Vidyalankar Institute of Technology — Accredited A+ by NAAC	DEPARTMENT OF COMPUTER ENGINEERING

Experiment No. 05

Semester	B.E. Semester VIII – Computer Engineering
Subject	Deep Learning Lab
Subject Professor In-charge	Prof. Kavita Shirsat
Academic Year	2024-25

Student Name	Deep Salunkhe
Roll Number	21102A0014

Title: Backpropagation algorithm to train a fully connected DNN

Explanation:

The bp function implements the **backpropagation algorithm**, which is a key component of training artificial neural networks. It is used to adjust the weights of the network based on the error between the predicted output and the actual target values. The function follows these steps:

Step 1: Initialize Required Data Structures

- nm: A new map to store updated weights.
- deltas: A map to store error gradients (partial derivatives) for weight updates.
- nta: The learning rate (set to 1 in this case).
- nl: Total number of layers in the neural network.
- sl: Index of the second-last layer (output layer is at nl-1, so second-last is nl-2).

Step 2: Compute Output Layer Error

For the **output layer**, the gradient (delta) is computed as:

$$\delta = \text{neuron}[sl+1][j] \times (1 - \text{neuron}[sl+1][j]) \times (\text{target}[j] - \text{neuron}[sl+1][j])$$

This formula comes from differentiating the loss function (usually Mean Squared Error or Cross-Entropy) with respect to the neuron activation.

- **For each neuron j in the output layer (sl+1)**:
  - Compute the delta value.
  - Store it in the deltas map.
  - Update the corresponding weight using:

$$\Delta w = \text{learning rate} \times \delta \times \text{neuron}[sl][i]$$

- The updated weight is stored in nm.

Step 3: Compute Hidden Layer Errors

For hidden layers (i going from sl-1 to 0):

- The delta for each neuron is computed using the **chain rule** by propagating the error backward.

$$\delta = \text{neuron}[i+1][k] \times (1 - \text{neuron}[i+1][k]) \times \sum(\delta_{\text{next layer}} \times \text{weight}_{\text{current to next}})$$

- The **sum term** accumulates contributions from all neurons in the next layer (i+2).
- The weight update follows the same formula as in the output layer.
- Store the updated weights in nm.

Step 4: Update Weights

Finally, replace the original weight matrix m with nm, ensuring the updated weights are used in the next forward pass.

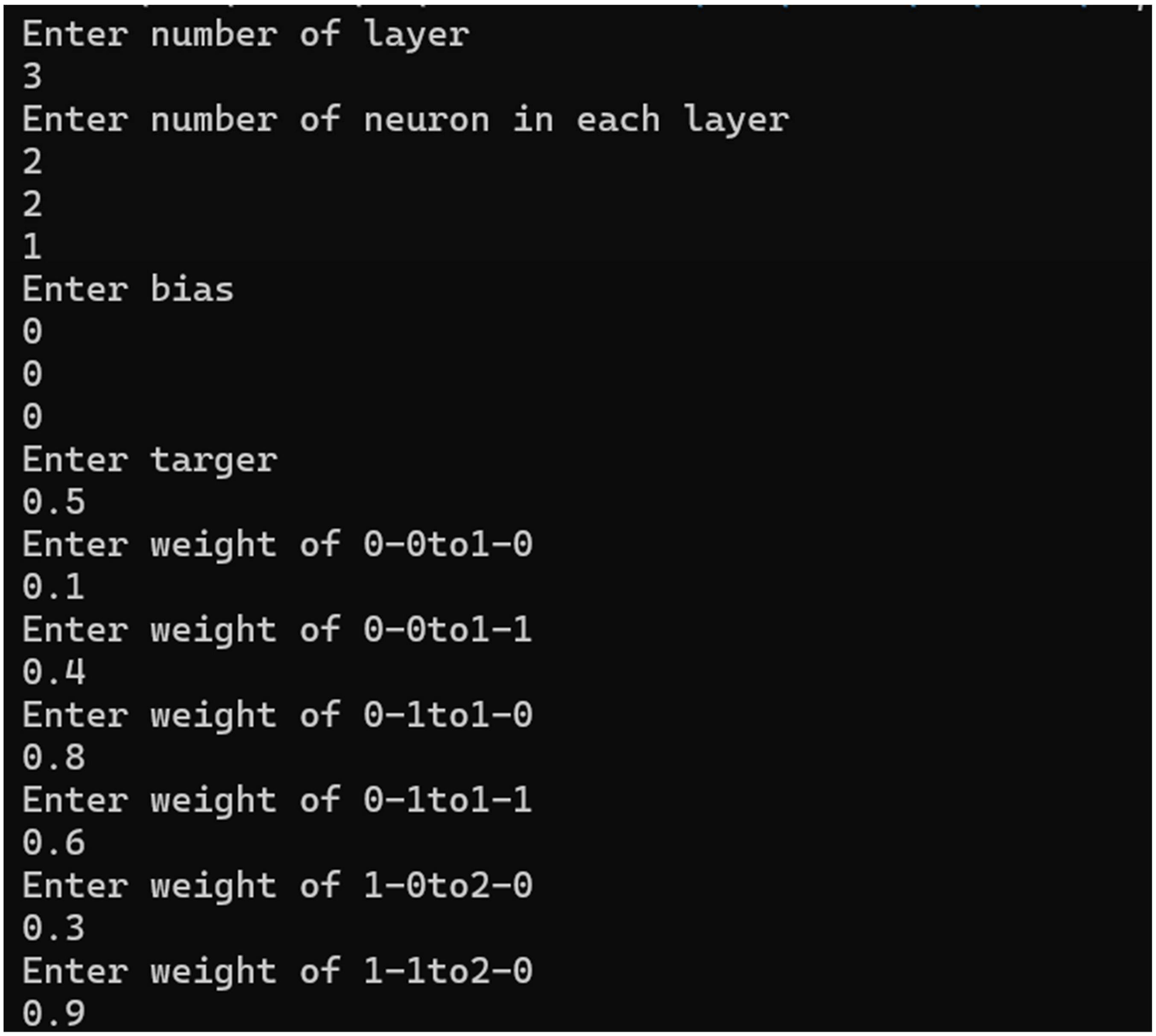
Implementation:

```
#include <iostream>
#include <vector>
#include <map>
#include <math.h>
using namespace std;

void printMap(map<pair<pair<int, int>, pair<int, int>>, float> &m)
{
    for (const auto &entry : m)
    {
        const auto &key = entry.first;
        const auto &value = entry.second;

        // Printing the key: pair<pair<int, int>, pair<int, int>>
        cout << "Key: ((" << key.first.first << ", " << key.first.second << "), ("
             << key.second.first << ", " << key.second.second << ")) ";
        // Printing the value
        cout << "Value: " << value << endl;
    }
}

void takeweights(map<pair<pair<int, int>, pair<int, int>>, float> &m, vector<int>
neuronCount)
{
    int nl = neuronCount.size();
    for (int i = 0; i < nl - 1; i++)
    {
        for (int j = 0; j < neuronCount[i]; j++)
        {
            for (int k = 0; k < neuronCount[i + 1]; k++)
            {
                cout << "Enter weight of " << i << "-" << j << "to" << i + 1 << "-" <<
k << endl;
                float t;
                cin >> t;
                m[{{i, j}, {i + 1, k}}] = t;
            }
        }
    }
```

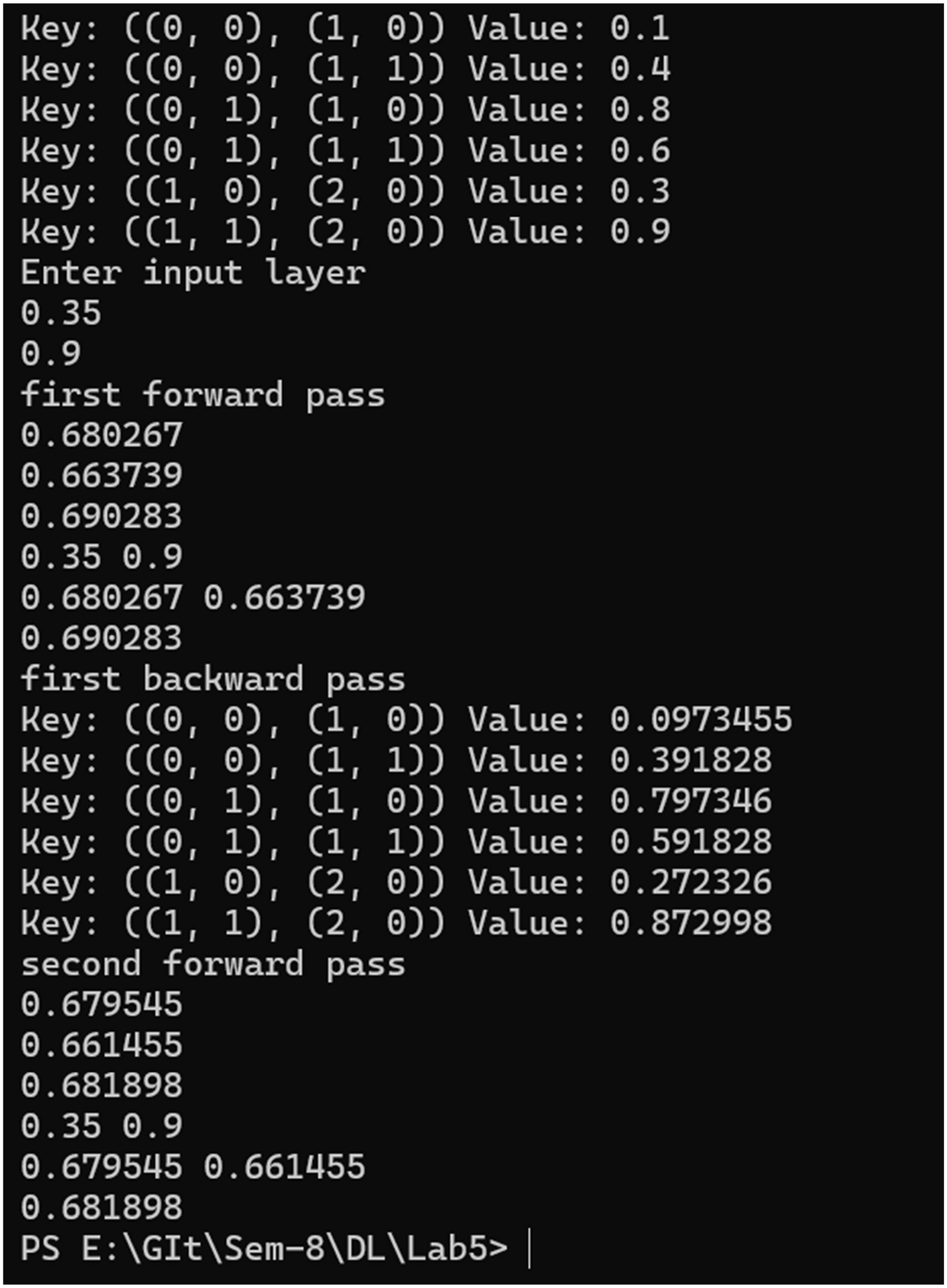
```
}

void inputlayer(vector<vector<float>> &neuron, vector<int> neuronCount)
{
    int inls = neuronCount[0];

    cout << "Enter input layer" << endl;

    for (int i = 0; i < inls; i++)
    {
        float t;
        cin >> t;
        neuron[0].push_back(t);
    }
}

// void
ff(vector<vector<float>>neuron,vector<int>neuronCount,  map<pair<pair<int,int>,pair<int
,int>>,float>m,vector<float>bias){
//   int nn=neuronCount.size();
//   for(int i=0;i<nn-1;i++){
//       for(int j=0;j<neuronCount[i+1];j++){
//           float cal=0;
//           for(int k=0;k<neuronCount[i];k++){
//                cal+=neuron[i][k]*m[{{i,k},{i+1,j}}];
//           }
//           cal=cal+bias[i+1];
//           neuron[i+1].push_back(1/(1+pow(2.71828,-cal)));
//           cout<<neuron[i+1].back()<<endl;
//       }
//       cout<<"hi"<<endl;
//       cout<<neuron[i+1].size()<<endl;
//   }
// }

void ff(vector<vector<float>> &neuron, vector<int> &neuronCount, map<pair<pair<int,
int>, pair<int, int>>, float> &m, vector<float> &bias)
{
    int nn = neuronCount.size();

    // Make sure all layers except the first are pre-sized (if you want to add elements
dynamically)
    for (int i = 1; i < nn; i++)
    {
        neuron[i].clear(); // Clear the previous layer values, if any
    }

    for (int i = 0; i < nn - 1; i++)
    {
        for (int j = 0; j < neuronCount[i + 1]; j++)
        {
            float cal = 0;

            // Calculate weighted sum for the current neuron in the next layer
            for (int k = 0; k < neuronCount[i]; k++)
            {
                cal += neuron[i][k] * m[{{i, k}, {i + 1, j}}]; // weight from layer i
to layer i+1
            }

            // Add bias for the current neuron in the next layer
            cal = cal + bias[i + 1];

            // Apply the sigmoid activation function
            float output = 1 / (1 + exp(-cal)); // Sigmoid function: 1 / (1 + e^(-x))

            // Push the output of the neuron in the next layer
            neuron[i + 1].push_back(output);

            cout << neuron[i + 1].back() << endl; // Print the output of the current
neuron
        }
        // cout << "hi" << endl;
        // cout << neuron[i + 1].size() << endl;  // Print the size of the next layer
    }
}

void printNeuron(vector<vector<float>> neuron, vector<int> neuronCount)
{
    int n = neuronCount.size();

    for (int i = 0; i < n; i++)
    {
        int ns = neuron[i].size();
        for (int j = 0; j < ns; j++)
        {
            cout << neuron[i][j] << " ";
        }
        cout << endl;
    }
}

// void printNeuron(const vector<vector<float>>& neuron, const vector<int>&
neuronCount) {
//     int n = neuronCount.size();
//
```

```
//     // Check if the size of neuron matches neuronCount
//     for(int i = 0; i < n; i++) {
//         int ns = neuronCount[i];
//
//         // Ensure that the number of neurons in each layer is consistent with the
neuronCount
//         if (neuron[i].size() != ns) {
//             cout << "Error: Mismatch in neuron size for layer " << i << endl;
//             return;  // Exit the function if there's an inconsistency
//         }
//
//         for(int j = 0; j < ns; j++) {
//             cout << neuron[i][j] << " ";
//         }
//         cout << endl;
//     }
// }

void bp(vector<vector<float>> neuron, map<pair<pair<int, int>, pair<int, int>>, float>
&m, vector<int> neuronCount, vector<float> target)
{
    map<pair<pair<int, int>, pair<int, int>>, float> nm;
    map<pair<pair<int, int>, pair<int, int>>, float> deltas;

    int nta = 1;

    // for output layer edges

    int nl = neuronCount.size(); // number of layer

    int sl = nl - 2;

    for (int i = 0; i < neuronCount[sl]; i++)
    {

        for (int j = 0; j < neuronCount[sl + 1]; j++)
        {
            float deltat = neuron[sl + 1][j] * (1 - neuron[sl + 1][j]) * (target[j] -
neuron[sl + 1][j]);
            deltas[{{sl, i}, {sl + 1, j}}] = deltat;
            float deltaw = nta * deltat * neuron[sl][i];

            nm[{{sl, i}, {sl + 1, j}}] = m[{{sl, i}, {sl + 1, j}}] + deltaw;
        }
    }

    // for remaning edges
    for (int i = sl - 1; i >= 0; i--)
    {
        for (int j = 0; j < neuronCount[i]; j++)
        {
            for (int k = 0; k < neuronCount[i + 1]; k++)
            {

                float thatsum = 0;

                for (int t = 0; t < neuronCount[i + 2]; t++)
                {
                    thatsum += deltas[{{i + 1, k}, {i + 2, t}}] * m[{{i + 1, k}, {i +
2, t}}];
                }

                float deltat = neuron[i + 1][k] * (1 - neuron[i + 1][k]) * thatsum;
                deltas[{{i, j}, {i + 1, k}}] = deltat;

                float deltaw = nta * deltat * neuron[i][j];
                nm[{{i, j}, {i + 1, k}}] = m[{{i, j}, {i + 1, k}}] + deltat;
            }
        }
    }

    printMap(nm);
    m = nm;
}

int main()
{

    int hl;
    cout << "Enter number of layer" << endl;
    cin >> hl;
    vector<int> neuronCount(hl);
    cout << "Enter number of neuron in each layer" << endl;
    for (int i = 0; i < hl; i++)
    {
        cin >> neuronCount[i];
    }
    vector<vector<float>> neuron(hl);
    cout << "Enter bias" << endl;
    vector<float> bias(hl);
    for (int i = 0; i < hl; i++)
    {
        float t;
        cin >> t;
        bias[i] = t;
    }

    vector<float> target(neuronCount[hl - 1]);
    cout << "Enter targer" << endl;
    for (int i = 0; i < neuronCount[hl - 1]; i++)
    {
        cin >> target[i];
    }

    map<pair<pair<int, int>, pair<int, int>>, float> m;
    takeweights(m, neuronCount);
    printMap(m);
    inputlayer(neuron, neuronCount);
    cout << "first forward pass" << endl;
    ff(neuron, neuronCount, m, bias);
    printNeuron(neuron, neuronCount);
    cout << "first backward pass" << endl;
    bp(neuron, m, neuronCount, target);
    cout << "second forward pass" << endl;
    ff(neuron, neuronCount, m, bias);
    printNeuron(neuron, neuronCount);

    return 0;
}
```

Output:



```
Enter number of layer
3
Enter number of neuron in each layer
2
2
1
Enter bias
0
0
0
Enter targer
0.5
Enter weight of 0-0to1-0
0.1
Enter weight of 0-0to1-1
0.4
Enter weight of 0-1to1-0
0.8
Enter weight of 0-1to1-1
0.6
Enter weight of 1-0to2-0
0.3
Enter weight of 1-1to2-0
0.9
```



```
Key: ((0, 0), (1, 0)) Value: 0.1
Key: ((0, 0), (1, 1)) Value: 0.4
Key: ((0, 1), (1, 0)) Value: 0.8
Key: ((0, 1), (1, 1)) Value: 0.6
Key: ((1, 0), (2, 0)) Value: 0.3
Key: ((1, 1), (2, 0)) Value: 0.9
Enter input layer
0.35
0.9
first forward pass
0.680267
0.663739
0.690283
0.35 0.9
0.680267 0.663739
0.690283
first backward pass
Key: ((0, 0), (1, 0)) Value: 0.0973455
Key: ((0, 0), (1, 1)) Value: 0.391828
Key: ((0, 1), (1, 0)) Value: 0.797346
Key: ((0, 1), (1, 1)) Value: 0.591828
Key: ((1, 0), (2, 0)) Value: 0.272326
Key: ((1, 1), (2, 0)) Value: 0.872998
second forward pass
0.679545
0.661455
0.681898
0.35 0.9
0.679545 0.661455
0.681898
PS E:\GIt\Sem-8\DL\Lab5>
```