Sustainable Data Science and Artificial Intelligence

Tutorial #5

**Instructions**

The following C code is for a neural network that learns the XOR logical operation. The two key hyperparameters (LEARNING\_RATE and EPOCHS) are defined near the top of the code as follows:

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| **C Programming Language** |
| #include <stdio.h>  #include <stdlib.h>  #include <math.h>  // Parameters  #define LEARNING\_RATE 0.5  #define EPOCHS 10000  // Sigmoid activation function  double sigmoid(double x) {  return 1 / (1 + exp(-x));  }  // Derivative of sigmoid  double sigmoid\_derivative(double x) {  return x \* (1 - x);  }  int main() {  // Training data (XOR problem)  double input[4][2] = {  {0, 0},  {0, 1},  {1, 0},  {1, 1}  };  double expected\_output[4] = {0, 1, 1, 0};  // Initialize weights and biases with random values  double hidden\_weights[2][3] = {{0.5, -0.2, 0.3}, {-0.3, 0.8, -0.5}};  double hidden\_bias[3] = {0.1, -0.1, 0.2};  double output\_weights[3] = {0.6, -0.4, 0.7};  double output\_bias = 0.2;  // Training loop  for (int epoch = 0; epoch < EPOCHS; epoch++) {  double total\_error = 0;  for (int i = 0; i < 4; i++) {  // Forward pass - Hidden layer  double hidden\_layer[3];  for (int j = 0; j < 3; j++) {  hidden\_layer[j] = sigmoid(input[i][0] \* hidden\_weights[0][j] +  input[i][1] \* hidden\_weights[1][j] +  hidden\_bias[j]);  }  // Forward pass - Output layer  double output = sigmoid(hidden\_layer[0] \* output\_weights[0] +  hidden\_layer[1] \* output\_weights[1] +  hidden\_layer[2] \* output\_weights[2] +  output\_bias);  // Compute error  double error = expected\_output[i] - output;  total\_error += error \* error;  // Backpropagation - Output layer  double output\_delta = error \* sigmoid\_derivative(output);  // Backpropagation - Hidden layer  double hidden\_delta[3];  for (int j = 0; j < 3; j++) {  hidden\_delta[j] = output\_delta \* output\_weights[j] \* sigmoid\_derivative(hidden\_layer[j]);  }  // Update weights and biases  for (int j = 0; j < 3; j++) {  output\_weights[j] += LEARNING\_RATE \* output\_delta \* hidden\_layer[j];  hidden\_weights[0][j] += LEARNING\_RATE \* hidden\_delta[j] \* input[i][0];  hidden\_weights[1][j] += LEARNING\_RATE \* hidden\_delta[j] \* input[i][1];  hidden\_bias[j] += LEARNING\_RATE \* hidden\_delta[j];  }  output\_bias += LEARNING\_RATE \* output\_delta;  }  }  // Testing the trained network  for (int i = 0; i < 4; i++) {  double hidden\_layer[3];  // Forward pass - Hidden layer  for (int j = 0; j < 3; j++) {  hidden\_layer[j] = sigmoid(input[i][0] \* hidden\_weights[0][j] +  input[i][1] \* hidden\_weights[1][j] +  hidden\_bias[j]);  }  // Forward pass - Output layer  double output = sigmoid(hidden\_layer[0] \* output\_weights[0] +  hidden\_layer[1] \* output\_weights[1] +  hidden\_layer[2] \* output\_weights[2] +  output\_bias);  printf("Input: (%.0f, %.0f) -> Output: %.4f\n", input[i][0], input[i][1], output);  }  return 0;  } |

With those settings you should get the following:

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| **Hyperparameters** | **Outputs** |
| #define LEARNING\_RATE 0.5  #define EPOCHS 10000 | Input: (0, 0) -> Output: 0.0164  Input: (0, 1) -> Output: 0.9790  Input: (1, 0) -> Output: 0.9869  Input: (1, 1) -> Output: 0.0146 |

For this tutorial change the LEARNING\_RATE, and record the outputs, as follows:

Learning Rate = 1, Epochs = 10000

Learning Rate = 5, Epochs = 10000

Learning Rate = 10, Epochs = 10000

Learning Rate = 15, Epochs = 10000

Learning Rate = 20, Epochs = 10000

Learning Rate = 25, Epochs = 10000

Learning Rate = 30, Epochs = 10000

Learning Rate = 35, Epochs = 10000

Learning Rate = 40, Epochs = 10000

Learning Rate = 45, Epochs = 10000

1. Identify which settings give you the closest to 0,1,1,0.
2. If the best setting is N, then test if any of the following gives a better answer:

N - 3, N - 2, N - 1, N + 1, N + 2, or N + 3

**Submission Instructions**

Please submit in the following two ways

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| Please e-mail me your completed solution, and with filename:  *Familyname\_FirstName\_TU850\_1\_SDSaAI\_Tutorial5.docx*  e.g.  *Gordon\_Damian\_TU850\_1\_SDSaAI\_ Tutorial5.docx*  e-mail to [Damian.X.Gordon@TUDublin.ie](mailto:Damian.X.Gordon@TUDublin.ie) with subject heading as follows:  [DT850/1] SDSaAI Tutorial #5 |
| Please submit into Brightspace in:   * Assessment   + Assignments     - Tutorial #5 |

For the email, please include the following message:

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| **Damian,**  **I am a student in your Sustainable DS & AI (CMPU1040) class in the BSc in DS & AI (DT850/1).**    **Please find attached Tutorial #5**  **Regards,**  **Your Name**  **Student Number.**  **DT580, BSc in DS & AI** |