Tugas Besar A IF3270 Pembelajaran Mesin

Implementasi Forward Propagation *untuk* Feed Forward Neural Network

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PROGRAM STUDI TEKNIK INFORMATIKA

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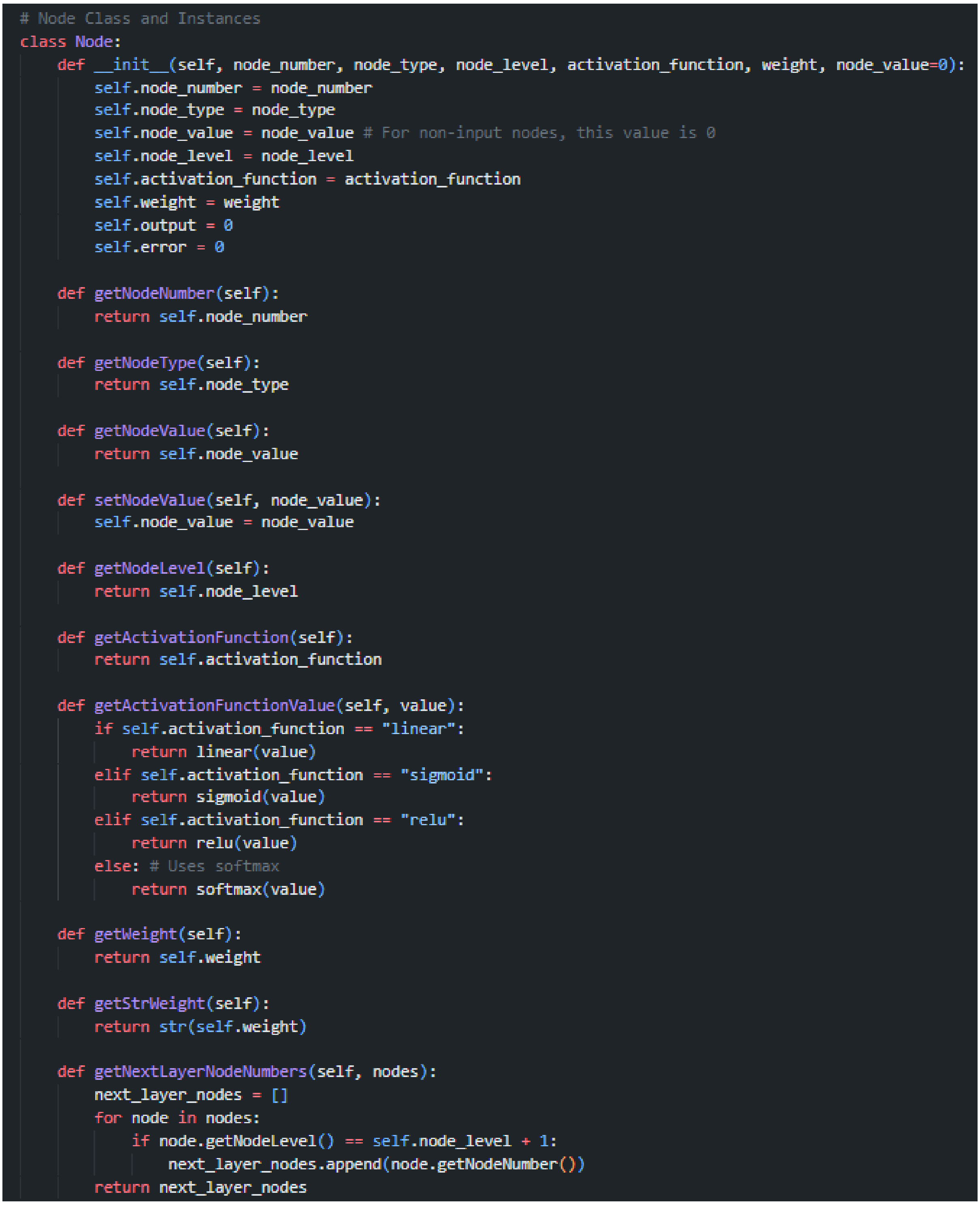
I. *Feed-Forward Neural Network (FFNN)*

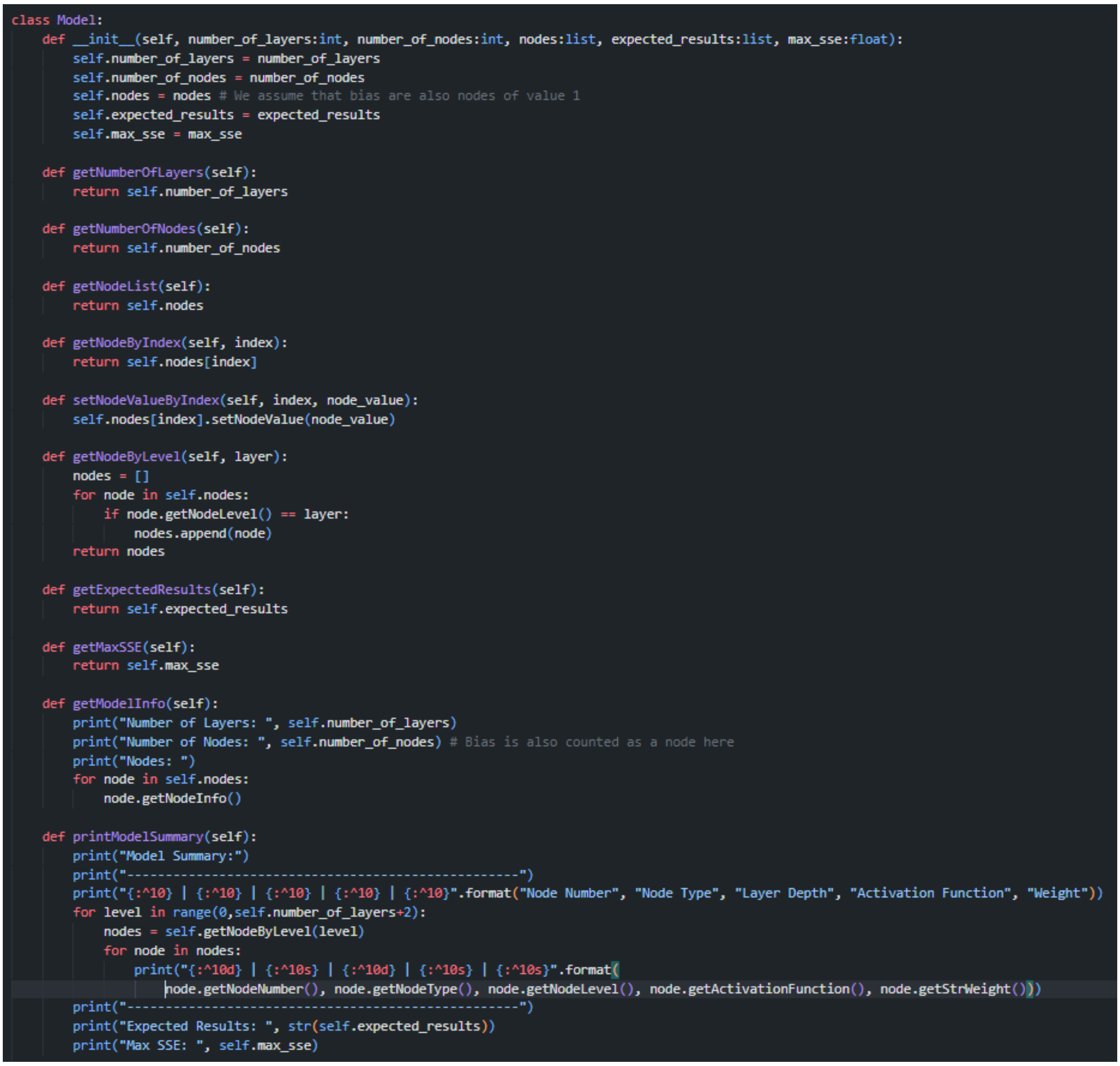
Feed-forward neural network adalah sebuah *neural network* atau jaringan saraf buatan yang digunakan oleh mesin untuk mengklasifikasi *instance data* ke dalam satu dari beberapa *class*. Metode pembelajaran FFNN ini tergolong *supervised learning* karena membutuhkan *labeled data* atau *data* yang sudah diklasifikasikan untuk kalibrasi modelnya. Model FFNN, seperti jaringan saraf pada makhluk hidup, terdiri atas banyak *neuron* atau sel saraf. Secara umum, sebuah model FFNN terdiri atas tiga jenis lapisan: *input layer, hidden layer,* dan *output layer*. *Input layer* adalah lapisan dimana mesin/model menerima masukan data untuk melatih model atau melakukan inferensi dan identifikasi kelas. *Hidden layer* adalah sekumpulan *neuron* di dalam sebuah lapisan yang memproses masukan data dari *input layer*. Pemrosesan ini dilakukan menggunakan dua variabel atau komponen: fungsi aktivasi dan bobot *neuron*. Fungsi aktivasi ini menentukan transformasi nilai yang dimasukkan dari *neuron* pada *input layer* atau dari *hidden layer* sebelumnya. Lalu, untuk bobot akan digunakan untuk menentukan seberapa besar nilai dari *neuron* tersebut mempengaruhi nilai dari *neuron* yang terhubung selanjutnya.

II. Implementasi model FFNN

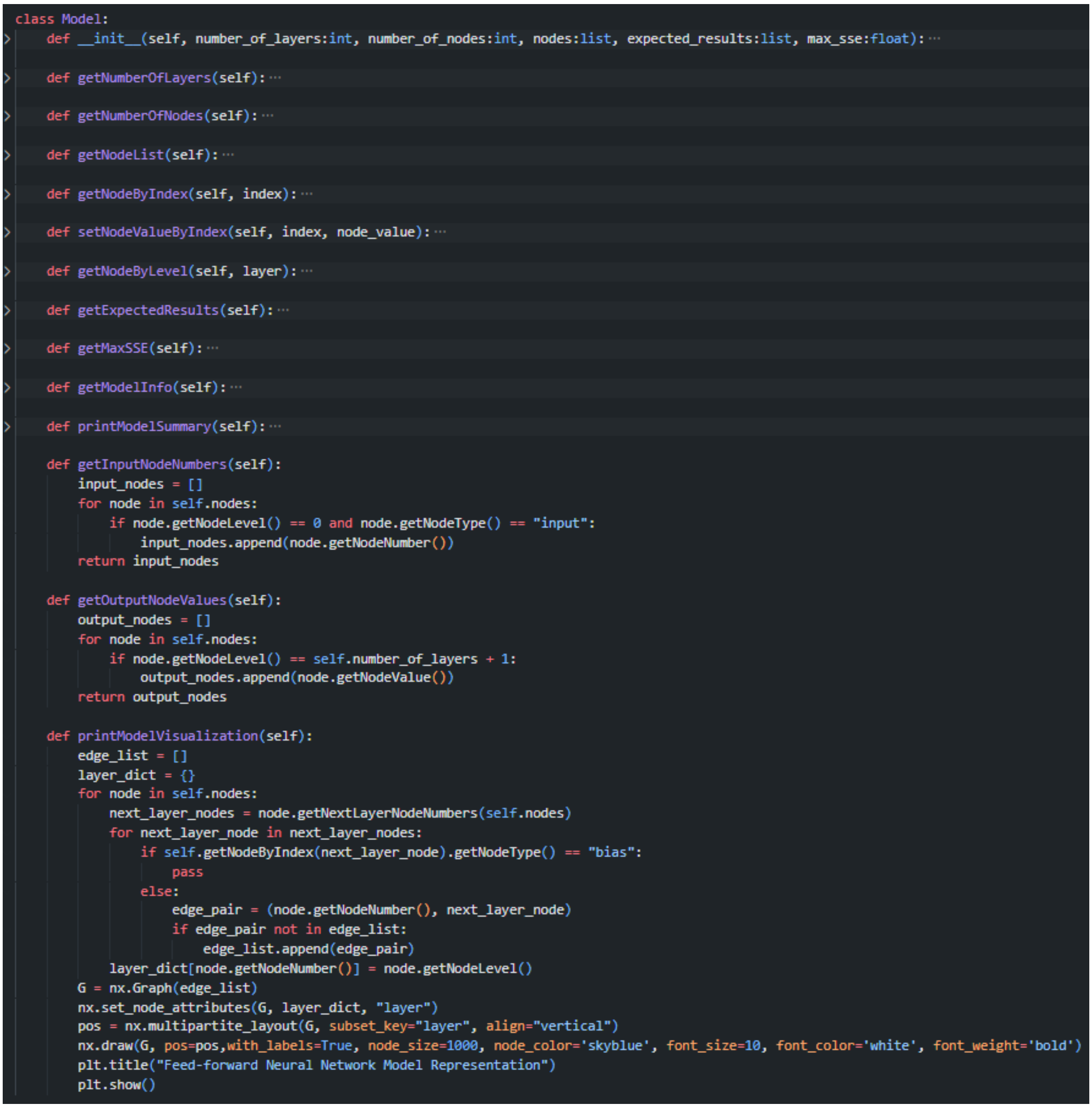
Pada tugas besar ini, penulis menggunakan pendekatan pemrograman berbasis objek dalam bahasa Python untuk mengimplementasikan model FFNN dari *scratch*. Berikut adalah kelas dan instansiasi objek Model dan Node (*Neuron*):



```python
# Node Class and Instances
class Node:
    def __init__(self, node_number, node_type, node_level, activation_function, weight, node_value=0):
        self.node_number = node_number
        self.node_type = node_type
        self.node_value = node_value # For non-input nodes, this value is 0
        self.node_level = node_level
        self.activation_function = activation_function
        self.weight = weight
        self.output = 0
        self.error = 0

    def getNodeNumber(self):
        return self.node_number

    def getNodeType(self):
        return self.node_type

    def getNodeValue(self):
        return self.node_value

    def setNodeValue(self, node_value):
        self.node_value = node_value

    def getNodeLevel(self):
        return self.node_level

    def getActivationFunction(self):
        return self.activation_function

    def getActivationFunctionValue(self, value):
        if self.activation_function == "linear":
            return linear(value)
        elif self.activation_function == "sigmoid":
            return sigmoid(value)
        elif self.activation_function == "relu":
            return relu(value)
        else: # Uses softmax
            return softmax(value)

    def getWeight(self):
        return self.weight

    def getStrWeight(self):
        return str(self.weight)

    def getNextLayerNodeNumbers(self, nodes):
        next_layer_nodes = []
        for node in nodes:
            if node.getNodeLevel() == self.node_level + 1:
                next_layer_nodes.append(node.getNodeNumber())
        return next_layer_nodes
```

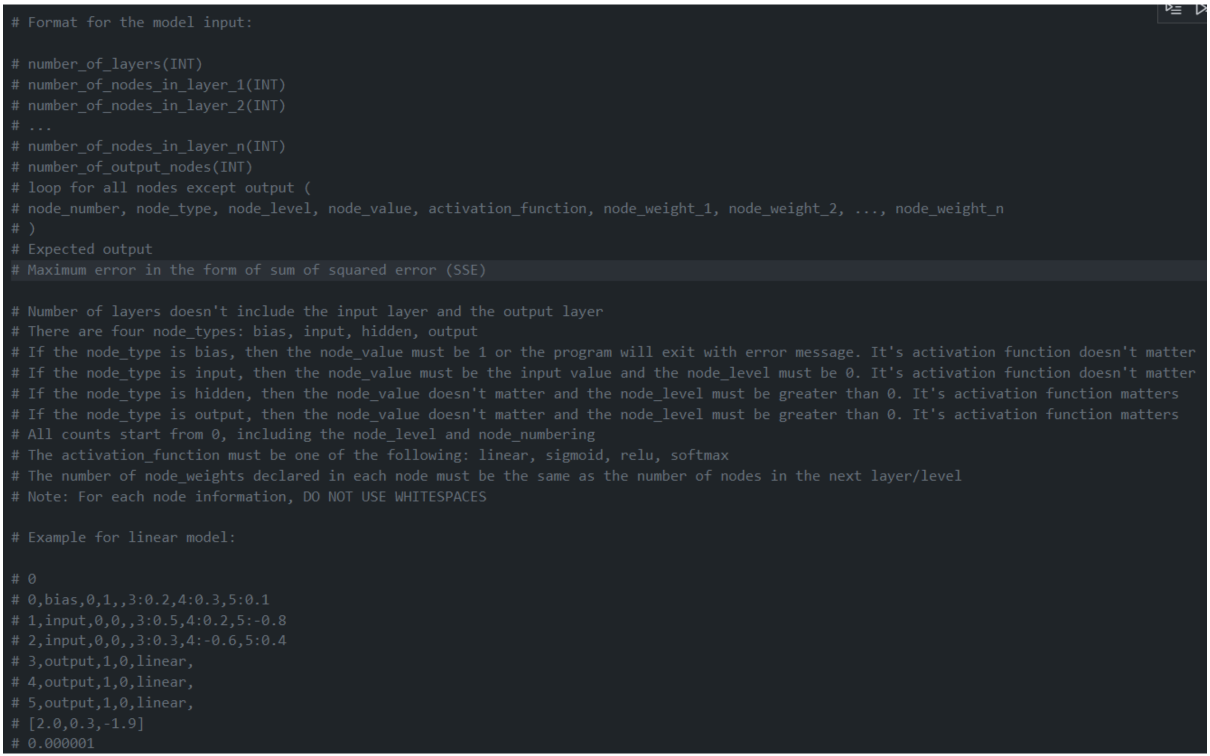


```python
class Model:
    def __init__(self, number_of_layers:int, number_of_nodes:int, nodes:list, expected_results:list, max_sse:float):
        self.number_of_layers = number_of_layers
        self.number_of_nodes = number_of_nodes
        self.nodes = nodes # We assume that bias are also nodes of value 1
        self.expected_results = expected_results
        self.max_sse = max_sse

    def getNumberOfLayers(self):
        return self.number_of_layers

    def getNumberOfNodes(self):
        return self.number_of_nodes

    def getNodeList(self):
        return self.nodes

    def getNodeByIndex(self, index):
        return self.nodes[index]

    def setNodeValueByIndex(self, index, node_value):
        self.nodes[index].setNodeValue(node_value)

    def getNodeByLevel(self, layer):
        nodes = []
        for node in self.nodes:
            if node.getNodeLevel() == layer:
                nodes.append(node)
        return nodes

    def getExpectedResults(self):
        return self.expected_results

    def getMaxSSE(self):
        return self.max_sse

    def getModelInfo(self):
        print("Number of Layers: ", self.number_of_layers)
        print("Number of Nodes: ", self.number_of_nodes) # Bias is also counted as a node here
        print("Nodes: ")
        for node in self.nodes:
            node.getNodeInfo()

    def printModelSummary(self):
        print("Model Summary:")
        print("---------------------------------------------------")
        print("{:^10} | {:^10} | {:^10} | {:^10} | {:^10}".format("Node Number", "Node Type", "Layer Depth", "Activation Function", "Weight"))
        for level in range(0,self.number_of_layers+2):
            nodes = self.getNodeByLevel(level)
            for node in nodes:
                print("{:^10d} | {:^10s} | {:^10d} | {:^10s} | {:^10s}".format(
                    node.getNodeNumber(), node.getNodeType(), node.getNodeLevel(), node.getActivationFunction(), node.getStrWeight()))
        print("---------------------------------------------------")
        print("Expected Results: ", str(self.expected_results))
        print("Max SSE: ", self.max_sse)
```

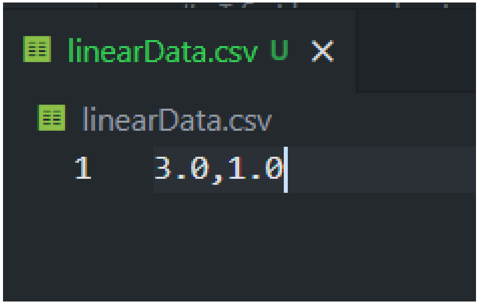


```python
class Model:
    def __init__(self, number_of_layers:int, number_of_nodes:int, nodes:list, expected_results:list, max_sse:float):···

    def getNumberOfLayers(self):···

    def getNumberOfNodes(self):···

    def getNodeList(self):···

    def getNodeByIndex(self, index):···

    def setNodeValueByIndex(self, index, node_value):···

    def getNodeByLevel(self, layer):···

    def getExpectedResults(self):···

    def getMaxSSE(self):···

    def getModelInfo(self):···

    def printModelSummary(self):···

    def getInputNodeNumbers(self):
        input_nodes = []
        for node in self.nodes:
            if node.getNodeLevel() == 0 and node.getNodeType() == "input":
                input_nodes.append(node.getNodeNumber())
        return input_nodes

    def getOutputNodeValues(self):
        output_nodes = []
        for node in self.nodes:
            if node.getNodeLevel() == self.number_of_layers + 1:
                output_nodes.append(node.getNodeValue())
        return output_nodes

    def printModelVisualization(self):
        edge_list = []
        layer_dict = {}
        for node in self.nodes:
            next_layer_nodes = node.getNextLayerNodeNumbers(self.nodes)
            for next_layer_node in next_layer_nodes:
                if self.getNodeByIndex(next_layer_node).getNodeType() == "bias":
                    pass
                else:
                    edge_pair = (node.getNodeNumber(), next_layer_node)
                    if edge_pair not in edge_list:
                        edge_list.append(edge_pair)
            layer_dict[node.getNodeNumber()] = node.getNodeLevel()
        G = nx.Graph(edge_list)
        nx.set_node_attributes(G, layer_dict, "layer")
        pos = nx.multipartite_layout(G, subset_key="layer", align="vertical")
        nx.draw(G, pos=pos,with_labels=True, node_size=1000, node_color='skyblue', font_size=10, font_color='white', font_weight='bold')
        plt.title("Feed-forward Neural Network Model Representation")
        plt.show()
```

Selain pembentukan definisi kelas serta instansiasi objeknya, dibutuhkan juga metode untuk membaca teks file untuk data yang akan difeed ke dalam modelnya serta untuk memodifikasi isi dan pengaturan modelnya. Pada tugas besar ini, digunakan dua jenis data: sebuah *file* berformat .txt untuk memodifikasi model FFNN dan sebuah file berformat .csv yang berisikan data input. Berikut adalah format beserta contoh format data untuk tipe csv dan txt untuk testcase linear model.

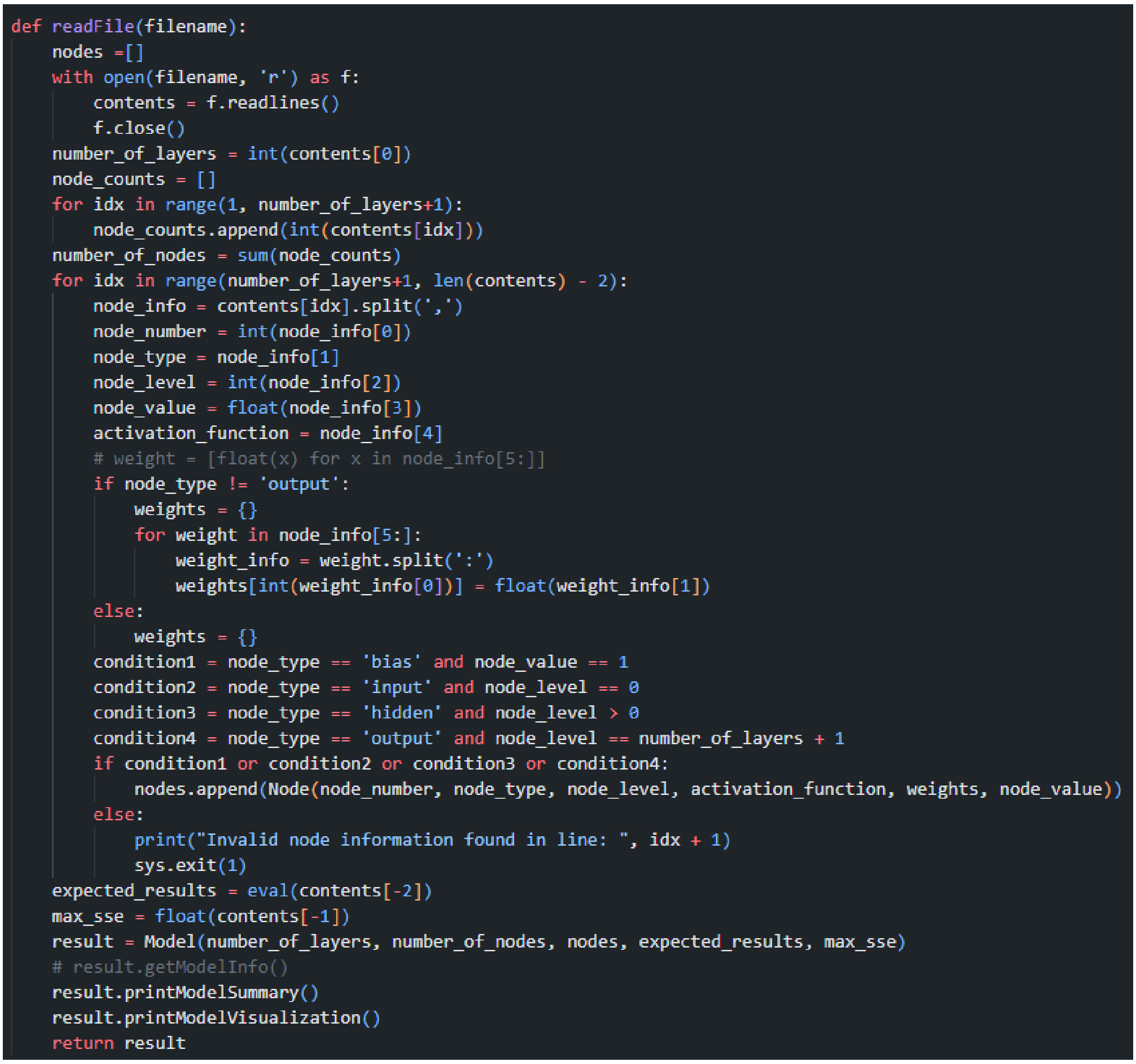


```
# Format for the model input:

# number_of_layers(INT)
# number_of_nodes_in_layer_1(INT)
# number_of_nodes_in_layer_2(INT)
# ...
# number_of_nodes_in_layer_n(INT)
# number_of_output_nodes(INT)
# loop for all nodes except output (
# node_number, node_type, node_level, node_value, activation_function, node_weight_1, node_weight_2, ..., node_weight_n
# )
# Expected output
# Maximum error in the form of sum of squared error (SSE)

# Number of layers doesn't include the input layer and the output layer
# There are four node_types: bias, input, hidden, output
# If the node_type is bias, then the node_value must be 1 or the program will exit with error message. It's activation function doesn't matter
# If the node_type is input, then the node_value must be the input value and the node_level must be 0. It's activation function doesn't matter
# If the node_type is hidden, then the node_value doesn't matter and the node_level must be greater than 0. It's activation function matters
# If the node_type is output, then the node_value doesn't matter and the node_level must be greater than 0. It's activation function matters
# All counts start from 0, including the node_level and node_numbering
# The activation_function must be one of the following: linear, sigmoid, relu, softmax
# The number of node_weights declared in each node must be the same as the number of nodes in the next layer/level
# Note: For each node information, DO NOT USE WHITESPACES

# Example for linear model:

# 0
# 0,bias,0,1,,3:0.2,4:0.3,5:0.1
# 1,input,0,0,,3:0.5,4:0.2,5:-0.8
# 2,input,0,0,,3:0.3,4:-0.6,5:0.4
# 3,output,1,0,linear,
# 4,output,1,0,linear,
# 5,output,1,0,linear,
# [2.0,0.3,-1.9]
# 0.000001
```



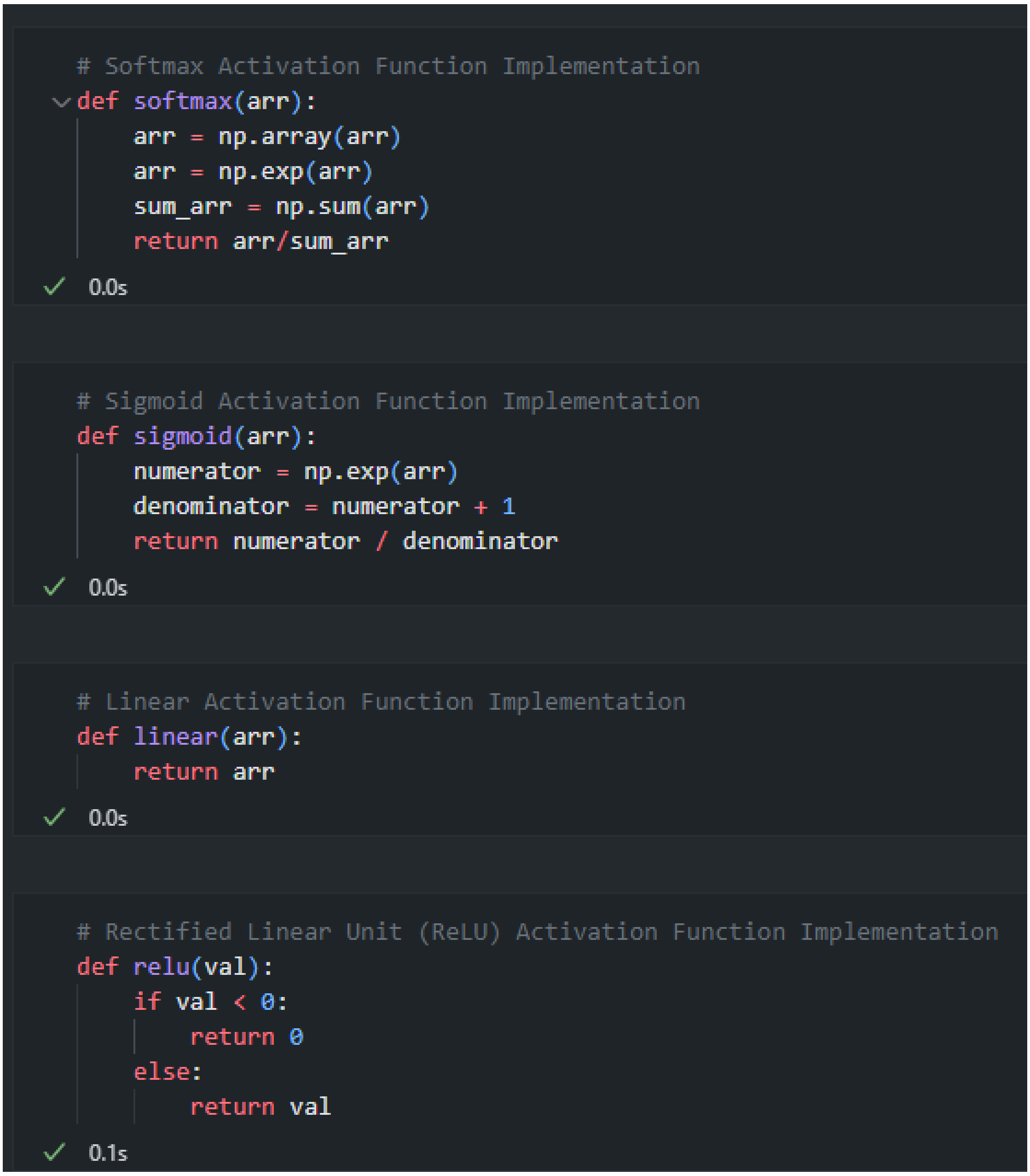
```
3.0,1.0
```

Lalu, file txt dibaca oleh potongan kode berikut ini untuk kemudian diinstansiasi modelnya lengkap dengan *neuron-neuron* di dalamnya. File .txt dibaca baris per baris sesuai dengan format yang telah ditentukan di atas.



```python
def readFile(filename):
    nodes =[]
    with open(filename, 'r') as f:
        contents = f.readlines()
        f.close()
    number_of_layers = int(contents[0])
    node_counts = []
    for idx in range(1, number_of_layers+1):
        node_counts.append(int(contents[idx]))
    number_of_nodes = sum(node_counts)
    for idx in range(number_of_layers+1, len(contents) - 2):
        node_info = contents[idx].split(',')
        node_number = int(node_info[0])
        node_type = node_info[1]
        node_level = int(node_info[2])
        node_value = float(node_info[3])
        activation_function = node_info[4]
        # weight = [float(x) for x in node_info[5:]]
        if node_type != 'output':
            weights = {}
            for weight in node_info[5:]:
                weight_info = weight.split(':')
                weights[int(weight_info[0])] = float(weight_info[1])
        else:
            weights = {}
        condition1 = node_type == 'bias' and node_value == 1
        condition2 = node_type == 'input' and node_level == 0
        condition3 = node_type == 'hidden' and node_level > 0
        condition4 = node_type == 'output' and node_level == number_of_layers + 1
        if condition1 or condition2 or condition3 or condition4:
            nodes.append(Node(node_number, node_type, node_level, activation_function, weights, node_value))
        else:
            print("Invalid node information found in line: ", idx + 1)
            sys.exit(1)
    expected_results = eval(contents[-2])
    max_sse = float(contents[-1])
    result = Model(number_of_layers, number_of_nodes, nodes, expected_results, max_sse)
    # result.getModelInfo()
    result.printModelSummary()
    result.printModelVisualization()
    return result
```

Kemudian, dilakukan inferensi data atau proses memasukkan data ke dalam model untuk kemudian dibandingkan hasilnya dengan *expected output*. Masing-masing neuron memiliki fungsi aktivasinya masing-masing yang implementasi dan deklarasi formulanya adalah sebagai berikut:



```python
# Softmax Activation Function Implementation
def softmax(arr):
    arr = np.array(arr)
    arr = np.exp(arr)
    sum_arr = np.sum(arr)
    return arr/sum_arr
```

✓ 0.0s

```python
# Sigmoid Activation Function Implementation
def sigmoid(arr):
    numerator = np.exp(arr)
    denominator = numerator + 1
    return numerator / denominator
```

✓ 0.0s

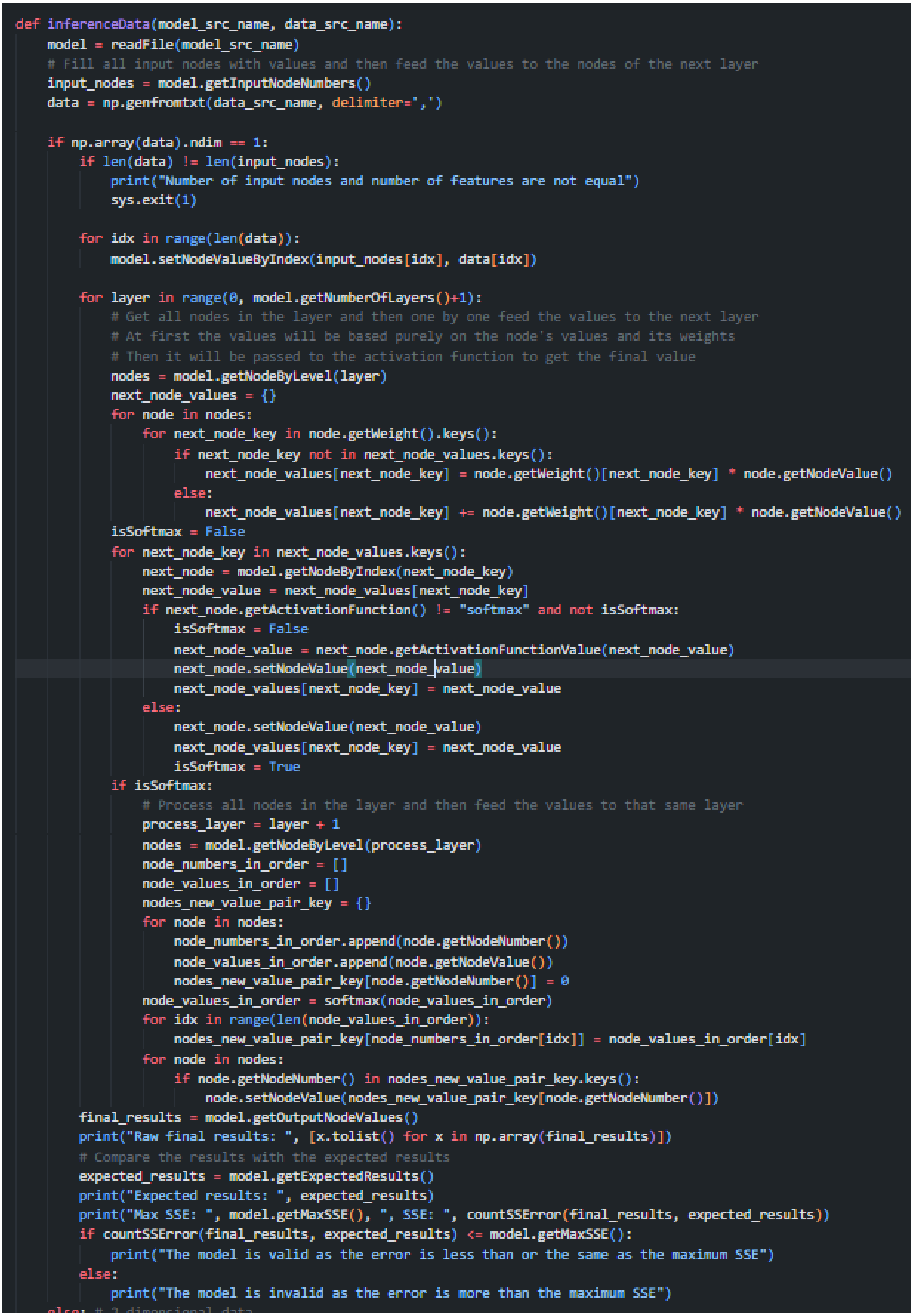
```python
# Linear Activation Function Implementation
def linear(arr):
    return arr
```

✓ 0.0s

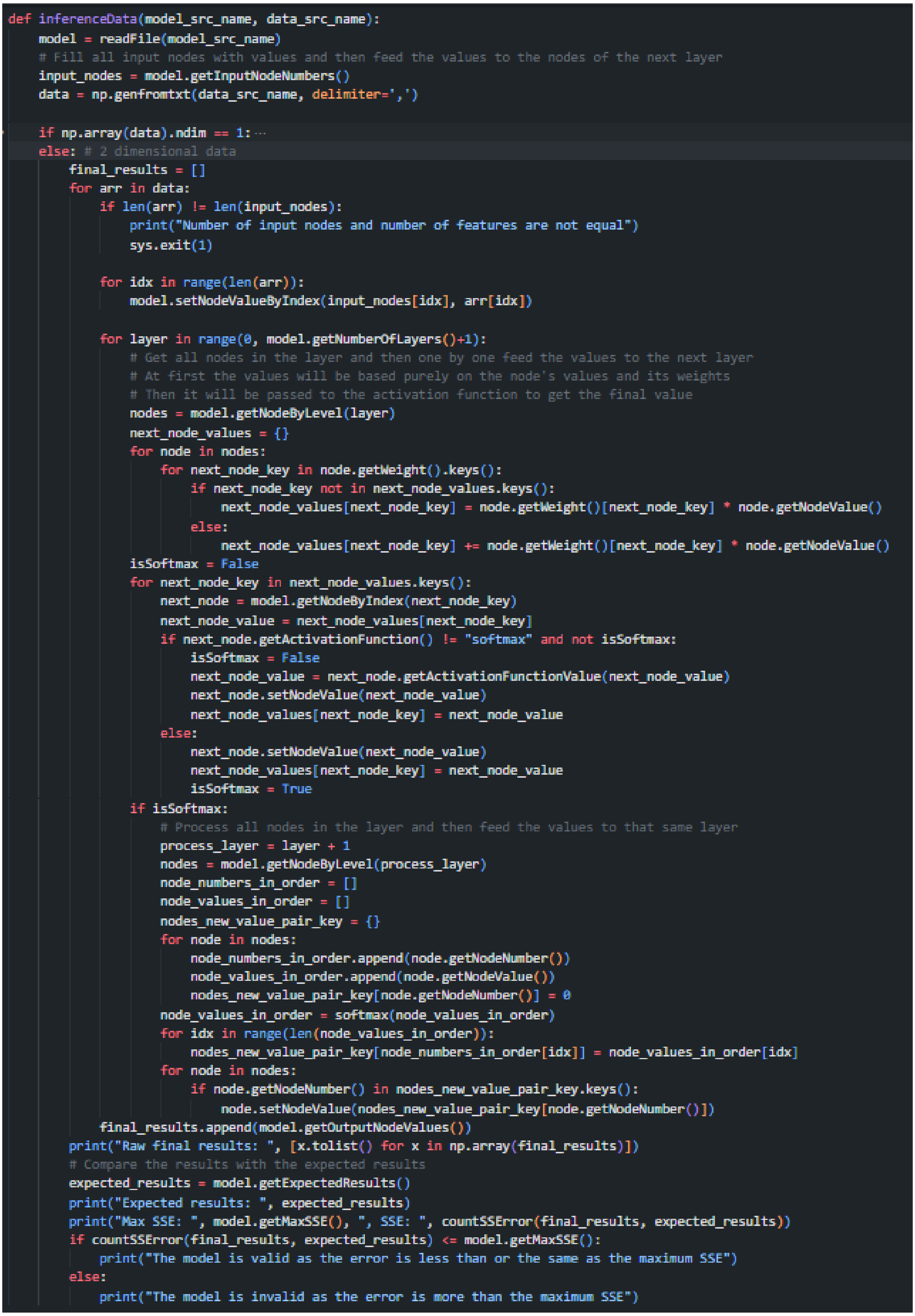
```python
# Rectified Linear Unit (ReLU) Activation Function Implementation
def relu(val):
    if val < 0:
        return 0
    else:
        return val
```

✓ 0.1s

Inferensi datanya menggunakan fungsi berikut ini yang dinamakan “inferenceData”. Pada proses ini, perlu ditentukan terlebih dahulu dimensi data yang akan di-feed ke dalam model. Apakah data ini hanya satu *instance* saja atau terdapat beberapa *instance* sehingga 2 dimensi? Maka dari itu, dibuatlah conditional untuk memproses dua jenis kemungkinan ini. Selain itu, terdapat juga conditionals untuk memproses layer yang menggunakan *softmax activation function*. Alasannya adalah, fungsi *softmax* menggunakan nilai dari *neighboring neurons* atau *neuron* yang berada pada layer yang sama untuk menentukan nilai probabilitasnya, berbeda dengan fungsi aktivasi linear, relu, dan sigmoid yang bergantung pada nilai lokal *neuron* tersebut.

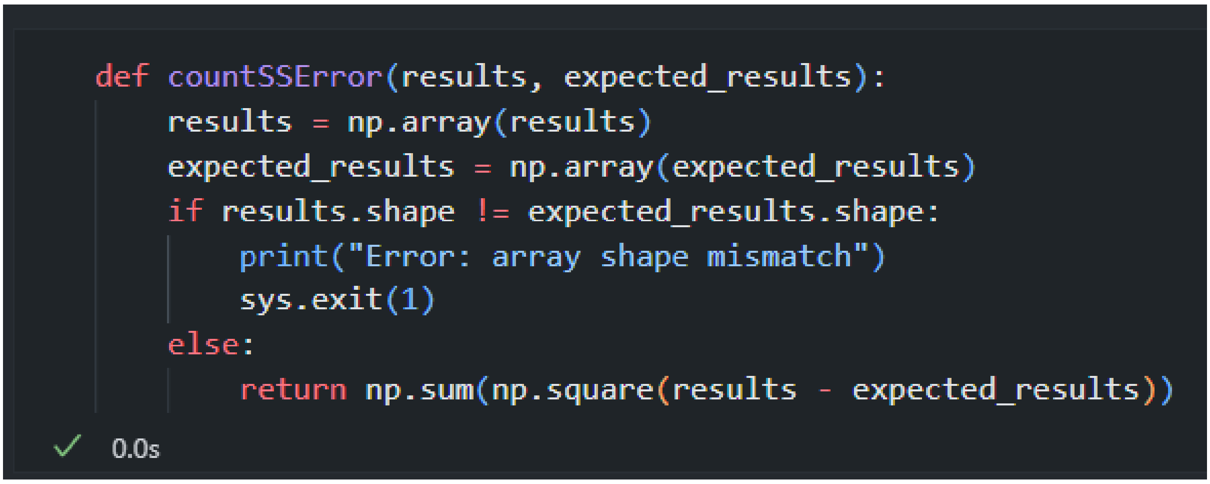


```python
def inferenceData(model_src_name, data_src_name):
    model = readFile(model_src_name)
    # Fill all input nodes with values and then feed the values to the nodes of the next layer
    input_nodes = model.getInputNodeNumbers()
    data = np.genfromtxt(data_src_name, delimiter=',')

    if np.array(data).ndim == 1:
        if len(data) != len(input_nodes):
            print("Number of input nodes and number of features are not equal")
            sys.exit(1)

        for idx in range(len(data)):
            model.setNodeValueByIndex(input_nodes[idx], data[idx])

        for layer in range(0, model.getNumberOfLayers()+1):
            # Get all nodes in the layer and then one by one feed the values to the next layer
            # At first the values will be based purely on the node's values and its weights
            # Then it will be passed to the activation function to get the final value
            nodes = model.getNodeByLevel(layer)
            next_node_values = {}
            for node in nodes:
                for next_node_key in node.getWeight().keys():
                    if next_node_key not in next_node_values.keys():
                        next_node_values[next_node_key] = node.getWeight()[next_node_key] * node.getNodeValue()
                    else:
                        next_node_values[next_node_key] += node.getWeight()[next_node_key] * node.getNodeValue()
            isSoftmax = False
            for next_node_key in next_node_values.keys():
                next_node = model.getNodeByIndex(next_node_key)
                next_node_value = next_node_values[next_node_key]
                if next_node.getActivationFunction() != "softmax" and not isSoftmax:
                    isSoftmax = False
                    next_node_value = next_node.getActivationFunctionValue(next_node_value)
                    next_node.setNodeValue(next_node_value)
                    next_node_values[next_node_key] = next_node_value
                else:
                    next_node.setNodeValue(next_node_value)
                    next_node_values[next_node_key] = next_node_value
                    isSoftmax = True
            if isSoftmax:
                # Process all nodes in the layer and then feed the values to that same layer
                process_layer = layer + 1
                nodes = model.getNodeByLevel(process_layer)
                node_numbers_in_order = []
                node_values_in_order = []
                nodes_new_value_pair_key = {}
                for node in nodes:
                    node_numbers_in_order.append(node.getNodeNumber())
                    node_values_in_order.append(node.getNodeValue())
                    nodes_new_value_pair_key[node.getNodeNumber()] = 0
                node_values_in_order = softmax(node_values_in_order)
                for idx in range(len(node_values_in_order)):
                    nodes_new_value_pair_key[node_numbers_in_order[idx]] = node_values_in_order[idx]
                for node in nodes:
                    if node.getNodeNumber() in nodes_new_value_pair_key.keys():
                        node.setNodeValue(nodes_new_value_pair_key[node.getNodeNumber()])
        final_results = model.getOutputNodeValues()
        print("Raw final results: ", [x.tolist() for x in np.array(final_results)])
        # Compare the results with the expected results
        expected_results = model.getExpectedResults()
        print("Expected results: ", expected_results)
        print("Max SSE: ", model.getMaxSSE(), ", SSE: ", countSSError(final_results, expected_results))
        if countSSError(final_results, expected_results) <= model.getMaxSSE():
            print("The model is valid as the error is less than or the same as the maximum SSE")
        else:
            print("The model is invalid as the error is more than the maximum SSE")
    else: # 2 dimensional data
```



```python
def inferenceData(model_src_name, data_src_name):
    model = readFile(model_src_name)
    # Fill all input nodes with values and then feed the values to the nodes of the next layer
    input_nodes = model.getInputNodeNumbers()
    data = np.genfromtxt(data_src_name, delimiter=',')

    if np.array(data).ndim == 1:···
    else: # 2 dimensional data
        final_results = []
        for arr in data:
            if len(arr) != len(input_nodes):
                print("Number of input nodes and number of features are not equal")
                sys.exit(1)

            for idx in range(len(arr)):
                model.setNodeValueByIndex(input_nodes[idx], arr[idx])

            for layer in range(0, model.getNumberOfLayers()+1):
                # Get all nodes in the layer and then one by one feed the values to the next layer
                # At first the values will be based purely on the node's values and its weights
                # Then it will be passed to the activation function to get the final value
                nodes = model.getNodeByLevel(layer)
                next_node_values = {}
                for node in nodes:
                    for next_node_key in node.getWeight().keys():
                        if next_node_key not in next_node_values.keys():
                            next_node_values[next_node_key] = node.getWeight()[next_node_key] * node.getNodeValue()
                        else:
                            next_node_values[next_node_key] += node.getWeight()[next_node_key] * node.getNodeValue()
                isSoftmax = False
                for next_node_key in next_node_values.keys():
                    next_node = model.getNodeByIndex(next_node_key)
                    next_node_value = next_node_values[next_node_key]
                    if next_node.getActivationFunction() != "softmax" and not isSoftmax:
                        isSoftmax = False
                        next_node_value = next_node.getActivationFunctionValue(next_node_value)
                        next_node.setNodeValue(next_node_value)
                        next_node_values[next_node_key] = next_node_value
                    else:
                        next_node.setNodeValue(next_node_value)
                        next_node_values[next_node_key] = next_node_value
                        isSoftmax = True
                if isSoftmax:
                    # Process all nodes in the layer and then feed the values to that same layer
                    process_layer = layer + 1
                    nodes = model.getNodeByLevel(process_layer)
                    node_numbers_in_order = []
                    node_values_in_order = []
                    nodes_new_value_pair_key = {}
                    for node in nodes:
                        node_numbers_in_order.append(node.getNodeNumber())
                        node_values_in_order.append(node.getNodeValue())
                        nodes_new_value_pair_key[node.getNodeNumber()] = 0
                    node_values_in_order = softmax(node_values_in_order)
                    for idx in range(len(node_values_in_order)):
                        nodes_new_value_pair_key[node_numbers_in_order[idx]] = node_values_in_order[idx]
                    for node in nodes:
                        if node.getNodeNumber() in nodes_new_value_pair_key.keys():
                            node.setNodeValue(nodes_new_value_pair_key[node.getNodeNumber()])
            final_results.append(model.getOutputNodeValues())
        print("Raw final results: ", [x.tolist() for x in np.array(final_results)])
        # Compare the results with the expected results
        expected_results = model.getExpectedResults()
        print("Expected results: ", expected_results)
        print("Max SSE: ", model.getMaxSSE(), ", SSE: ", countSSError(final_results, expected_results))
        if countSSError(final_results, expected_results) <= model.getMaxSSE():
            print("The model is valid as the error is less than or the same as the maximum SSE")
        else:
            print("The model is invalid as the error is more than the maximum SSE")
```

Pada proses inferensi data ini, juga dilakukan proses penghitungan kesalahan atau *error* dari hasil perhitungan menggunakan metode *sum of squared error* (SSE). Metode ini menjumlahkan kuadrat selisih antara nilai yang diharapkan dengan nilai yang dihitung oleh mesin. Berikut adalah fungsi implementasi untuk menghitung nilai SSE.

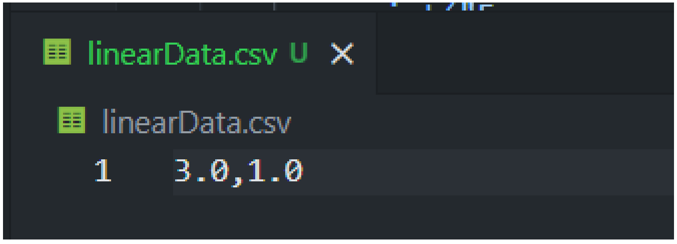


```python
def countSSError(results, expected_results):
    results = np.array(results)
    expected_results = np.array(expected_results)
    if results.shape != expected_results.shape:
        print("Error: array shape mismatch")
        sys.exit(1)
    else:
        return np.sum(np.square(results - expected_results))
```

III. Hasil Pengujian

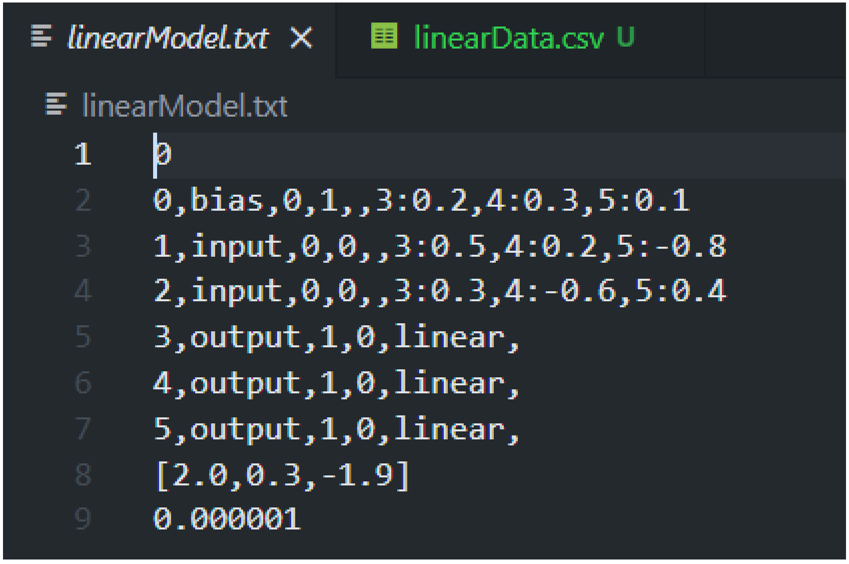
Berikut adalah *code snippet* beserta input data .txt dan .csv yang digunakan beserta hasil pengujiannya:

1. Linear Testcase
   a. File .csv ("linearData.csv")



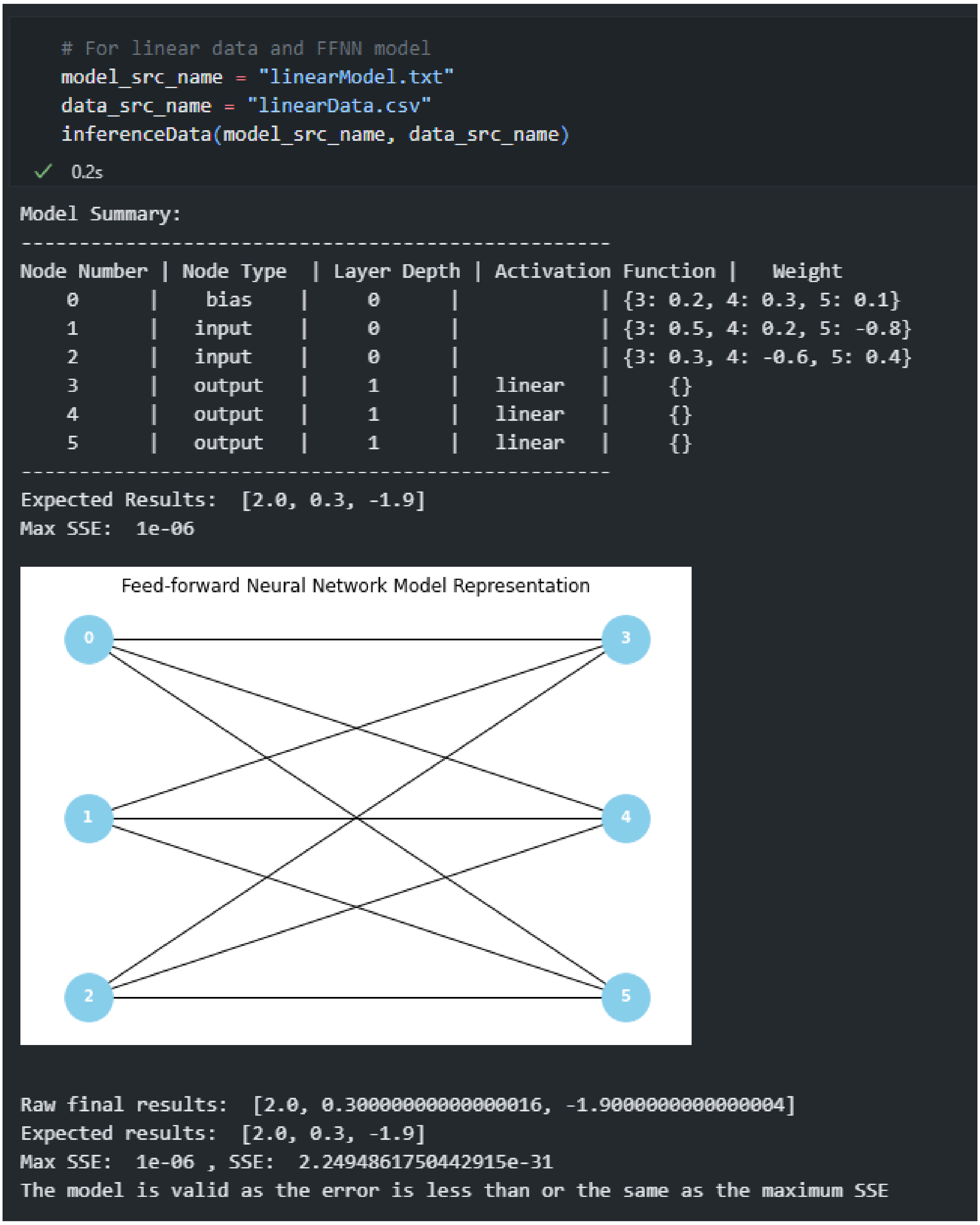
```
3.0,1.0
```

   b. File .txt ("linearModel.txt")



```
0
0,bias,0,1,,3:0.2,4:0.3,5:0.1
1,input,0,0,,3:0.5,4:0.2,5:-0.8
2,input,0,0,,3:0.3,4:-0.6,5:0.4
3,output,1,0,linear,
4,output,1,0,linear,
5,output,1,0,linear,
[2.0,0.3,-1.9]
0.000001
```

   c. Hasil Pengujian



```
# For linear data and FFNN model
model_src_name = "linearModel.txt"
data_src_name = "linearData.csv"
inferenceData(model_src_name, data_src_name)
```

✓ 0.2s

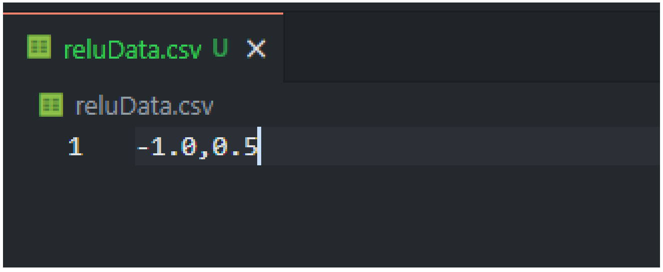
```
Model Summary:
---------------------------------------------------
Node Number | Node Type  | Layer Depth | Activation Function |   Weight
    0       |    bias    |     0       |            | {3: 0.2, 4: 0.3, 5: 0.1}
    1       |   input    |     0       |            | {3: 0.5, 4: 0.2, 5: -0.8}
    2       |   input    |     0       |            | {3: 0.3, 4: -0.6, 5: 0.4}
    3       |   output   |     1       |   linear   |     {}
    4       |   output   |     1       |   linear   |     {}
    5       |   output   |     1       |   linear   |     {}
---------------------------------------------------
Expected Results:  [2.0, 0.3, -1.9]
Max SSE:  1e-06
```

Feed-forward Neural Network Model Representation

```
Raw final results:  [2.0, 0.30000000000000016, -1.9000000000000004]
Expected results:  [2.0, 0.3, -1.9]
Max SSE:  1e-06 , SSE:  2.2494861750442915e-31
The model is valid as the error is less than or the same as the maximum SSE
```

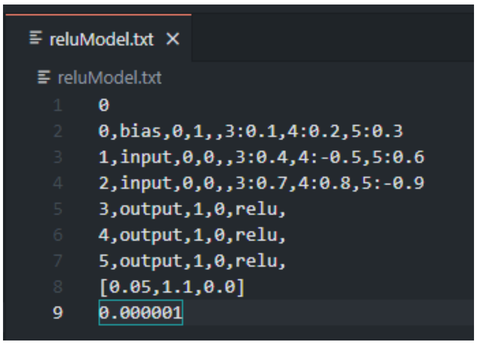
2. ReLU Testcase

   a. File .csv ("reluData.csv")



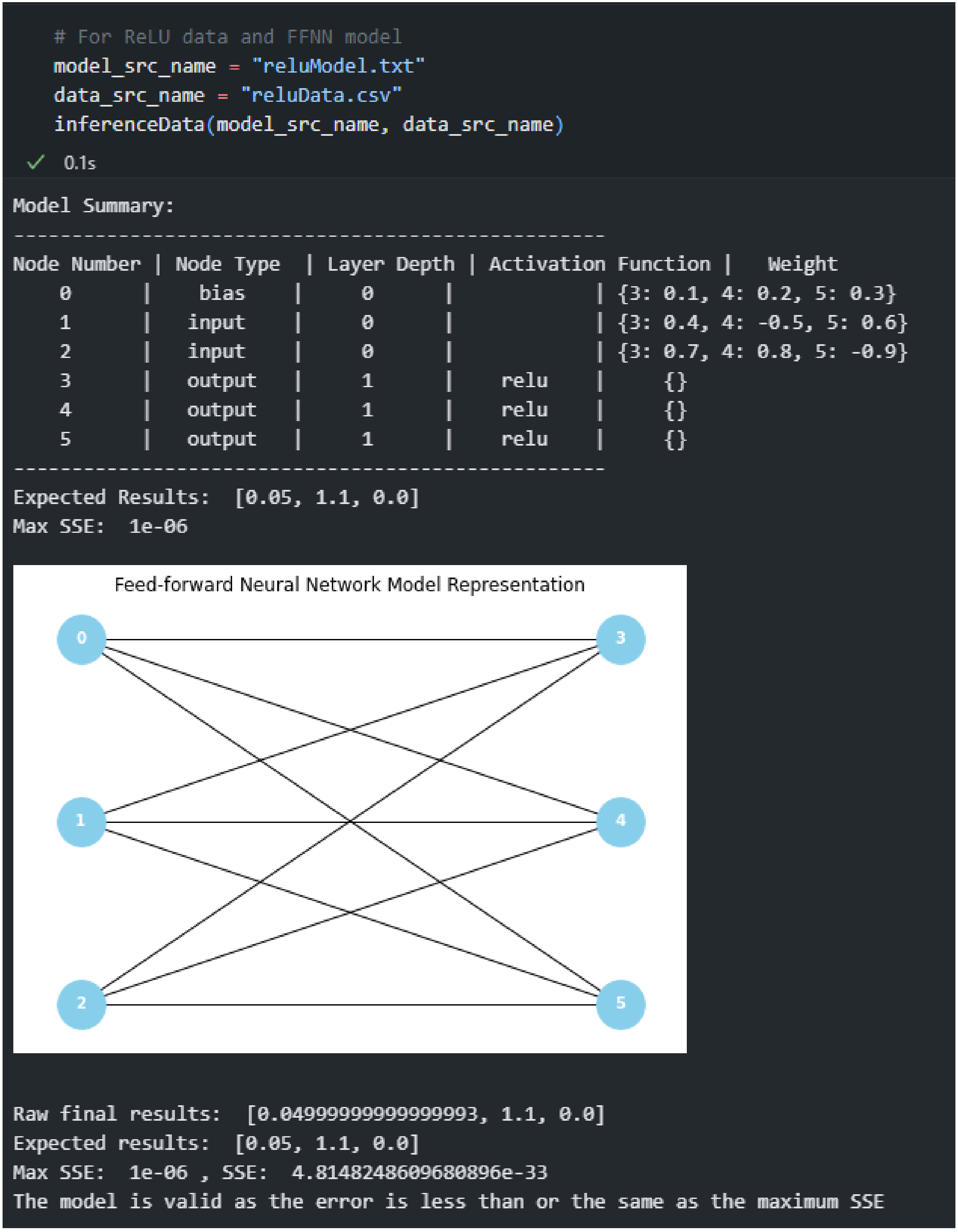
```
-1.0,0.5
```

   b. File .txt ("reluModel.txt")



```
0
0,bias,0,1,,3:0.1,4:0.2,5:0.3
1,input,0,0,,3:0.4,4:-0.5,5:0.6
2,input,0,0,,3:0.7,4:0.8,5:-0.9
3,output,1,0,relu,
4,output,1,0,relu,
5,output,1,0,relu,
[0.05,1.1,0.0]
0.000001
```

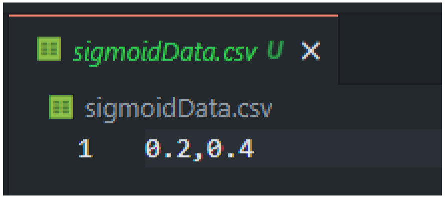
c. Hasil Pengujian



```
# For ReLU data and FFNN model
model_src_name = "reluModel.txt"
data_src_name = "reluData.csv"
inferenceData(model_src_name, data_src_name)
```

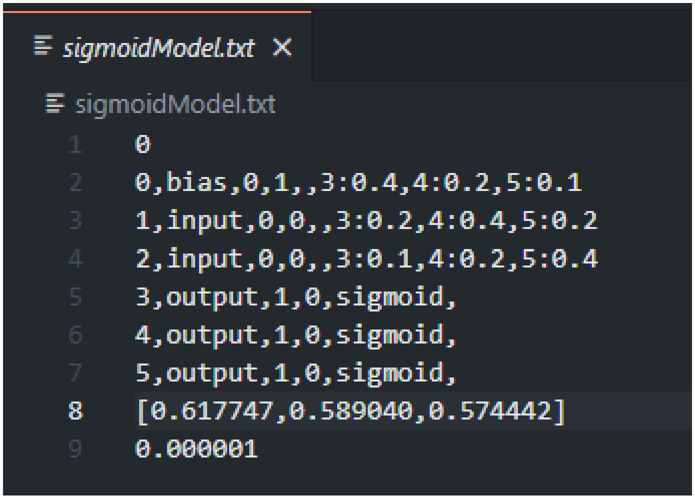
```
Model Summary:
---------------------------------------------------
Node Number | Node Type  | Layer Depth | Activation Function |   Weight
    0       |    bias    |      0      |             | {3: 0.1, 4: 0.2, 5: 0.3}
    1       |   input    |      0      |             | {3: 0.4, 4: -0.5, 5: 0.6}
    2       |   input    |      0      |             | {3: 0.7, 4: 0.8, 5: -0.9}
    3       |   output   |      1      |    relu     |     {}
    4       |   output   |      1      |    relu     |     {}
    5       |   output   |      1      |    relu     |     {}
---------------------------------------------------
Expected Results:  [0.05, 1.1, 0.0]
Max SSE:  1e-06

Raw final results:  [0.049999999999999993, 1.1, 0.0]
Expected results:  [0.05, 1.1, 0.0]
Max SSE:  1e-06 , SSE:  4.8148248609680896e-33
The model is valid as the error is less than or the same as the maximum SSE
```

3. Sigmoid Testcase
   a. File .csv (“sigmoidData.csv”)



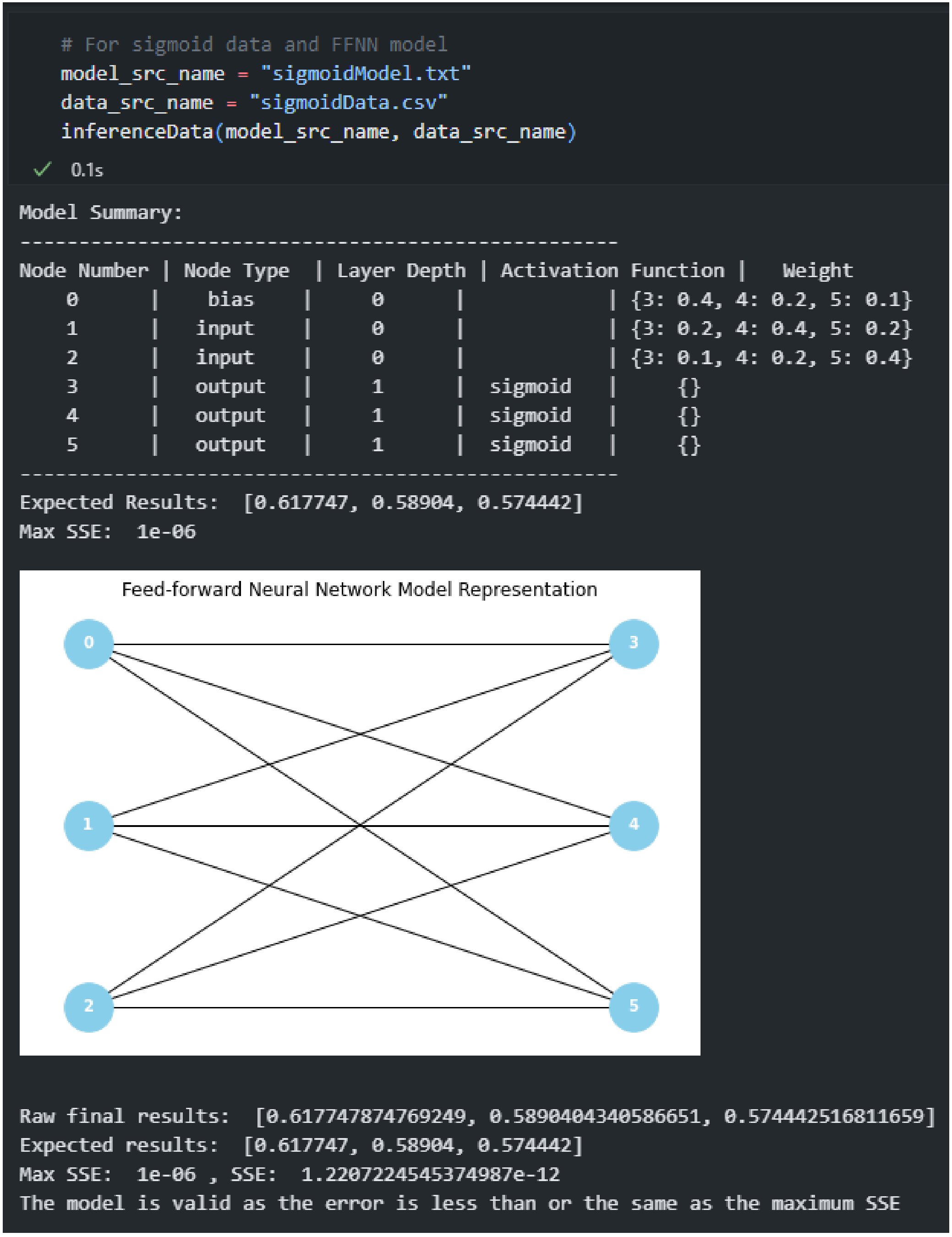
```
0.2,0.4
```

   b. File .txt (“sigmoidModel.txt”)



```
0
0,bias,0,1,,3:0.4,4:0.2,5:0.1
1,input,0,0,,3:0.2,4:0.4,5:0.2
2,input,0,0,,3:0.1,4:0.2,5:0.4
3,output,1,0,sigmoid,
4,output,1,0,sigmoid,
5,output,1,0,sigmoid,
[0.617747,0.589040,0.574442]
0.000001
```

c. Hasil Pengujian



```
# For sigmoid data and FFNN model
model_src_name = "sigmoidModel.txt"
data_src_name = "sigmoidData.csv"
inferenceData(model_src_name, data_src_name)
```

✓ 0.1s

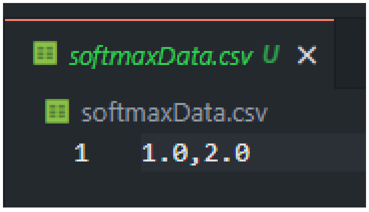
```
Model Summary:
---------------------------------------------------
Node Number | Node Type  | Layer Depth | Activation Function |   Weight
    0       |    bias    |     0       |             | {3: 0.4, 4: 0.2, 5: 0.1}
    1       |   input    |     0       |             | {3: 0.2, 4: 0.4, 5: 0.2}
    2       |   input    |     0       |             | {3: 0.1, 4: 0.2, 5: 0.4}
    3       |   output   |     1       |  sigmoid    |     {}
    4       |   output   |     1       |  sigmoid    |     {}
    5       |   output   |     1       |  sigmoid    |     {}
---------------------------------------------------
Expected Results:  [0.617747, 0.58904, 0.574442]
Max SSE:  1e-06
```

Feed-forward Neural Network Model Representation

```
Raw final results:  [0.617747874769249, 0.5890404340586651, 0.574442516811659]
Expected results:  [0.617747, 0.58904, 0.574442]
Max SSE:  1e-06 , SSE:  1.2207224545374987e-12
The model is valid as the error is less than or the same as the maximum SSE
```

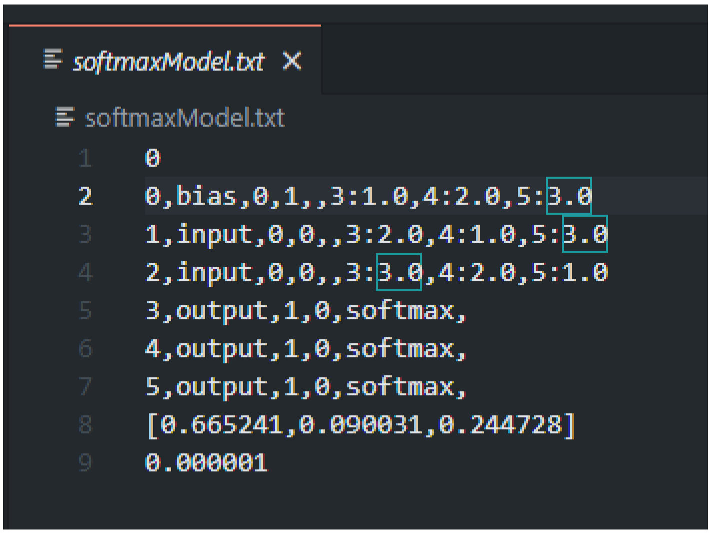
4. Softmax Testcase

a. File .csv ("softmaxData.csv")



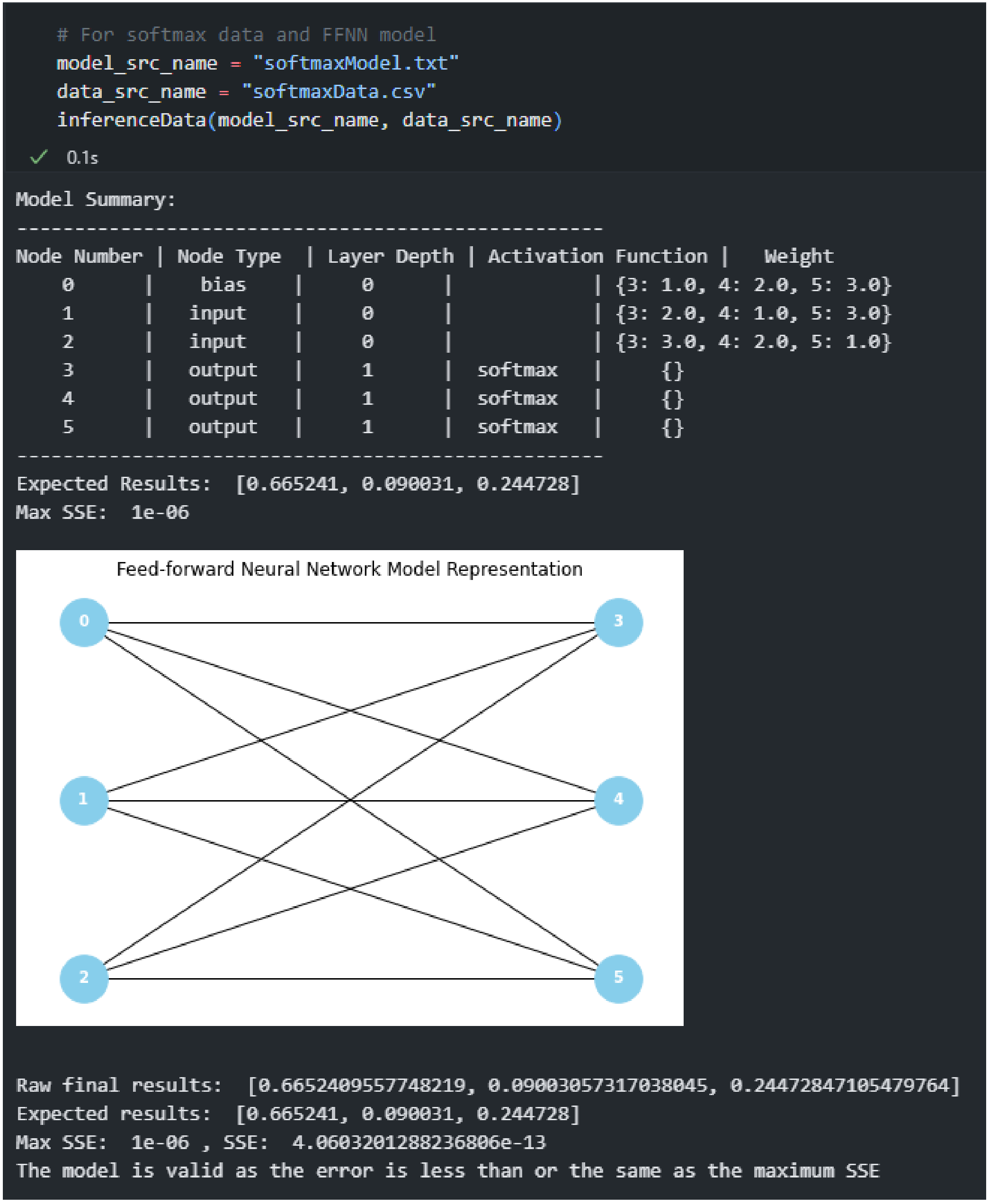
```
1    1.0,2.0
```

b. File .txt ("softmaxModel.txt")



```
0
0,bias,0,1,,3:1.0,4:2.0,5:3.0
1,input,0,0,,3:2.0,4:1.0,5:3.0
2,input,0,0,,3:3.0,4:2.0,5:1.0
3,output,1,0,softmax,
4,output,1,0,softmax,
5,output,1,0,softmax,
[0.665241,0.090031,0.244728]
0.000001
```

c. Hasil Pengujian



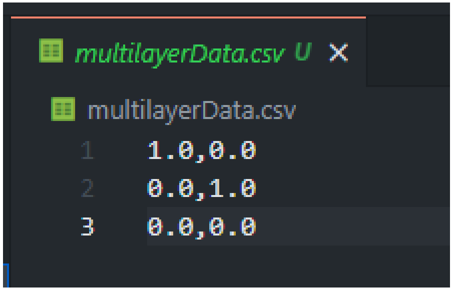
```
# For softmax data and FFNN model
model_src_name = "softmaxModel.txt"
data_src_name = "softmaxData.csv"
inferenceData(model_src_name, data_src_name)
```

```
Model Summary:
----------------------------------------------------
Node Number | Node Type  | Layer Depth | Activation Function |   Weight
    0       |    bias    |      0      |             | {3: 1.0, 4: 2.0, 5: 3.0}
    1       |   input    |      0      |             | {3: 2.0, 4: 1.0, 5: 3.0}
    2       |   input    |      0      |             | {3: 3.0, 4: 2.0, 5: 1.0}
    3       |   output   |      1      |   softmax   |     {}
    4       |   output   |      1      |   softmax   |     {}
    5       |   output   |      1      |   softmax   |     {}
----------------------------------------------------
Expected Results:  [0.665241, 0.090031, 0.244728]
Max SSE:  1e-06
```

```
Raw final results:  [0.6652409557748219, 0.09003057317038045, 0.24472847105479764]
Expected results:  [0.665241, 0.090031, 0.244728]
Max SSE:  1e-06 , SSE:  4.0603201288236806e-13
The model is valid as the error is less than or the same as the maximum SSE
```

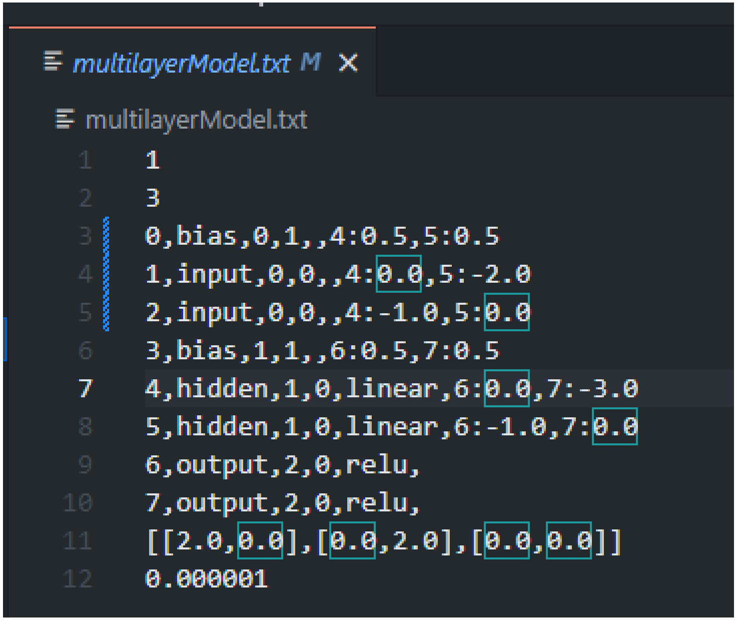
5. Multilayer Testcase

   a. File .csv (“multilayerData.csv”)



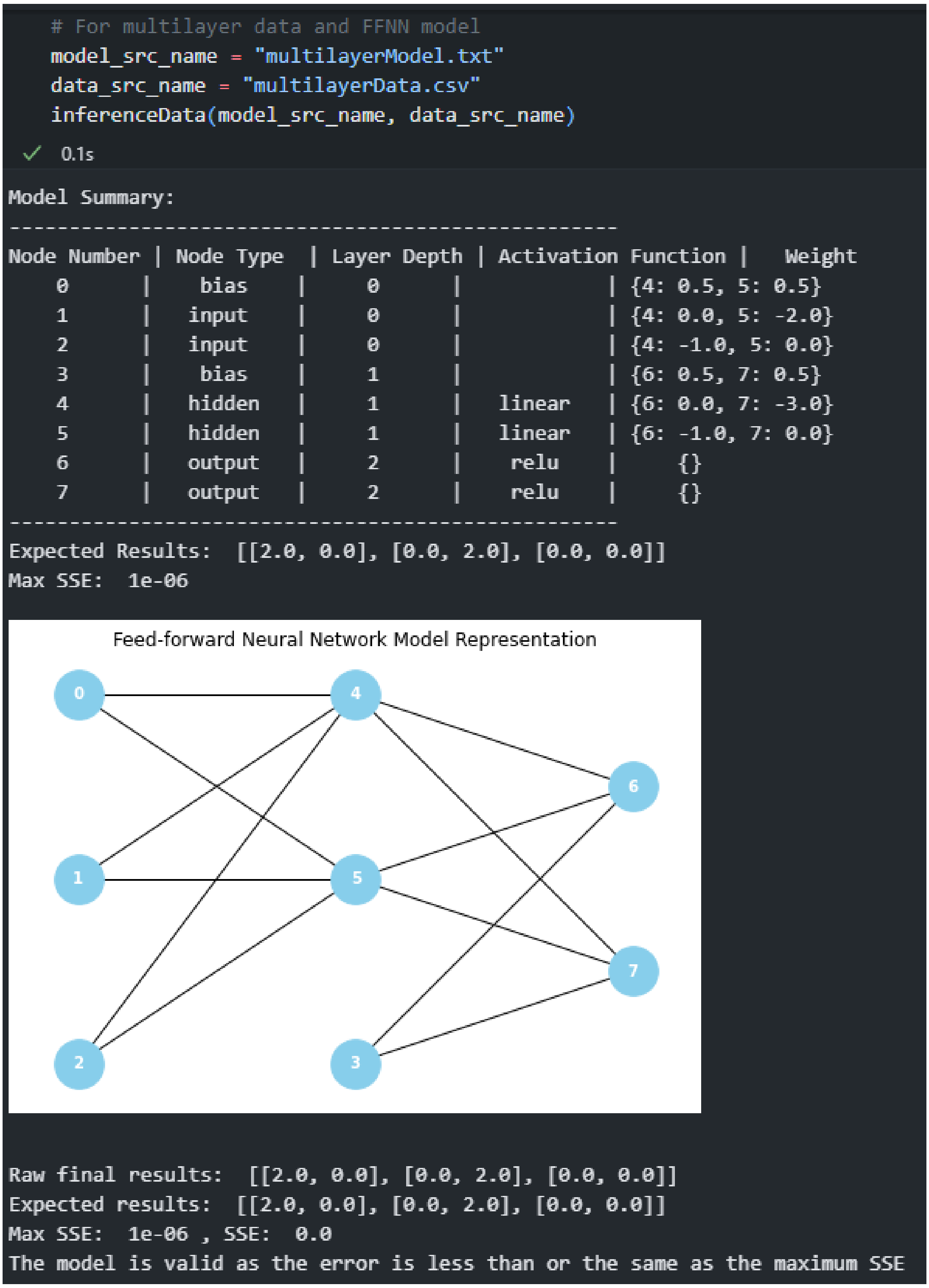
```
1.0,0.0
0.0,1.0
0.0,0.0
```

   b. File .txt (“multilayerModel.txt”)



```
1
3
0,bias,0,1,,4:0.5,5:0.5
1,input,0,0,,4:0.0,5:-2.0
2,input,0,0,,4:-1.0,5:0.0
3,bias,1,1,,6:0.5,7:0.5
4,hidden,1,0,linear,6:0.0,7:-3.0
5,hidden,1,0,linear,6:-1.0,7:0.0
6,output,2,0,relu,
7,output,2,0,relu,
[[2.0,0.0],[0.0,2.0],[0.0,0.0]]
0.000001
```

   c. Hasil Pengujian



```
# For multilayer data and FFNN model
model_src_name = "multilayerModel.txt"
data_src_name = "multilayerData.csv"
inferenceData(model_src_name, data_src_name)
```

✓ 0.1s

```
Model Summary:
---------------------------------------------------
Node Number | Node Type  | Layer Depth | Activation Function |   Weight
    0       |   bias     |     0       |            | {4: 0.5, 5: 0.5}
    1       |   input    |     0       |            | {4: 0.0, 5: -2.0}
    2       |   input    |     0       |            | {4: -1.0, 5: 0.0}
    3       |   bias     |     1       |            | {6: 0.5, 7: 0.5}
    4       |   hidden   |     1       |   linear   | {6: 0.0, 7: -3.0}
    5       |   hidden   |     1       |   linear   | {6: -1.0, 7: 0.0}
    6       |   output   |     2       |    relu    |     {}
    7       |   output   |     2       |    relu    |     {}
---------------------------------------------------
Expected Results:  [[2.0, 0.0], [0.0, 2.0], [0.0, 0.0]]
Max SSE:  1e-06
```

```
Raw final results:  [[2.0, 0.0], [0.0, 2.0], [0.0, 0.0]]
Expected results:  [[2.0, 0.0], [0.0, 2.0], [0.0, 0.0]]
Max SSE:  1e-06 , SSE:  0.0
The model is valid as the error is less than or the same as the maximum SSE
```

IV. Pembagian Tugas Anggota Kelompok

Semua bagian dari tugas besar ini, laporan dan sumber kode (*source code*), dikerjakan oleh Gede Prasidha Bhawarnawa dari kelas K01 dengan NIM 13520004.