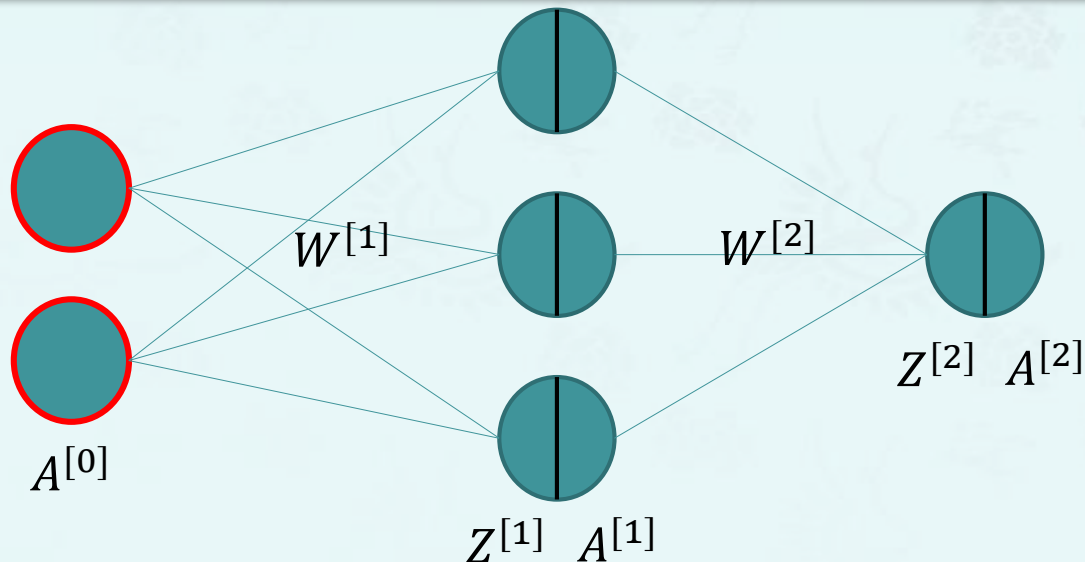
```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
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5     self.W1 = 2*np.random.random(W1_shape) - 1
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```


3. 오차 구하기 : 순전파

- 입력층 → 은닉층

A0 = X

```
Z1 = np.dot(self.W1, A0)
A1 = self.g(Z1)
Z2 = np.dot(self.W2, A1)
A2 = self.g(Z2)
```

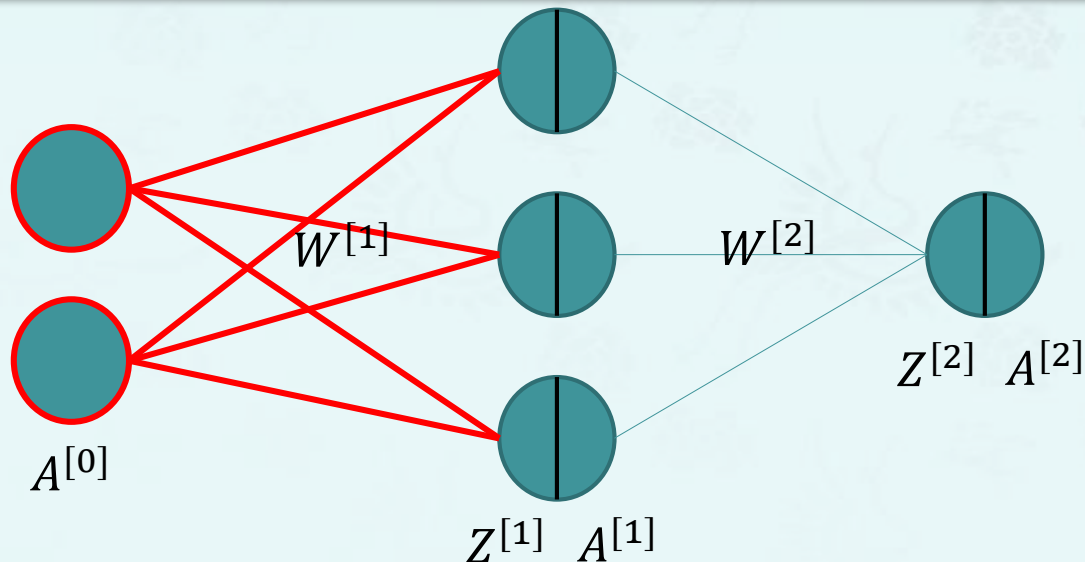


```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
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```

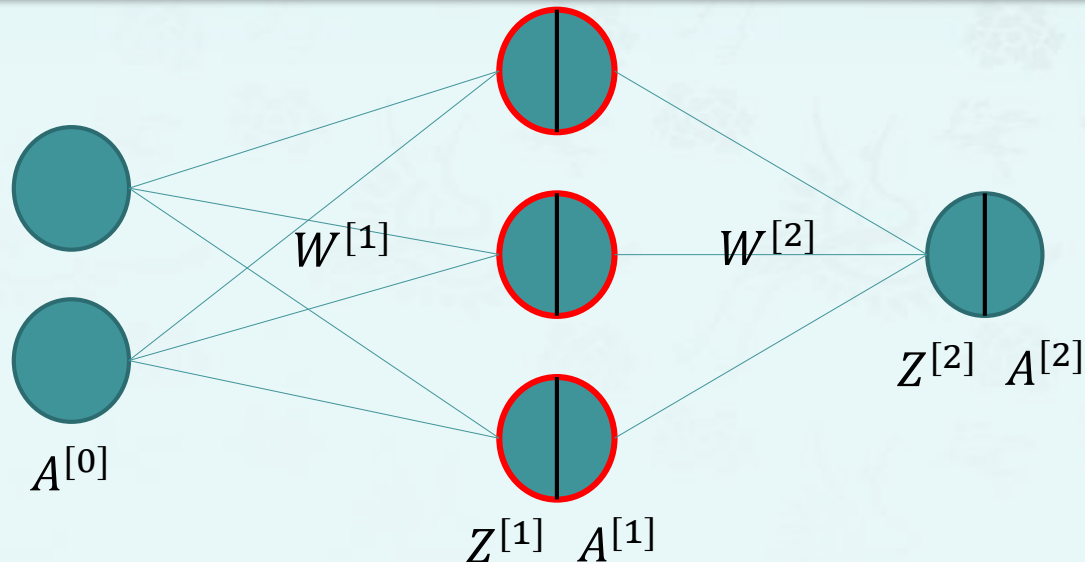


```
1 def fit(self, X, Y):  
2     np.random.seed(self.random_seed)  
3     W1_shape = (self.net_arch[1], self.net_arch[0])  
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5     self.W1 = 2*np.random.random(W1_shape) - 1  
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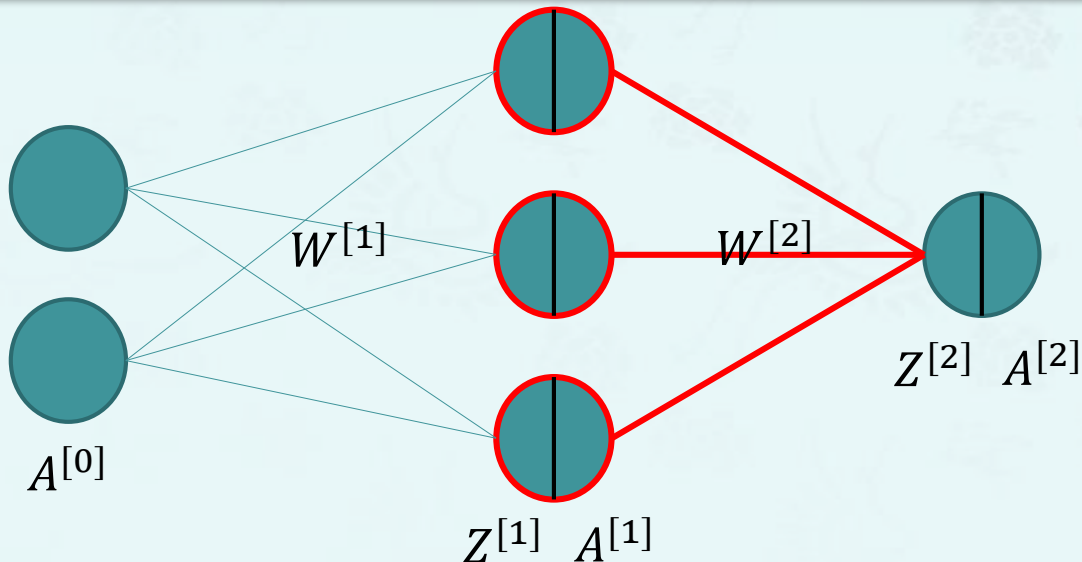


```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
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```

3. 오차 구하기 : 순전파

- 은닉층 → 출력층

```
A0 = X
Z1 = np.dot(self.W1, A0)
A1 = self.g(Z1)
Z2 = np.dot(self.W2, A1)
A2 = self.g(Z2)
```

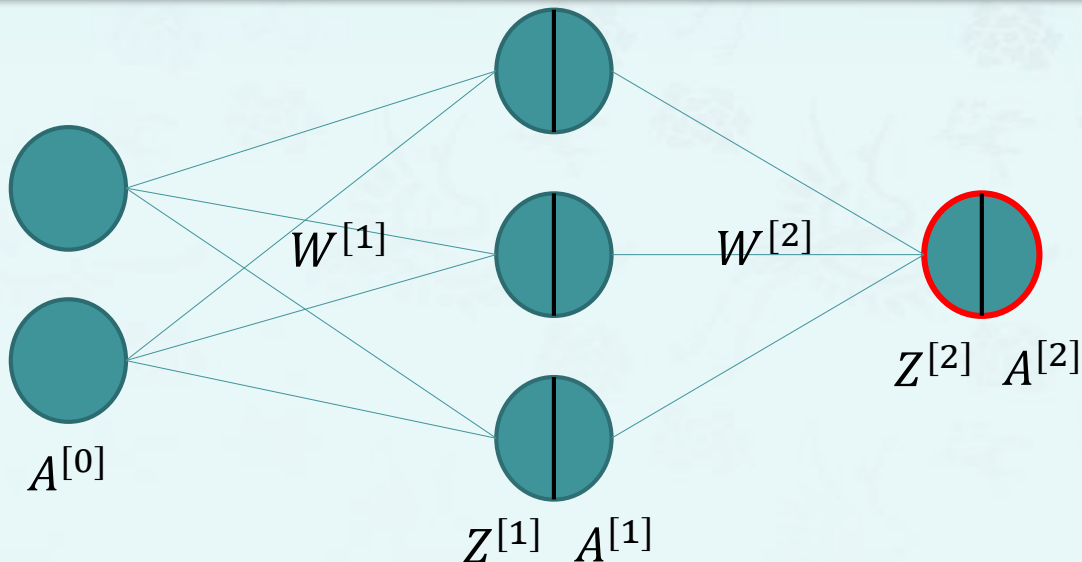


```
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3     W1_shape = (self.net_arch[1], self.net_arch[0])
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20        dZ2 = E2 * self.g_prime(Z2)
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23        self.W2 += np.dot(dZ2, A1.T)
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```

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```
A0 = X
Z1 = np.dot(self.W1, A0)
A1 = self.g(Z1)
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A2 = self.g(Z2)
```



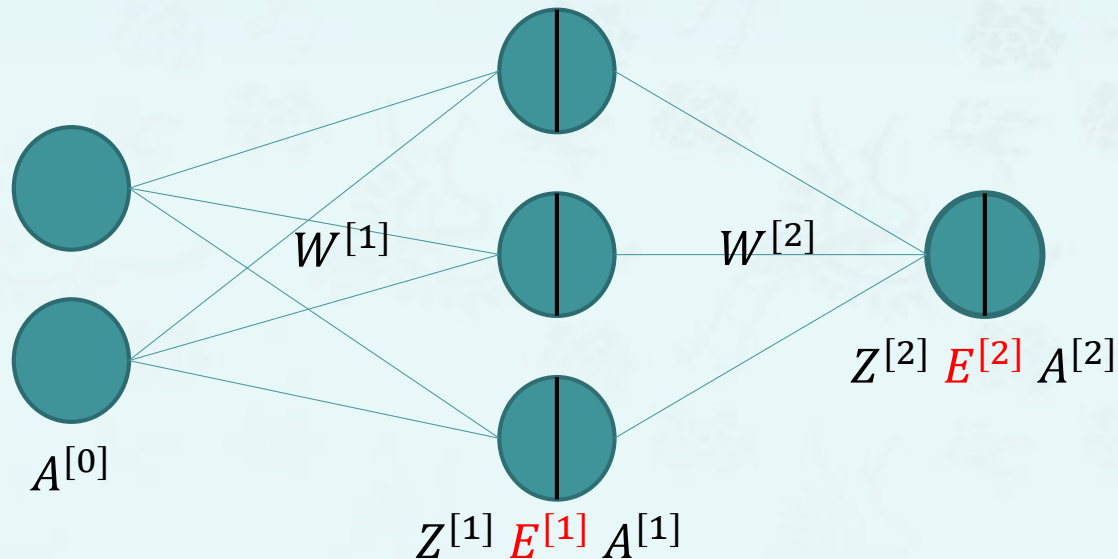
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23        self.W2 += np.dot(dz2, A1.T)
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25        self.cost_.append(np.sqrt(np.sum(E2 * E2)))
26    return self
```


3. 오차 구하기 : 역전파

- 오차 계산

$$E^{[2]} = Y - A^{[2]}$$

$$E^{[1]} = W^{[2] \cdot T} \cdot E^{[2]}$$



```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
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5     self.W1 = 2*np.random.random(W1_shape) - 1
6     self.W2 = 2*np.random.random(W2_shape) - 1
7
8     self.cost_ = []
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23        self.W2 += np.dot(dz2, A1.T)
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25        self.cost_.append(np.sqrt(np.sum(E2 * E2)))
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```


4. 가중치 조정

$$\Delta W^{[2]} = \frac{\partial E}{\partial W^{[2]}} = \boxed{-E^{[2]} \cdot g'(Z^{[2]})} \cdot A^{[1]T}$$

$dZ2$
↓

$$\Delta W^{[1]} = \frac{\partial E}{\partial W^{[1]}} = \boxed{-E^{[1]} \cdot g'(Z^{[1]})} \cdot A^{[0]T}$$

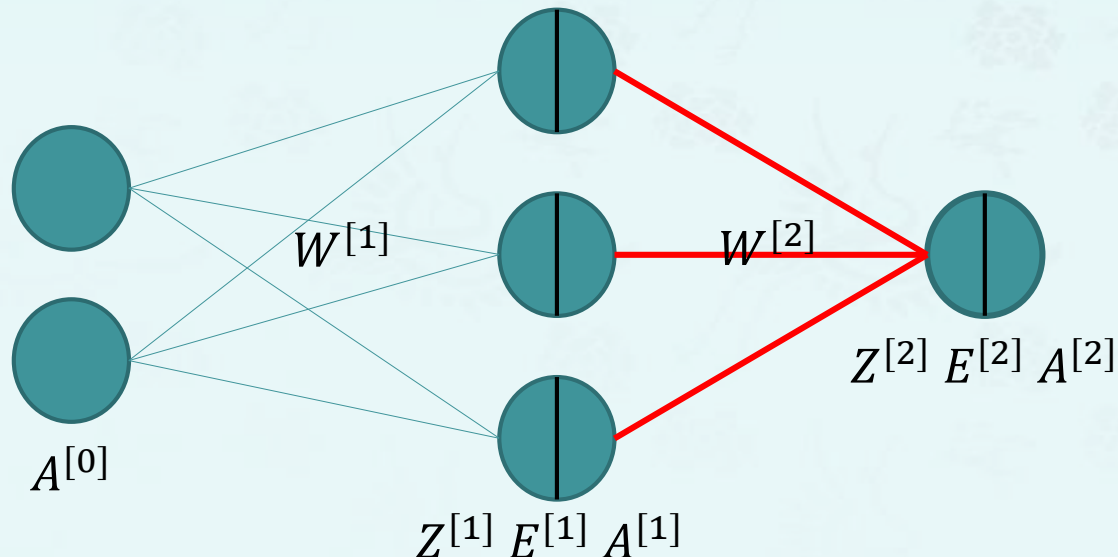
$dZ1$
↖

```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
4     W2_shape = (self.net_arch[2], self.net_arch[1])
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$$\rightarrow \Delta W^{[2]} = \frac{\partial E}{\partial W^{[2]}} = \boxed{-E^{[2]} \cdot g'(Z^{[2]})} \cdot A^{[1]T}$$

$$\Delta W^{[1]} = \frac{\partial E}{\partial W^{[1]}} = -E^{[1]} \cdot g'(Z^{[1]}) \cdot A^{[0]T}$$



```

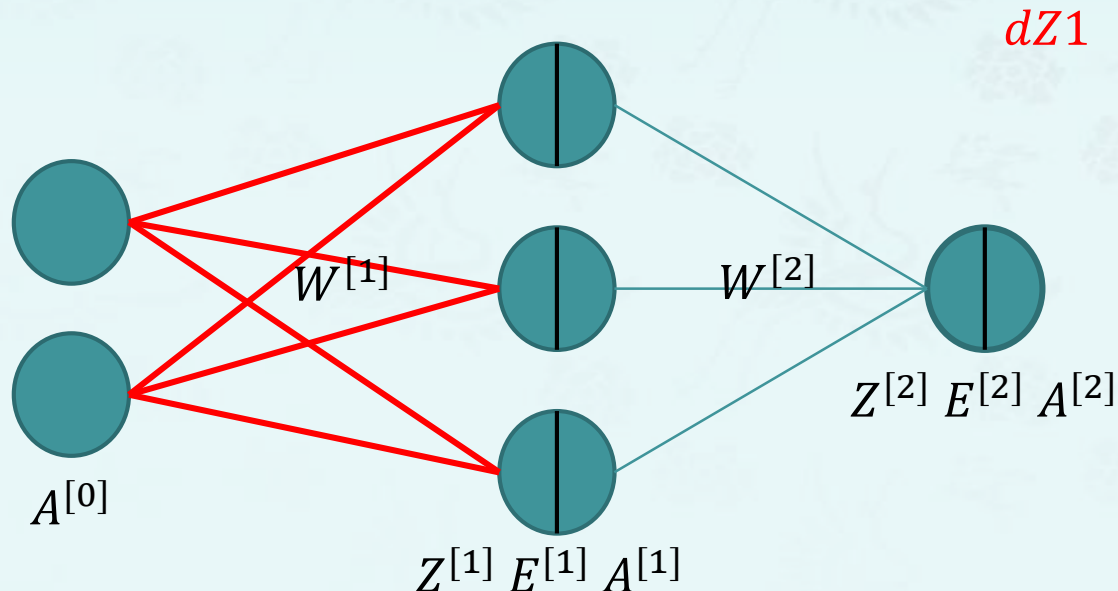
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```

4. 가중치 조정

$$\Delta W^{[2]} = \frac{\partial E}{\partial W^{[2]}} = -E^{[2]} \cdot g'(Z^{[2]}) \cdot A^{[1]T}$$

$$\rightarrow \Delta W^{[1]} = \frac{\partial E}{\partial W^{[1]}} = \boxed{-E^{[1]} \cdot g'(Z^{[1]})} \cdot A^{[0]T}$$



```

1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
4     W2_shape = (self.net_arch[2], self.net_arch[1])
5     self.W1 = 2*np.random.random(W1_shape) - 1
6     self.W2 = 2*np.random.random(W2_shape) - 1
7
8     self.cost_ = []
9
10    for _ in range(self.epochs):
11        A0 = X
12        Z1 = np.dot(self.W1, A0)
13        A1 = self.g(Z1)
14        Z2 = np.dot(self.W2, A1)
15        A2 = self.g(Z2)
16
17        E2 = Y - A2
18        E1 = np.dot(self.W2.T, E2)
19
20        dz2 = E2 * self.g_prime(Z2)
21        dz1 = E1 * self.g_prime(Z1)
22
23        → self.W2 += np.dot(dz2, A1.T)
24           self.W1 += np.dot(dz1, A0.T)
25           self.cost_.append(np.sqrt(np.sum(E2 * E2)))
26    return self
    
```

4. 가중치 조정

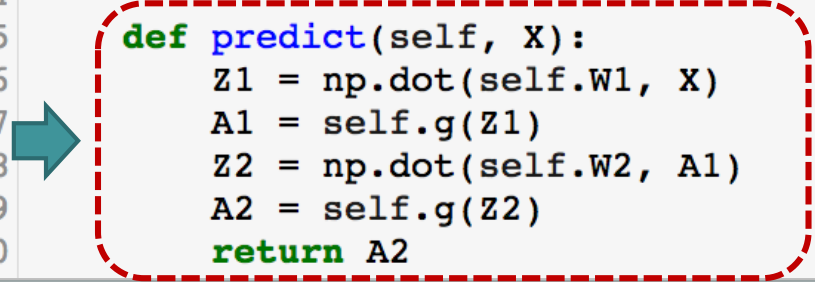
```
1 def fit(self, X, Y):
2     np.random.seed(self.random_seed)
3     W1_shape = (self.net_arch[1], self.net_arch[0])
4     W2_shape = (self.net_arch[2], self.net_arch[1])
5     self.W1 = 2*np.random.random(W1_shape) - 1
6     self.W2 = 2*np.random.random(W2_shape) - 1
7
8     self.cost_ = []
9
10    for _ in range(self.epochs):
11        A0 = X
12        Z1 = np.dot(self.W1, A0)
13        A1 = self.g(Z1)
14        Z2 = np.dot(self.W2, A1)
15        A2 = self.g(Z2)
16
17        E2 = Y - A2
18        E1 = np.dot(self.W2.T, E2)
19
20        dZ2 = E2 * self.g_prime(Z2)
21        dZ1 = E1 * self.g_prime(Z1)
22
23        self.W2 += np.dot(dZ2, A1.T)
24        self.W1 += np.dot(dZ1, A0.T)
25        self.cost_.append(np.sqrt(np.sum(E2 * E2)))
26    return self
```

5. 기타 메소드 : net_input()

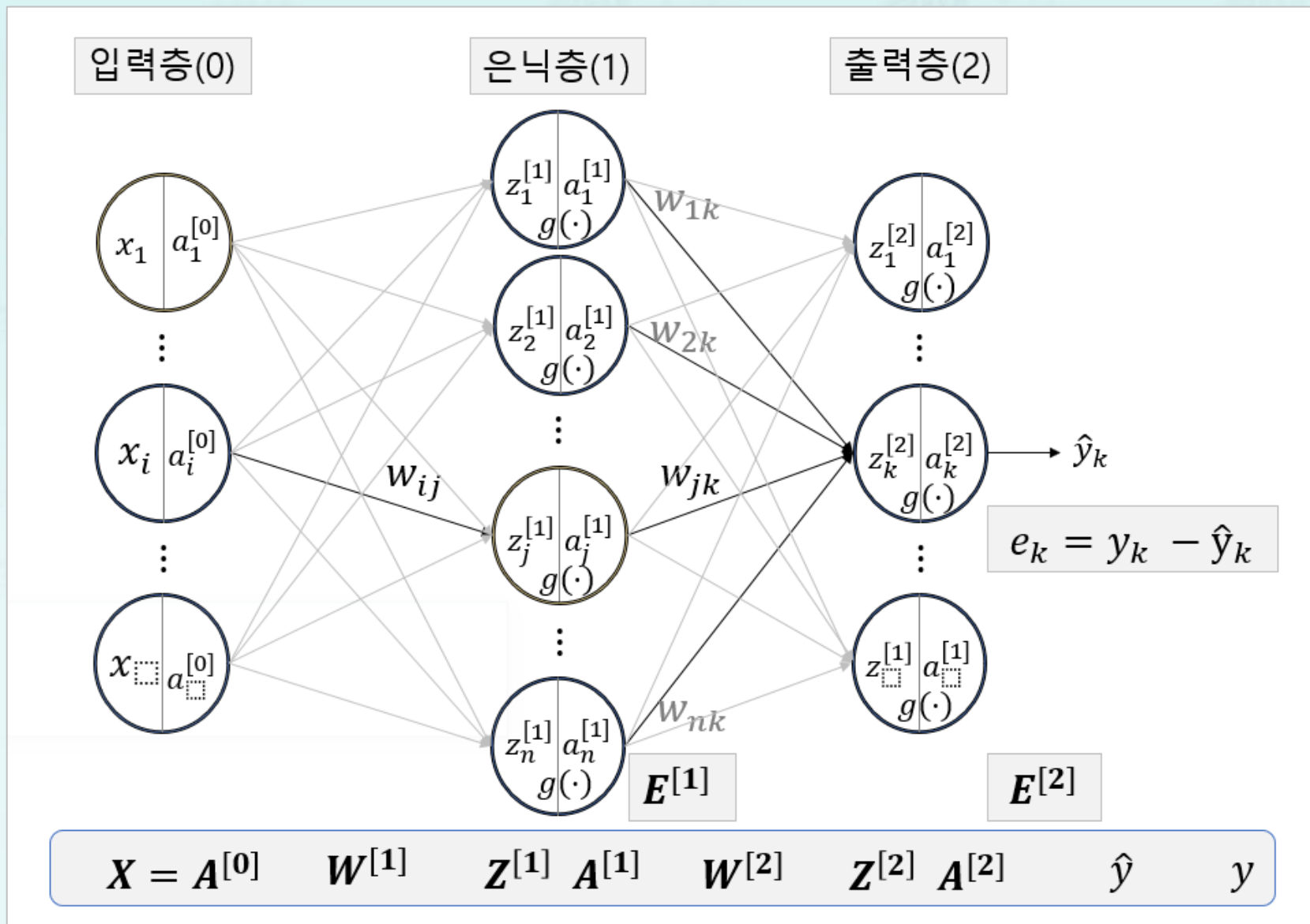
```
44         self.W1 += np.dot(dZ1, A0.T)
45         self.cost_.append(np.sqrt(
46             np.sum(E2 * E2)))
47     return self
48
49     def net_input(self, X):
50         if X.shape[0] == self.w.shape[0]:
51             return np.dot(X, self.w)
52         else:
53             return np.dot(X, self.w[1:]) + self.w[0]
54
55     def predict(self, X):
56         Z1 = np.dot(self.W1, X)
57         A1 = self.g(Z1)
58         Z2 = np.dot(self.W2, A1)
59         A2 = self.g(Z2)
60         return A2
```

5. 기타 메소드 : predict()

```
44         self.W1 += np.dot(dZ1, A0.T)
45         self.cost_.append(np.sqrt(
46             np.sum(E2 * E2)))
47     return self
48
49     def net_input(self, X):
50         if X.shape[0] == self.w.shape[0]:
51             return np.dot(X, self.w)
52         else:
53             return np.dot(X, self.w[1:]) + self.w[0]
54
55     def predict(self, X):
56         Z1 = np.dot(self.W1, X)
57         A1 = self.g(Z1)
58         Z2 = np.dot(self.W2, A1)
59         A2 = self.g(Z2)
60         return A2
```



7. XOR 신경망 학습 결과



7. XOR 신경망 학습 결과 : 은닉층 노드 3개

```
1 nn = NeuralNetwork(net_arch=[2, 3, 1],  
2                       epochs=1000)  
3 X = np.array([  
4     [0, 0, 1, 1],  
5     [0, 1, 0, 1]  
6 ]) )  
7 Y = np.array([0, 1, 1, 0])  
8 nn.fit(X, Y)
```

7. XOR 신경망 학습 결과 : 은닉층 노드 3개

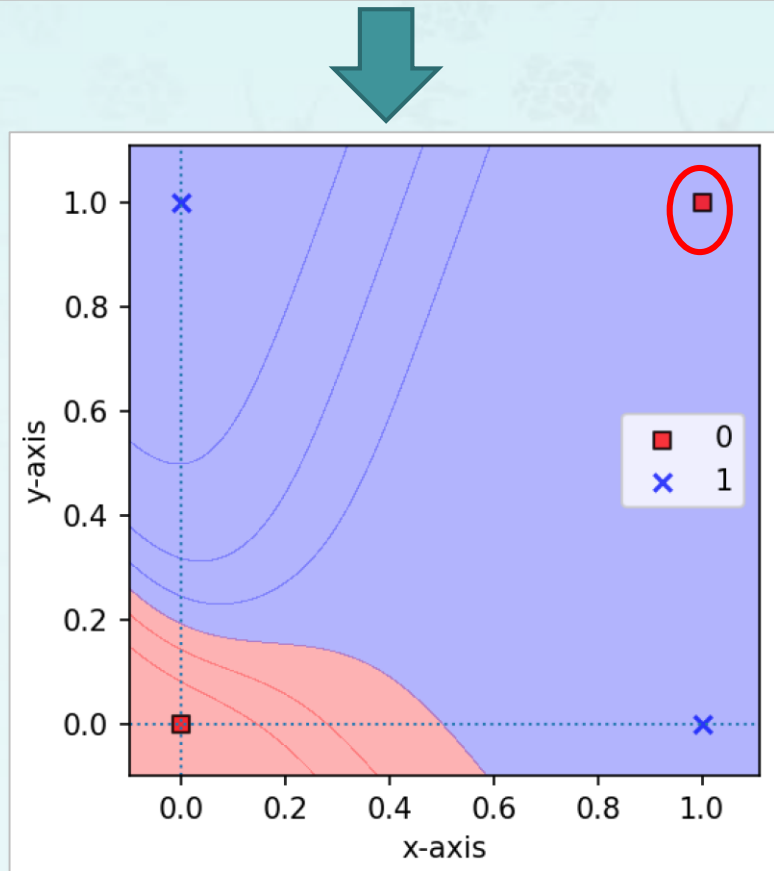
```
1 print("Final prediction of all")
2 A2 = nn.predict(X)
3 for x, yhat in zip(X.T, A2.T):
4     print(x, np.round(yhat, 3))
```



```
Final prediction of all
[0 0] [ 0.048]
[0 1] [ 0.955]
[1 0] [ 0.499]
[1 1] [ 0.501]
```

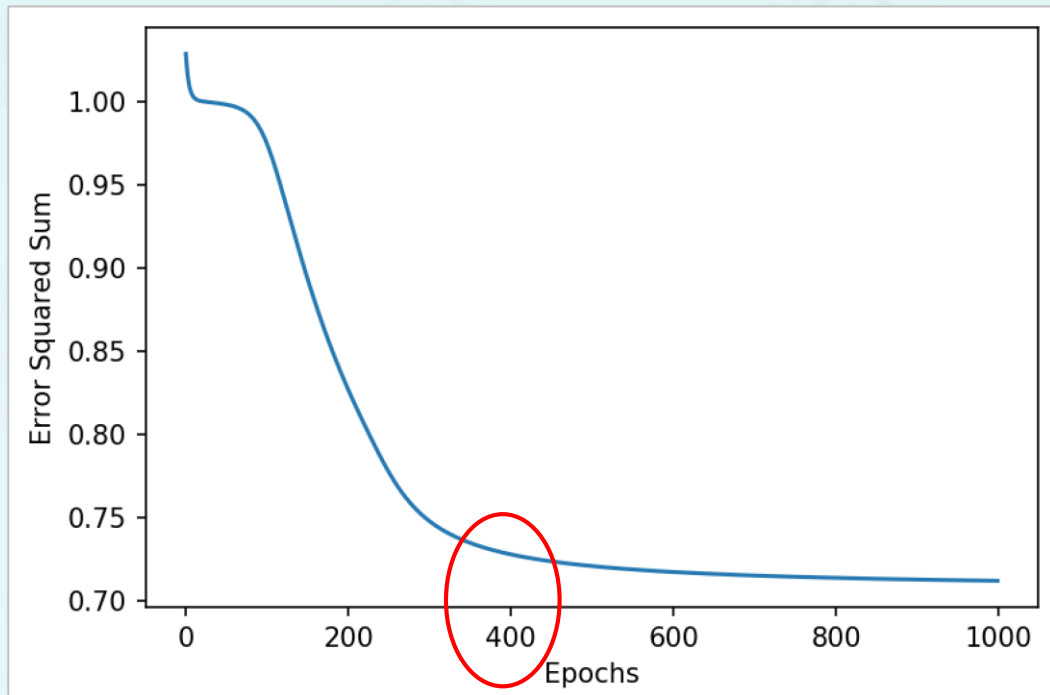
7. XOR 신경망 학습 결과 : 은닉층 노드 3개

```
1 joy.plot_decision_regions(X.T, Y,  
2                             lambda z : nn.predict(z.T))  
3 plt.xlabel('x-axis')  
4 plt.ylabel('y-axis')  
5 plt.legend(loc='best')  
6 plt.show()
```



7. XOR 신경망 학습 결과 : 은닉층 노드 3개

```
1 plt.plot(range(len(nn.cost_)), nn.cost_,  
2          marker='o')  
3 plt.xlabel('Epochs')  
4 plt.ylabel('Error Squared Sum')  
5 plt.show()
```



7. XOR 신경망 학습 결과 : 은닉층 노드 4개

```
1 print("Final prediction of all")
2 A2 = nn.predict(X)
3 for x, yhat in zip(X.T, A2.T):
4     print(x, np.round(yhat, 3))
```



```
Final prediction of all
[0 0] [ 0.077]
[0 1] [ 0.935]
[1 0] [ 0.94]
[1 1] [ 0.043]
```

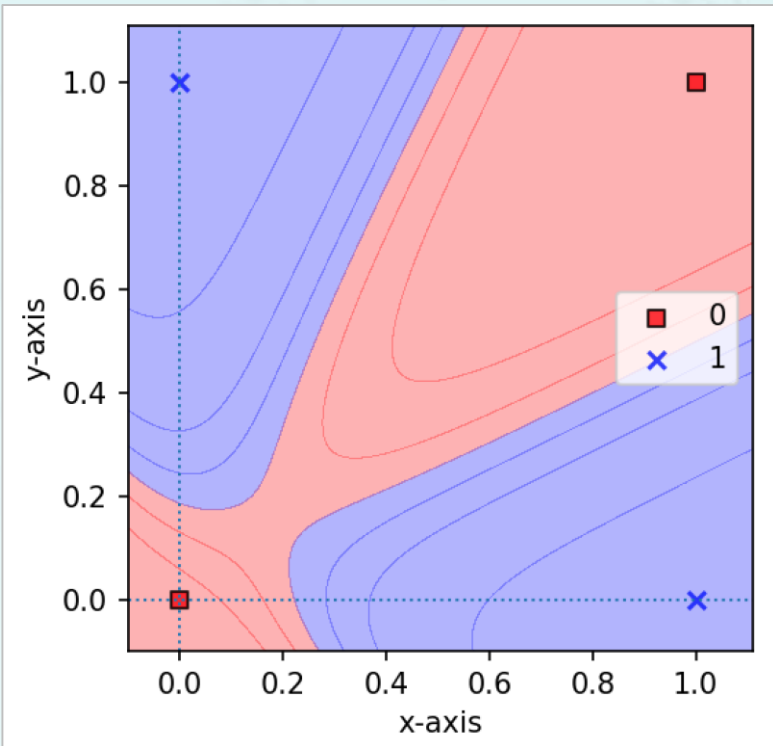
은닉층 노드 **4**개일 때

```
Final prediction of all
[0 0] [ 0.048]
[0 1] [ 0.955]
[1 0] [ 0.499]
[1 1] [ 0.501]
```

은닉층 노드 **3**개일 때

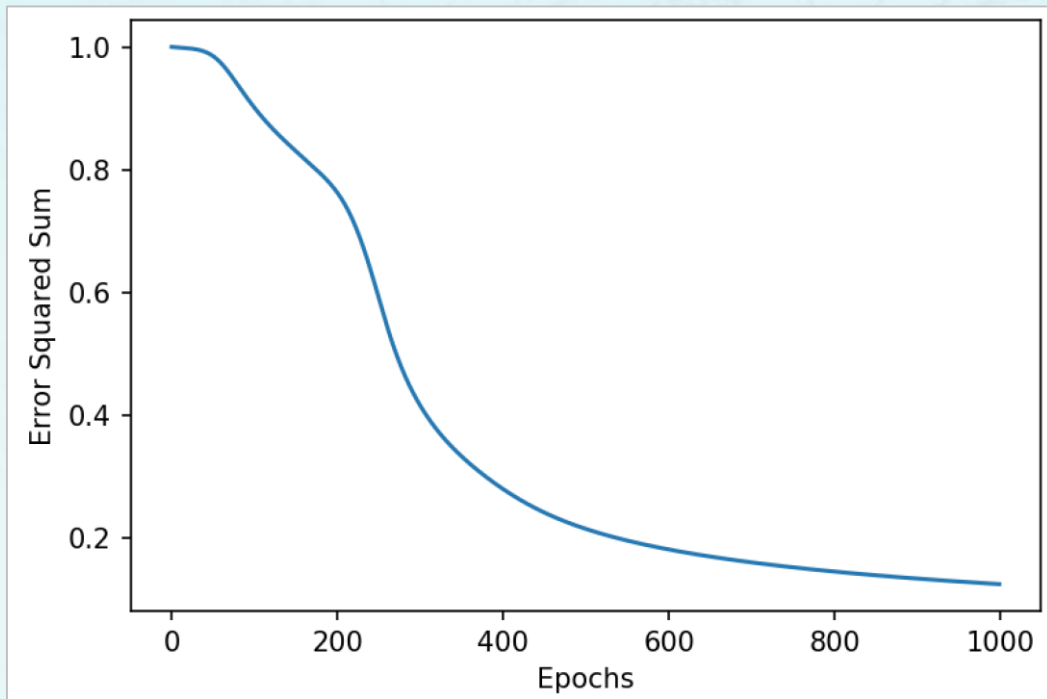
7. XOR 신경망 학습 결과 : 은닉층 노드 4개

```
1 joy.plot_decision_regions(X.T, Y,  
2                           lambda z : nn.predict(z.T))  
3 plt.xlabel('x-axis')  
4 plt.ylabel('y-axis')  
5 plt.legend(loc='best')  
6 plt.show()
```

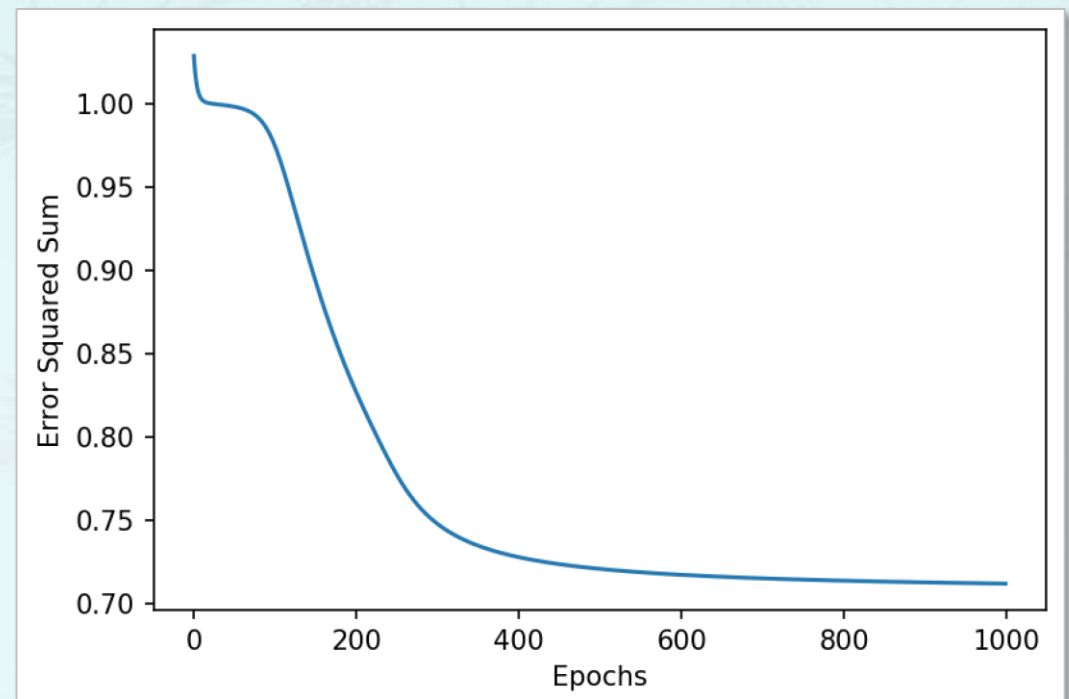


7. XOR 신경망 학습 결과 : 은닉층 노드 4개

```
1 plt.plot(range(len(nn.cost_)), nn.cost_,  
2          marker='o')  
3 plt.xlabel('Epochs')  
4 plt.ylabel('Error Squared Sum')  
5 plt.show()
```



은닉층 노드 **4**개일 때



은닉층 노드 **3**개일 때

XOR 신경망

- 학습 정리
 - **XOR** 신경망 코드 구현
 - **XOR** 신경망의 은닉층 갯수에 따른 결과 확인