# Assignment 4 Report

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This report is about the result of my implementation of Paricles Swarm Optimization (PSO) for optimizing the MLP on Rust language for 261456 - INTRO COMP INTEL FOR CPE class assignment. If you are interested to know how I implement PSO and use it to optimize the MLP , you can see the source code on my Github repository or in this document appendix.

## Problem

Given the AirQualityUCI dataset from UCI machine learning repository which has 9358 samples and 14 attributes as follows:

1. Date (DD/MM/YYYY)
2. Time (HH.MM.SS)
3. True hourly averaged concentration CO in mg/$m^3$ (reference analyzer)
4. PT08.S1 (tin oxide) hourly averaged sensor response (nominally CO targeted)
5. True hourly averaged overall Non Metanic HydroCarbons concentration in microg/$m^3$ (reference analyzer)
6. **True hourly averaged Benzene concentration in microg/$m^3$ (reference analyzer)**
7. PT08.S2 (titania) hourly averaged sensor response (nominally NMHC targeted)
8. True hourly averaged NOx concentration in ppb (reference analyzer)
9. PT08.S3 (tungsten oxide) hourly averaged sensor response (nominally NOx targeted)
10. True hourly averaged NO2 concentration in microg/$m^3$ (reference analyzer)
11. PT08.S4 (tungsten oxide) hourly averaged sensor response (nominally NO2 targeted)
12. PT08.S5 (indium oxide) hourly averaged sensor response (nominally O3 targeted)
13. Temperature in Â°C
14. Relative Humidity (%)
15. AH Absolute Humidity

We want to use the underlined attributes 4, 7, 9, 11, 12, 13, 14, 15 to predict attribute 6 (benzene concentration) in next 5 days and next 10 days.

## Dataset Preparation

We will refer to the underlined attributes as “features” and attribute 6 (benzene concentration) as “desired output”. The dataset preparation process will follow these steps (implementation on source code 7):

1. Load the dataset from the csv file and removing any samples that has a missing value (missing value are tagged with -200 value).
2. Match each features with desired output of the next 5 and 10 days, then we will get an array of tuple (features, next 5 days desired output) and tuple (features, next 10 days desired output).

The array of tuple (features, next 5 days desired output) and tuple (features, next 10 days desired output) will be used for training our MLP.

# Particles Swarm Optimization

## Particle Representation

A particle is represented by a list of weights and biases of MLP. We use weights and bias of top node to bottom node of each layer to create one individual, for an example: from 3-2-1 network in fig. 1 a particle is represented by (w1, w2, w3, b1, w4, w5, w6, b2, w7, w8, b3).

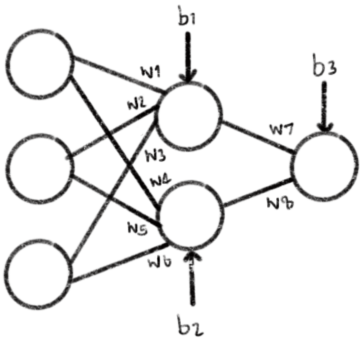



Figure 1: The 3-2-1 network.

## Full Process

Using 10% cross-validation, and preprocess each iteration training and validation set with min-max normalization. The min-max normalization process is done by for each feature $f$ on training set we find $max(f)$ and $min(f)$ then for each datapoint $f_x$ we compute new datapoint on both training set and validation set $f'_x = \frac{f_x - min(f)}{max(f) - min(f)}$, this will guarantee that we applied the min-max normalization using $min$ and $max$ from training set on both training set and validation set. Next, for each cross-validation iteration we follow the local best method described on [Aue13] page 138 which is (implementation on source code 5 and 6):

1. Initialize the particles population $P(t)$ at $t = 0$ which has 5 groups of 4 particles and for each particle we set the weights to a random number in range [-1.0, 1.0], and bias of each node to to 1.0.
2. For each group $j$ and each particle $i$ in group $j$ do:
   (a) Evaluate its performance $F$ using its current position $x_i(t)$ through all samples in training set.
   (b) Compare evaluation result from (a) with its best evaluation result $\text{pbest}_i$.
   **if** $F(x_i(t)) < \text{pbest}_i$ **then**
   $\text{pbest}_i = F(x_i(t))$
   $x_i^{\text{pbest}} = x_i(t)$
   **end if**
   (c) Compare evaluation result from (a) with the group's $\text{lbest}_j$.
   **if** $F(x_i(t)) < \text{lbest}_j$ **then**
   $\text{lbest}_j = F(x_i(t))$
   $x_{\text{lbest}_j} = x_i(t)$
   **end if**
   (d) Update the speed of $i$ by using following equation:

$$v_i(t) = v_i(t-1) + \rho_1(x_i^{pbest} - x_i(t)) + \rho_2(x_{\text{lbest}_j} - x_i(t))$$

   where $\rho_1 = r_1 c_1$ and $\rho_2 = r_2 c_2$ with $c_1 = 1.0$, $c_2 = 1.5$ and $r_1$, $r_2$ are a random number from uniform distribution of $(0, 1)$
   (e) Update $x_i$ by $x_i(t) = x_i(t-1) + v_i(t)$ and set $t = t + 1$
3. Repeat step 2. until $t = 100$.

## Training Result

For both next 5 days dataset and next 10 days dataset, we will experiment with 3 models to see if their training result will have any significant differences in training time and MAE (mean absolute error). The 3 models (implementation on source code 5) are

- **air-8-4-1**: The base model that contains 8 input nodes, 1 hidden layer with 4 nodes, and 1 output node. The result is shown on fig. 2 and fig. 3
- **air-8-1-1**: A smaller model with 8 input nodes, 1 hidden layer with 1 nodes, and 1 output node. The result is shown on fig. 4 and fig. 5
- **air-8-8-4-1**: A larger model with 8 input nodes, 2 hidden layers with 8 and 4 nodes, and 1 output node. The result is shown on fig. 6 and fig. 7

which the output node use linear activation function and other nodes use relu activation function. We use Rust compiler with release profile to build and run all training.

## Analysis

From table 1 and table 2, we can see that every model train on both next 5 days dataset and next 10 days dataset have a similar validation set MAE and similar training process as we can see in fig. 2, fig. 3, fig. 4, fig. 5, fig. 6 and fig. 7. The training process from those figures shows that every model seem to converge to MAE $\approx 5$ in less than $t = 25$ and can't find a position to make MAE lower. The reason why every model can not make MAE lower maybe is because this dataset need a much more complex MLP structure to create a better regression model. Next, the training time of each model is less with the less complex it is and more with the more complex it is, showing that PSO training times correlate with MLP complexity.

| Model | Training Time (seconds) | Mean Absolute Error (MAE) |
|---|---|---|
| air-8-4-1 | 62.233 | 5.194 |
| air-8-1-1 | 58.504 | 5.184 |
| air-8-8-4-1 | 81.596 | 5.216 |

Table 1: Training time and validation set MAE of next 5 days dataset (red line on fig. 2b, fig. 4b, and fig. 6b) of each model.

| Model | Training Time (seconds) | Mean Absolute Error (MAE) |
|---|---|---|
| air-8-4-1 | 61.401 | 5.107 |
| air-8-1-1 | 53.990 | 5.122 |
| air-8-8-4-1 | 78.985 | 5.256 |

Table 2: Training time and validation set MAE of next 10 days dataset (red line on fig. 3b, fig. 5b, and fig. 7b) of each model.

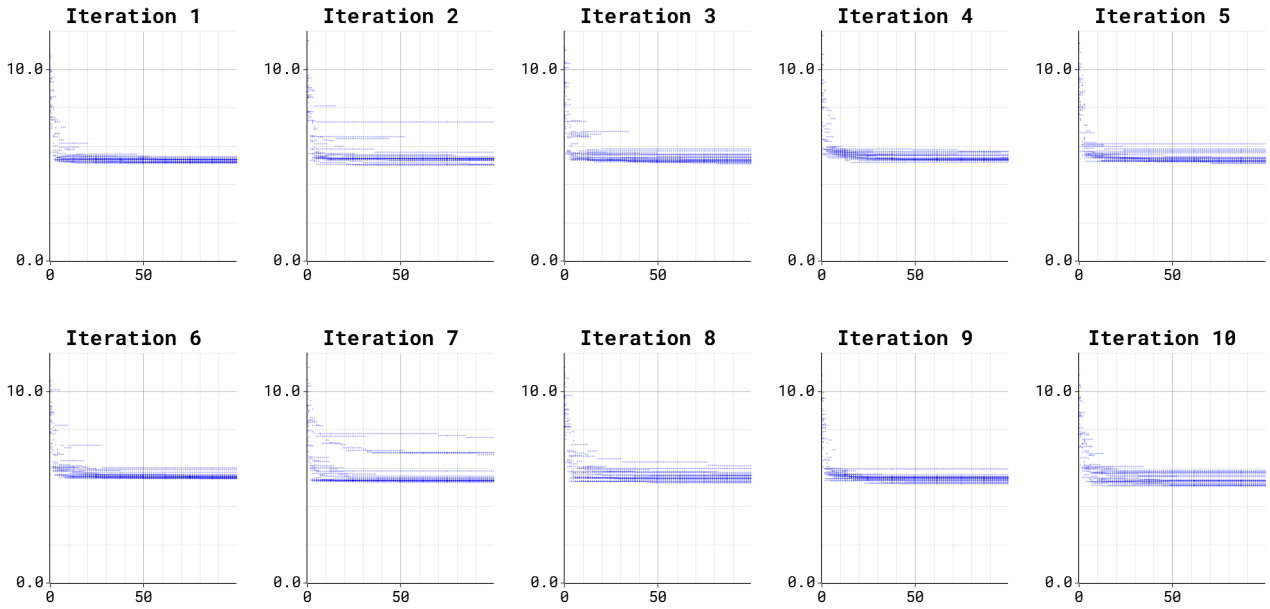
## Summary

Particles Swarm Optimization (PSO) can be used for training MLP with an okay performance within a reasonable times as shown on our experiment. Training the regression MLP for AirQualityUCI dataset seem to be a challenging problem with PSO, this may need a further investigation. Finally, Rust is a great languate to implement PSO with how fast it is and how easy it is to write a memory-safe program.

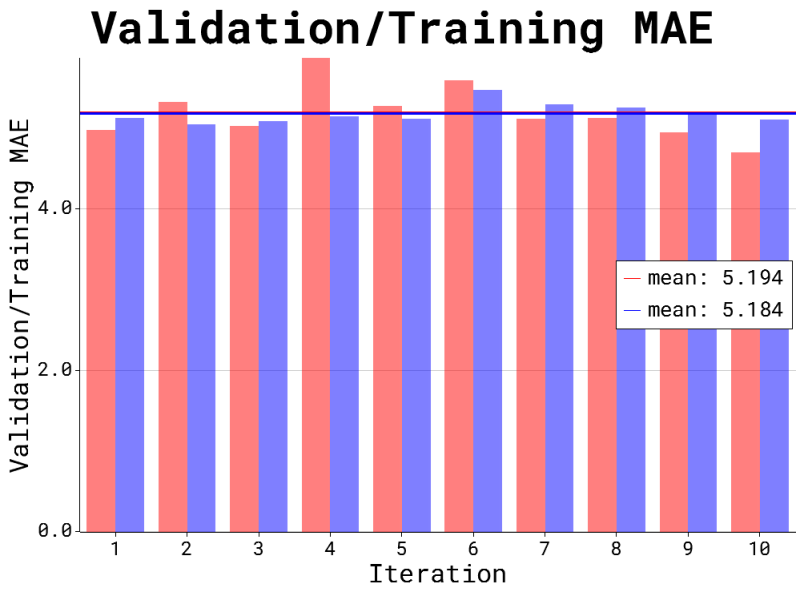
## References

[Aue13] Sansanee Auephanwiriyakul. *Introduction to Computational Intelligence for Computer Engineering.* 2013. URL: `http://myweb.cmu.ac.th/sansanee.a/Intro_CI_withwatermark.pdf`. (accessed: 8.11.2022).

# Appendix

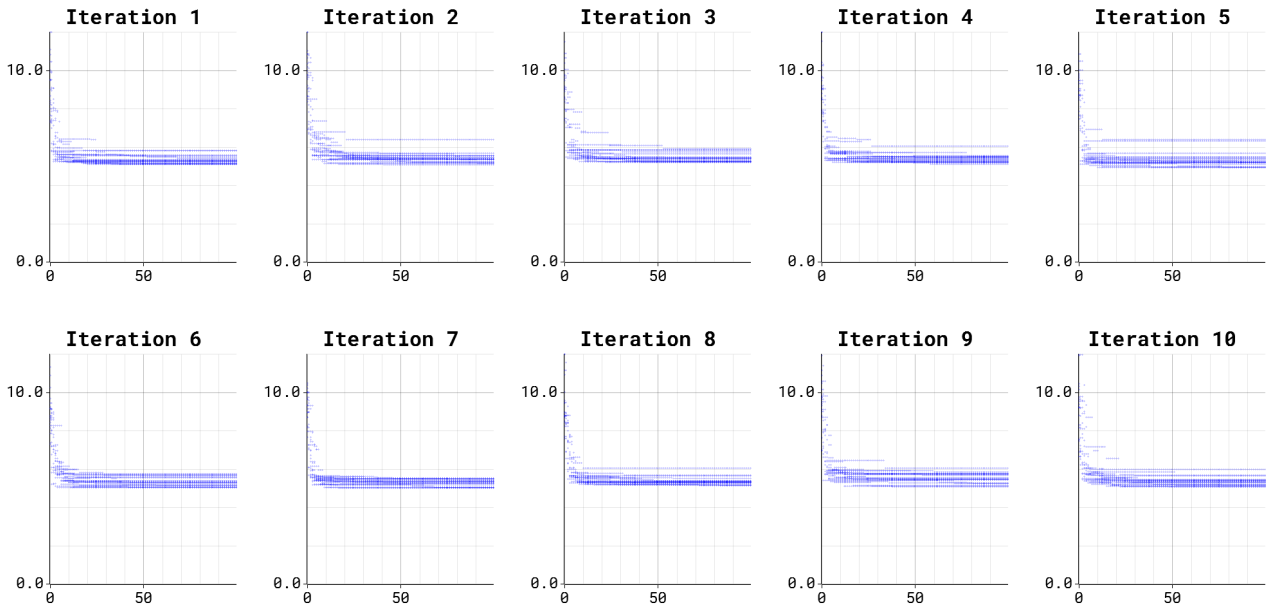



(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.

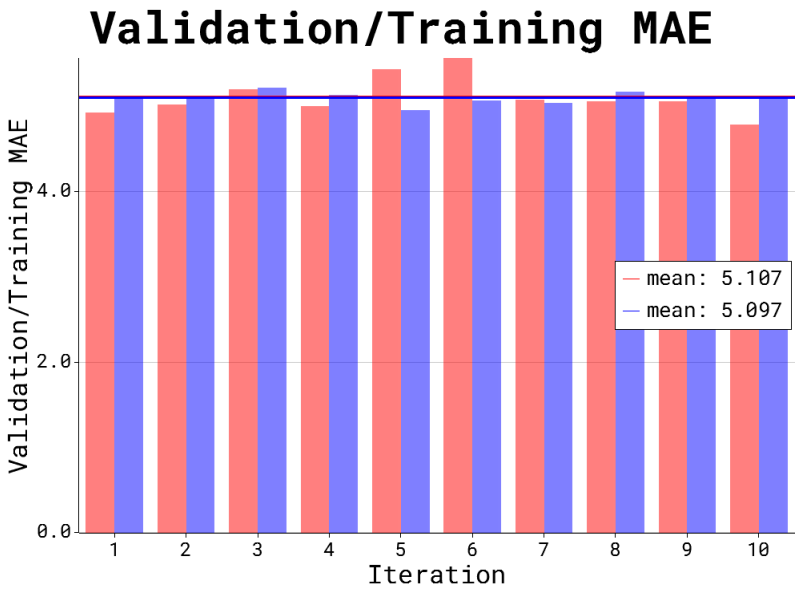



(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 2: Training result of air-8-4-1 of next 5 days dataset with 63.233 seconds used for training.

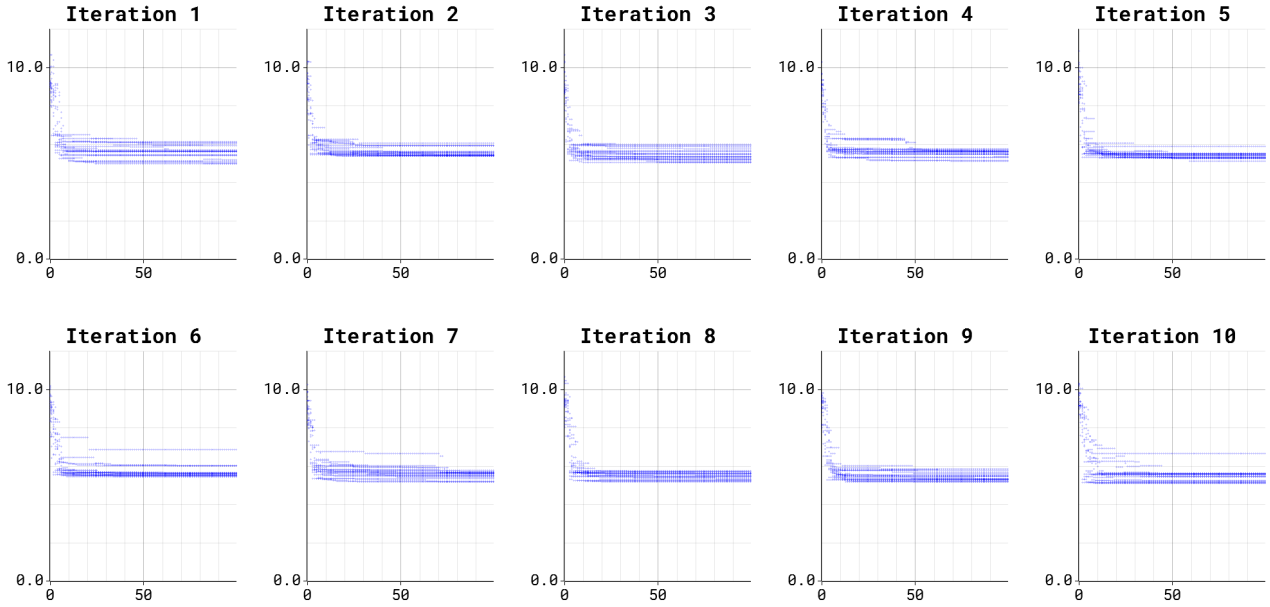



(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.

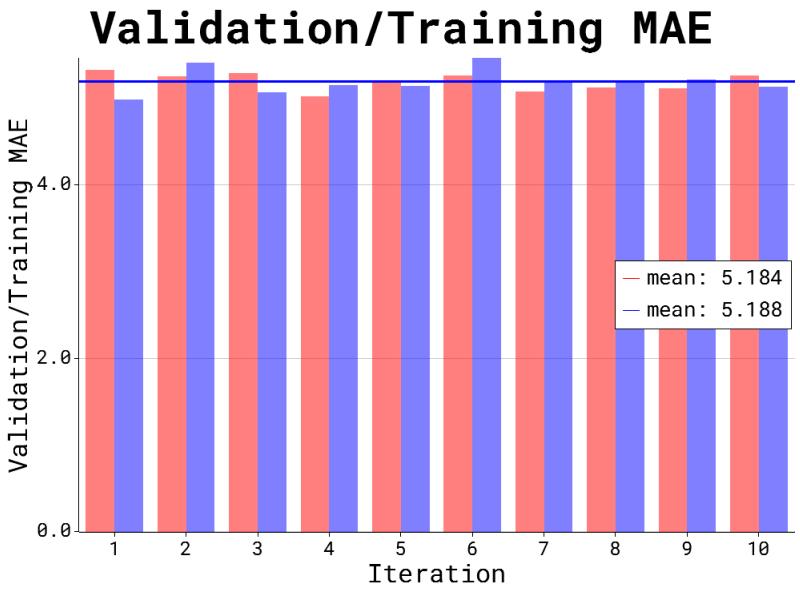



(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 3: Training result of air-8-4-1 of next 10 days dataset with 61.401 seconds used for training.

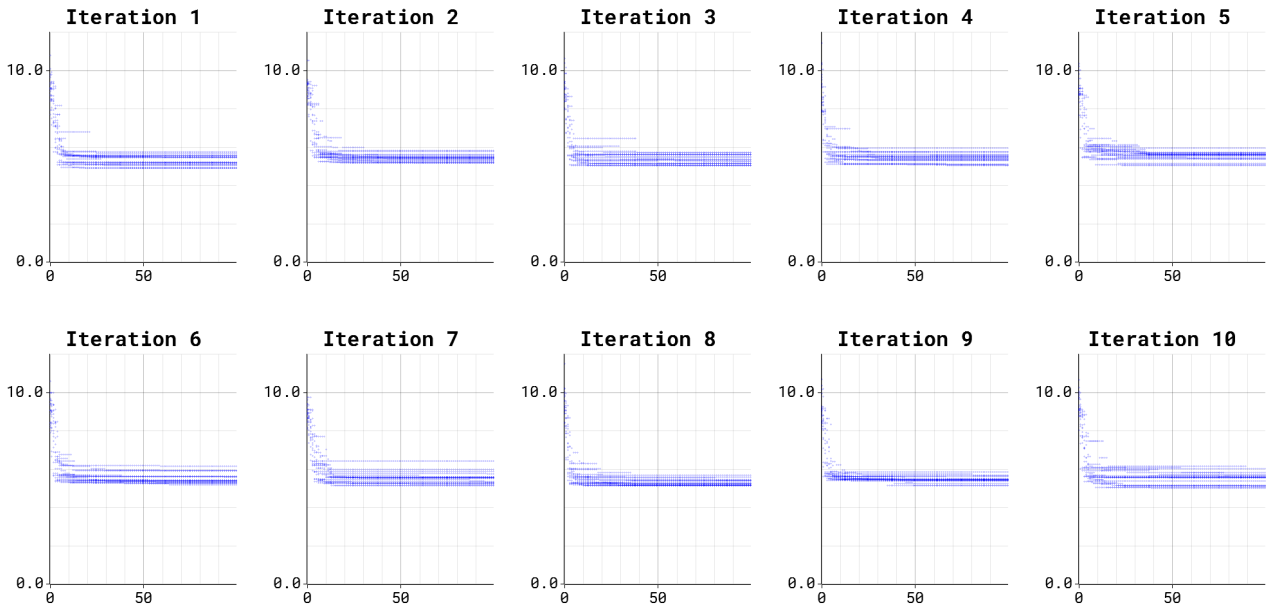



(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.

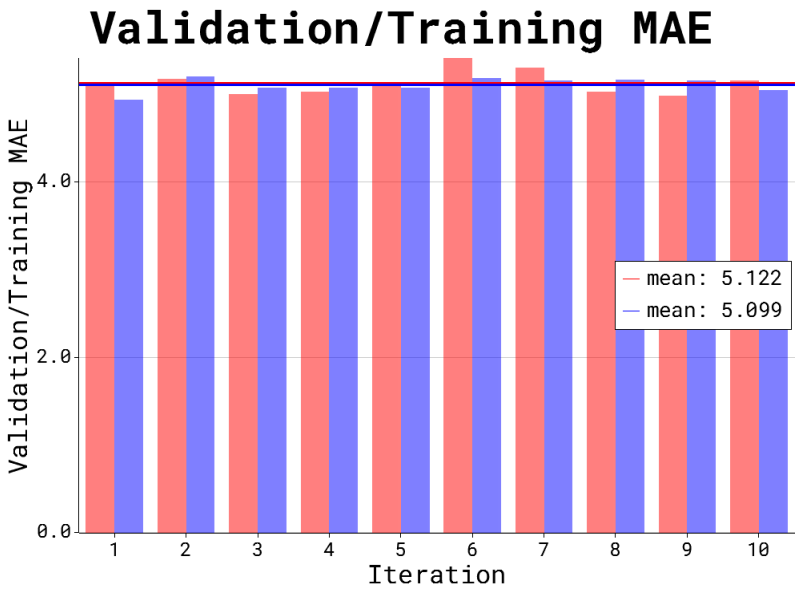



(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 4: Training result of air-8-1-1 of next 5 days dataset with 58.504 seconds used for training.

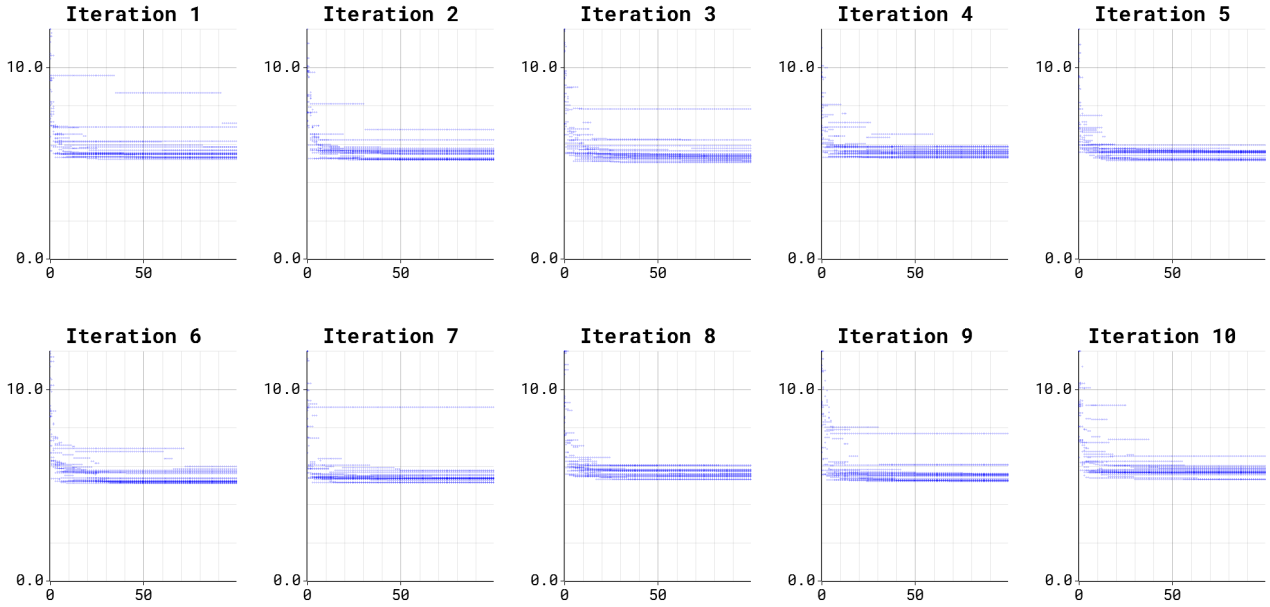



(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.

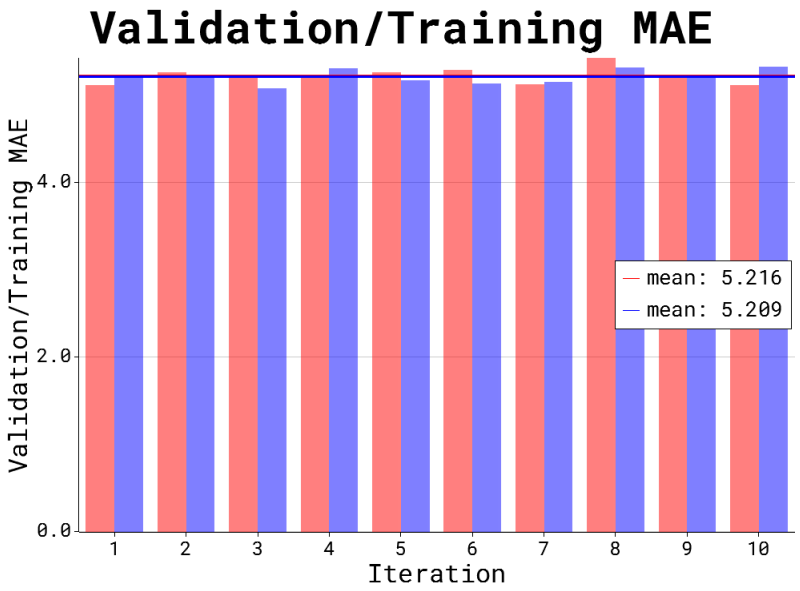



(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 5: Training result of air-8-1-1 of next 10 days dataset with 53.990 seconds used for training.

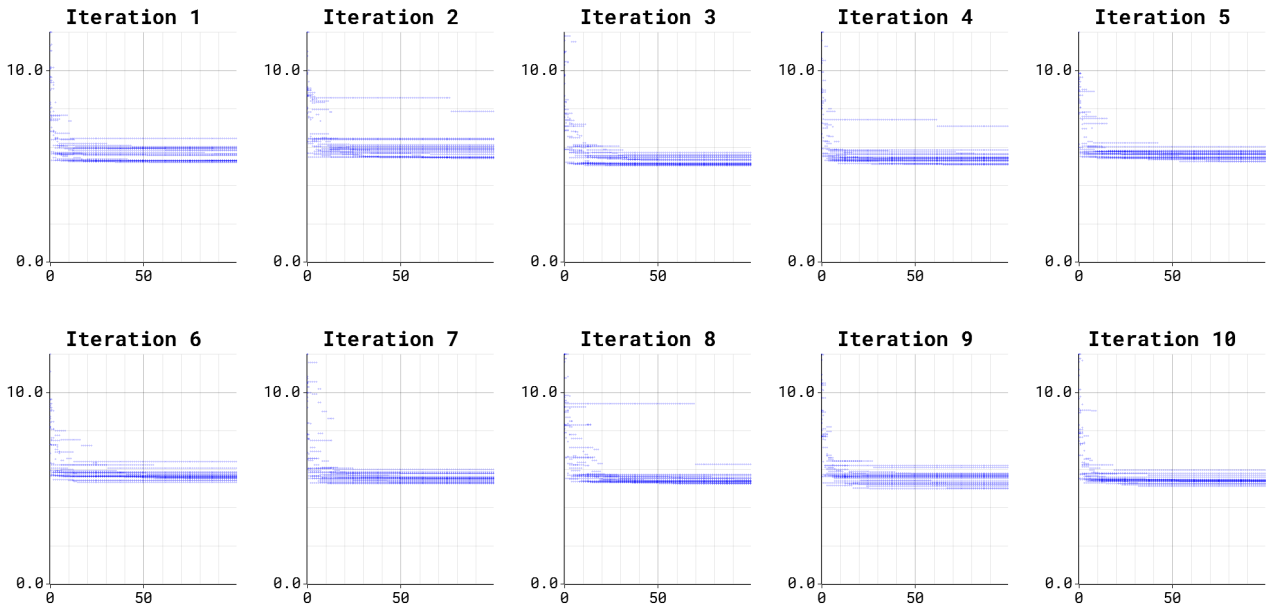



(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.

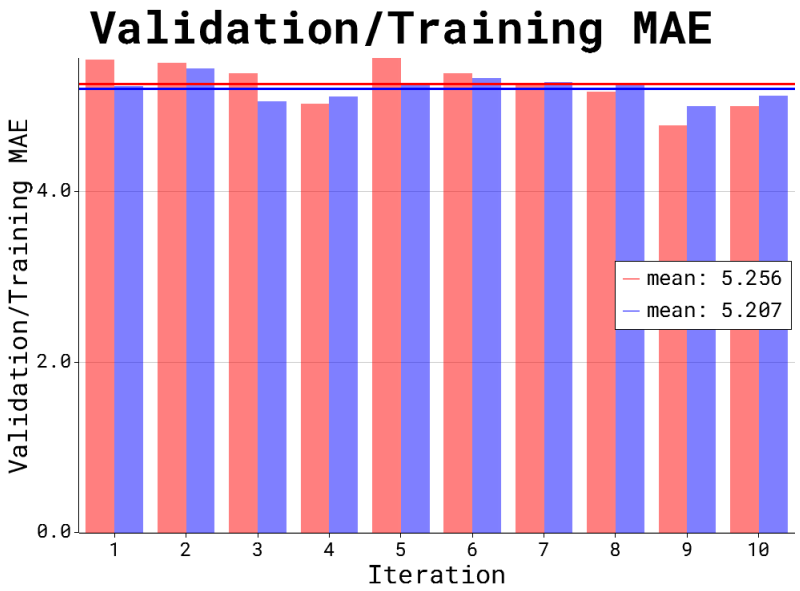



(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 6: Training result of air-8-8-4-1 of next 5 days dataset with 81.596 seconds used for training.




(a) The training process of each cross-valiation iteration: x-axis is $t$ value, y-axis is the evaluation result (MAE), and each blue dot is an particle at time $t$ with its MAE.




(b) The best particle from each cross-validation iteration MAE on training set (blue) and validation set (red).

Figure 7: Training result of air-8-8-4-1 of next 10 days dataset with 78.985 seconds used for training.

Source Code 1: main.rs

```rust
    pub mod activator;
    pub mod ga;
    pub mod loss;
    pub mod mlp;
    pub mod models;
    pub mod utills;

    use std::error::Error;
    fn main() -> Result<(), Box<dyn Error>> {
        models::airquality::air_8_4_1();
        models::airquality::air_8_1_1();
        models::airquality::air_8_8_4_1();
        Ok(())
    }
```

Source Code 2: mlp.rs

```rust
use crate::activator;

#[derive(Debug)]
pub struct Layer {
    pub inputs: Vec<f64>,
    pub outputs: Vec<f64>, // need to save this for backward pass
    pub w: Vec<Vec<f64>>,
    pub b: Vec<f64>,
    pub grads: Vec<Vec<f64>>,
    pub w_prev_changes: Vec<Vec<f64>>,
    pub local_grads: Vec<f64>,
    pub b_prev_changes: Vec<f64>,
    pub act: activator::ActivationContainer,
}

impl Layer {
    pub fn new(
        input_features: u64,
        output_features: u64,
        bias: f64,
        act: activator::ActivationContainer,
    ) -> Layer {
        // initialize weights matrix
        let mut weights: Vec<Vec<f64>> = vec![];
        let mut inputs: Vec<f64> = vec![];
        let mut outputs: Vec<f64> = vec![];
        let mut grads: Vec<Vec<f64>> = vec![];
        let mut local_grads: Vec<f64> = vec![];
        let mut w_prev_changes: Vec<Vec<f64>> = vec![];
        let mut b_prev_changes: Vec<f64> = vec![];
        let mut b: Vec<f64> = vec![];

        for _ in 0..output_features {
            outputs.push(0.0);
            local_grads.push(0.0);
            b_prev_changes.push(0.0);
            b.push(bias);

            let mut w: Vec<f64> = vec![];
            let mut g: Vec<f64> = vec![];
            for _ in 0..input_features {
                if (inputs.len() as u64) < input_features {
                    inputs.push(0.0);
                }
                g.push(0.0);
                // random both positive and negative weight
                w.push(2f64 * rand::random::<f64>() - 1f64);
            }
            weights.push(w);
            grads.push(g.clone());
            w_prev_changes.push(g);
        }
        Layer {
            inputs,
```

```
            outputs,
            w: weights,
            b,
            grads,
            w_prev_changes,
            local_grads,
            b_prev_changes,
            act,
        }
    }

    pub fn forward(&mut self, inputs: &Vec<f64>) -> Vec<f64> {
        if inputs.len() != self.inputs.len() {
            panic!("forward: input size is wrong");
        }

        let result: Vec<f64> = self
            .w
            .iter()
            .zip(self.b.iter())
            .zip(self.outputs.iter_mut())
            .map(|((w_j, b_j), o_j)| {
                let sum = inputs
                    .iter()
                    .zip(w_j.iter())
                    .fold(0.0, |s, (v, w_ji)| s + w_ji * v)
                    + b_j;
                *o_j = sum;
                (self.act.func)(sum)
            })
            .collect();

        self.inputs = inputs.clone();
        result
    }

    pub fn update(&mut self, lr: f64, momentum: f64) {
        for j in 0..self.w.len() {
            let delta_b = lr * self.local_grads[j] + momentum * self.b_prev_changes[j];
            self.b[j] -= delta_b; // update each neuron bias
            self.b_prev_changes[j] = delta_b;
            for i in 0..self.w[j].len() {
                // update each weights
                let delta_w = lr * self.grads[j][i] + momentum * self.w_prev_changes[j][i];
                self.w[j][i] -= delta_w;
                self.w_prev_changes[j][i] = delta_w;
            }
        }
    }

    pub fn zero_grad(&mut self) {
        for j in 0..self.outputs.len() {
            self.local_grads[j] = 0.0;
            for i in 0..self.grads[j].len() {
                self.grads[j][i] = 0.0;
            }
        }
    }
}

#[derive(Debug)]
pub struct Net {
    pub layers: Vec<Layer>,
    pub parameters: u64,
}

impl Net {
    pub fn from_layers(layers: Vec<Layer>) -> Net {
        let mut parameters: u64 = 0;
        for l in &layers {
            parameters += (l.w.len() * l.w[0].len()) as u64;
            parameters += l.b.len() as u64;
        }

        Net { layers, parameters }
    }
```

```rust

    pub fn new(architecture: Vec<u64>) -> Net {
        let mut layers: Vec<Layer> = vec![];
        for i in 1..architecture.len() {
            layers.push(Layer::new(
                architecture[i - 1],
                architecture[i],
                1f64,
                activator::sigmoid(),
            ))
        }
        Net::from_layers(layers)
    }

    /// Set this network parameters from flattened parameters.
    pub fn set_params(&mut self, params: &Vec<f64>) {
        if self.parameters != params.len() as u64 {
            panic!["The neural network parameters size is not equal to individual size"];
        }
        let mut idx: usize = 0;

        for l in self.layers.iter_mut() {
            l.w.iter_mut().for_each(|w_j| {
                w_j.iter_mut().for_each(|w_ji| {
                    *w_ji = params[idx];
                    idx += 1;
                })
            });

            l.b.iter_mut().for_each(|b_i| {
                *b_i = params[idx];
                idx += 1;
            });
        }
    }

    pub fn zero_grad(&mut self) {
        for l in 0..self.layers.len() {
            self.layers[l].zero_grad();
        }
    }

    pub fn forward(&mut self, input: &Vec<f64>) -> Vec<f64> {
        let mut result = self.layers[0].forward(input);
        for l in 1..self.layers.len() {
            result = self.layers[l].forward(&result);
        }
        result
    }

    pub fn update(&mut self, lr: f64, momentum: f64) {
        for l in 0..self.layers.len() {
            self.layers[l].update(lr, momentum);
        }
    }
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn test_linear_new() {
        let linear = Layer::new(2, 3, 1.0, activator::linear());
        assert_eq!(linear.outputs.len(), 3);
        assert_eq!(linear.inputs.len(), 2);

        assert_eq!(linear.w.len(), 3);
        assert_eq!(linear.w[0].len(), 2);
        assert_eq!(linear.b.len(), 3);

        assert_eq!(linear.grads.len(), 3);
        assert_eq!(linear.w_prev_changes.len(), 3);
        assert_eq!(linear.grads[0].len(), 2);
        assert_eq!(linear.w_prev_changes[0].len(), 2);
        assert_eq!(linear.local_grads.len(), 3);
```

```
        assert_eq!(linear.b_prev_changes.len(), 3);
    }

    #[test]
    fn test_linear_forward1() {
        let mut linear = Layer::new(2, 1, 1.0, activator::sigmoid());

        for j in 0..linear.w.len() {
            for i in 0..linear.w[j].len() {
                linear.w[j][i] = 1.0;
            }
        }

        assert_eq!(linear.forward(&vec![1.0, 1.0])[0], 0.9525741268224334);
        assert_eq!(linear.outputs[0], 3.0);
    }

    #[test]
    fn test_linear_forward2() {
        let mut linear = Layer::new(2, 2, 1.0, activator::sigmoid());

        for j in 0..linear.w.len() {
            for i in 0..linear.w[j].len() {
                linear.w[j][i] = (j as f64) + 1.0;
            }
        }
        let result = linear.forward(&vec![0.0, 1.0]);
        assert_eq!(linear.outputs[0], 2.0);
        assert_eq!(linear.outputs[1], 3.0);
        assert_eq!(result[0], 0.8807970779778823);
        assert_eq!(result[1], 0.9525741268224334);
    }

    #[test]
    fn test_set_params() {
        let mut layers: Vec<Layer> = vec![];
        layers.push(Layer::new(2, 2, 1.0, activator::relu()));
        layers.push(Layer::new(2, 1, 1.0, activator::linear()));
        let mut net = Net::from_layers(layers);
        net.set_params(&vec![1.0, 1.0, 1.0, 1.0, 2.0, 2.0, 1.0, 1.0, 2.0]);

        assert_eq!(net.layers[0].w[0], vec![1.0, 1.0]);
        assert_eq!(net.layers[0].w[1], vec![1.0, 1.0]);
        assert_eq!(net.layers[0].b, vec![2.0, 2.0]);
    }
}

```

Source Code 3: activator.rs

```
#[derive(Debug)]
pub struct ActivationContainer {
    pub func: fn(f64) -> f64,
    pub der: fn(f64) -> f64,
    pub name: String,
}

pub fn sigmoid() -> ActivationContainer {
    fn func(input: f64) -> f64 {
        1.0 / (1.0 + (-input).exp())
    }
    fn der(input: f64) -> f64 {
        func(input) * (1.0 - func(input))
    }
    ActivationContainer {
        func,
        der,
        name: "sigmoid".to_string(),
    }
}

pub fn relu() -> ActivationContainer {
    fn func(input: f64) -> f64 {
        return f64::max(0.0, input);
    }
```

```rust
    fn der(input: f64) -> f64 {
        if input > 0.0 {
            return 1.0;
        } else {
            return 0.0;
        }
    }
    ActivationContainer {
        func,
        der,
        name: "relu".to_string(),
    }
}

pub fn linear() -> ActivationContainer {
    fn func(input: f64) -> f64 {
        input
    }
    fn der(_input: f64) -> f64 {
        1.0
    }
    ActivationContainer {
        func,
        der,
        name: "linear".to_string(),
    }
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn test_sigmoid() {
        let act = sigmoid();

        assert_eq!((act.func)(1.0), 0.7310585786300048792512);
        assert_eq!((act.func)(-1.0), 0.2689414213699951207488);
        assert_eq!((act.func)(0.0), 0.5);
        assert_eq!((act.der)(1.0), 0.19661193324148185253 74);
        assert_eq!((act.der)(-1.0), 0.19661193324148185253 74);
        assert_eq!((act.der)(0.0), 0.25);
    }

    #[test]
    fn test_relu() {
        let act = relu();

        assert_eq!((act.func)(-1.0), 0.0);
        assert_eq!((act.func)(20.0), 20.0);
        assert_eq!((act.der)(-1.0), 0.0);
        assert_eq!((act.der)(20.0), 1.0);
    }
}

```

Source Code 4: loss.rs

```rust
use crate::mlp;

pub struct Loss {
    outputs: Vec<f64>,
    desired: Vec<f64>,
    pub func: fn(f64, f64) -> f64,
    pub der: fn(f64, f64) -> f64,
}

impl Loss {
    /// Absolute Error
    pub fn abs_err() -> Loss {
        fn func(output: f64, desired: f64) -> f64 {
            (output - desired).abs()
        }
        fn der(output: f64, desired: f64) -> f64 {
            if output > desired {
```

```
                1.0
            } else {
                -1.0
            }
        }

        Loss {
            outputs: vec![],
            desired: vec![],
            func,
            der,
        }
    }

    /// Squared Error
    pub fn square_err() -> Loss {
        fn func(output: f64, desired: f64) -> f64 {
            0.5 * (output - desired).powi(2)
        }
        fn der(output: f64, desired: f64) -> f64 {
            output - desired
        }

        Loss {
            outputs: vec![],
            desired: vec![],
            func,
            der,
        }
    }

    /// Binary Cross Entropy
    pub fn bce() -> Loss {
        fn func(output: f64, desired: f64) -> f64 {
            -desired * output.ln() + (1.0 - desired) * (1.0 - output).ln()
        }
        fn der(output: f64, desired: f64) -> f64 {
            -(desired / output - (1.0 - desired) / (1.0 - output))
        }

        Loss {
            outputs: vec![],
            desired: vec![],
            func,
            der,
        }
    }

    pub fn criterion(&mut self, outputs: &Vec<f64>, desired: &Vec<f64>) -> f64 {
        if outputs.len() != desired.len() {
            panic!("outputs size is not equal to desired size");
        }
        let loss = outputs
            .iter()
            .zip(desired.iter())
            .fold(0.0, |ls, (o, d)| ls + (self.func)(*o, *d));
        self.outputs = outputs.clone();
        self.desired = desired.clone();
        loss
    }

    pub fn backward(&self, layers: &mut Vec<mlp::Layer>) {
        for l in (0..layers.len()).rev() {
            // output layer
            if l == layers.len() - 1 {
                for j in 0..layers[l].outputs.len() {
                    // compute grads
                    let local_grad = (self.der)(self.outputs[j], self.desired[j])
                        * (layers[l].act.der)(layers[l].outputs[j]);

                    layers[l].local_grads[j] = local_grad;

                    // set grads for each weight
                    for k in 0..(layers[l - 1].outputs.len()) {
                        layers[l].grads[j][k] =
                            (layers[l - 1].act.func)(layers[l - 1].outputs[k]) * local_grad;
```

```
                    }
                }
                continue;
            }
            // hidden layer
            for j in 0..layers[l].outputs.len() {
                // calculate local_grad based on previous local_grad
                let mut local_grad = 0f64;
                for i in 0..layers[l + 1].w.len() {
                    for k in 0..layers[l + 1].w[i].len() {
                        local_grad += layers[l + 1].w[i][k] * layers[l + 1].local_grads[i];
                    }
                }
                local_grad = (layers[l].act.der)(layers[l].outputs[j]) * local_grad;
                layers[l].local_grads[j] = local_grad;

                // set grads for each weight
                if l == 0 {
                    for k in 0..layers[l].inputs.len() {
                        layers[l].grads[j][k] = layers[l].inputs[k] * local_grad;
                    }
                } else {
                    for k in 0..layers[l - 1].outputs.len() {
                        layers[l].grads[j][k] =
                            (layers[l - 1].act.func)(layers[l - 1].outputs[k]) * local_grad;
                    }
                }
            }
        }
    }
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn test_mse_func() {
        assert_eq!((Loss::square_err().func)(2.0, 1.0), 0.5);
        assert_eq!((Loss::square_err().func)(5.0, 0.0), 12.5);
    }

    #[test]
    fn test_mse_der() {
        assert_eq!((Loss::square_err().der)(2.0, 1.0), 1.0);
        assert_eq!((Loss::square_err().der)(5.0, 0.0), 5.0);
    }

    #[test]
    fn test_mse() {
        let mut loss = Loss::square_err();

        let l = loss.criterion(&vec![2.0, 1.0, 0.0], &vec![0.0, 1.0, 2.0]);
        assert_eq!(l, 4.0);

        loss.criterion(
            &vec![34.0, 37.0, 44.0, 47.0, 48.0],
            &vec![37.0, 40.0, 46.0, 44.0, 46.0],
        );
        assert_eq!(l, 4.0);
    }

    #[test]
    fn test_bce_func() {
        println!("{}", (Loss::bce().func)(0.9, 0.0));
        println!("{}", (Loss::bce().func)(0.9, 1.0));
    }
}

```

Source Code 5: models/airquality.rs

```
use std::time::Instant;

use crate::{
```

```
    activator, loss,
    mlp::{Layer, Net},
    swarm::{self, gen_rho},
    utills::{
        data::{self, DataSet},
        graph,
    },
};

const IMGPATH: &str = "report/assignment_4/images";

pub fn air_8_4_1() {
    fn model() -> Net {
        let mut layers: Vec<Layer> = vec![];
        layers.push(Layer::new(8, 4, 1.0, activator::relu()));
        layers.push(Layer::new(4, 1, 1.0, activator::linear()));
        Net::from_layers(layers)
    }
    air_particle_swarm(&model, "air-8-4-1");
}

pub fn air_8_1_1() {
    fn model() -> Net {
        let mut layers: Vec<Layer> = vec![];
        layers.push(Layer::new(8, 1, 1.0, activator::relu()));
        layers.push(Layer::new(1, 1, 1.0, activator::linear()));
        Net::from_layers(layers)
    }
    air_particle_swarm(&model, "air-8-1-1");
}

pub fn air_8_8_4_1() {
    fn model() -> Net {
        let mut layers: Vec<Layer> = vec![];
        layers.push(Layer::new(8, 8, 1.0, activator::relu()));
        layers.push(Layer::new(8, 4, 1.0, activator::relu()));
        layers.push(Layer::new(4, 1, 1.0, activator::linear()));
        Net::from_layers(layers)
    }
    air_particle_swarm(&model, "air-8-8-4-1");
}

pub fn validation_test(net: &mut Net, validation_set: &DataSet, training_set: &DataSet) -> (f64, f64) {
    let mut mae = 0.0;
    for data in validation_set.get_datas() {
        let result = net.forward(&data.inputs);
        let abs_err = loss::Loss::abs_err().criterion(&result, &data.labels);
        mae += abs_err;
    }
    mae = mae / validation_set.len() as f64;

    let mut t_mae = 0.0;
    for data in training_set.get_datas() {
        let result = net.forward(&data.inputs);
        let abs_err = loss::Loss::abs_err().criterion(&result, &data.labels);
        t_mae += abs_err;
    }
    (mae, t_mae/training_set.len() as f64)
}

pub fn pso_fit(model: &dyn Fn() -> Net, dataset: &DataSet, folder: String) -> f32 {
    let mut loss = loss::Loss::abs_err();
    let max_epoch = 100;
    let mut train_proc: Vec<Vec<(i32, f64)>> = (0..10).into_iter().map(|_| vec![]).collect();
    let mut valid_mae: Vec<f64> = vec![];
    let mut train_mae: Vec<f64> = vec![];

    let start = Instant::now();
    for (j, dt) in dataset.cross_valid_set(0.1).iter().enumerate() {
        let (training_set, validation_set) = dt.0.minmax_norm(&dt.1);

        let mut net = model();
        let mut groups = swarm::init_particles_group(&net, 5, 4);

        for i in 0..max_epoch {
            for (k, g) in groups.iter_mut().enumerate() {
```

```
                for (_, x) in g.particles.iter_mut().enumerate() {
                    net.set_params(&x.position);
                    let mut run_loss = 0.0;
                    for data in training_set.get_shuffled() {
                        let result = net.forward(&data.inputs);
                        run_loss += loss.criterion(&result, &data.labels);
                    }
                    let mae = run_loss / training_set.len() as f64; // Mean Absolute Error, F(x_i(t))
                    if mae < x.f {
                        x.f = mae;
                        x.best_pos = x.position.clone();
                    }
                    if mae < g.lbest_f {
                        g.lbest_f = mae; // set gbest
                        g.lbest_pos = x.position.clone();
                    }
                    x.update_speed(&g.lbest_pos, gen_rho(1.0), gen_rho(1.5));
                    x.change_pos();
                    train_proc[j].push((i, x.f));
                }
                println!("{}, {} lbest : {:.5e}", k, i, g.lbest_f);
            }
        }

        let best_group = &groups
            .iter()
            .reduce(|best, x| if best.lbest_f < x.lbest_f { best } else { x })
            .unwrap();

        let gbest = best_group
            .particles
            .iter()
            .reduce(|best, ind| if best.f < ind.f { best } else { ind })
            .unwrap();

        net.set_params(&gbest.best_pos);
        //io::save(&net.layers, "models/air/air-8-4-1.json".into()).unwrap();
        let (v_mae, t_mae) = validation_test(&mut net, &validation_set, &training_set);
        valid_mae.push(v_mae);
        train_mae.push(t_mae);
    }

    let duration = start.elapsed();

    graph::draw_ga_progress(
        &train_proc,
        format!("{}/{}/train_proc.png", IMGPATH, folder),
        12.0,
    )
    .unwrap();

    graph::hist::draw_2hist(
        [&valid_mae, &train_mae],
        "Validation/Training MAE",
        ("Iteration", "Validation/Training MAE"),
        format!("{}/{}/mae.png", IMGPATH, folder),
    ).unwrap();

    duration.as_secs_f32()
}

pub fn air_particle_swarm(model: &dyn Fn() -> Net, folder: &str) {
    let (dataset_five, dataset_ten) =
        data::airquality_dataset().expect("Something wrong with airquality_dataset");

    let t1 = pso_fit(model, &dataset_five, format!("5days/{}", folder));
    let t2 = pso_fit(model, &dataset_ten, format!("10days/{}", folder));

    println!("t1: {:.3} sec, t2: {:.3} sec", t1, t2);
}


```

Source Code 6: swarm/mod.rs

```rust
use rand::{distributions::Uniform, prelude::Distribution};

use crate::mlp::Net;

#[derive(Debug, Clone)]
pub struct Individual {
    pub best_pos: Vec<f64>,
    pub position: Vec<f64>,
    pub f: f64, // evaluation of this individual
    pub speed: Vec<f64>,
}

impl Individual {
    pub fn new(position: Vec<f64>) -> Individual {
        let mut rand = rand::thread_rng();
        let dist = Uniform::from(-1.0..=1.0);
        let speed: Vec<f64> = position.iter().map(|_i| dist.sample(&mut rand)).collect();
        Individual {
            best_pos: position.clone(),
            position,
            f: f64::MAX,
            speed,
        }
    }

    /// Individual best speed updater
    pub fn ind_update_speed(&mut self, rho: f64) {
        self.speed
            .iter_mut()
            .zip(self.best_pos.iter().zip(self.position.iter()))
            .for_each(|(v, (x_b, x))| {
                *v = *v + rho * (*x_b - *x);
            });
    }

    /// Speed updator with social component included
    pub fn update_speed(&mut self, other_best: &Vec<f64>, rho1: f64, rho2: f64) {
        let w = 1.0;
        self.speed
            .iter_mut()
            .zip(
                self.position
                    .iter()
                    .zip(self.best_pos.iter().zip(other_best.iter())),
            )
            .for_each(|(v, (x, (x_b, x_gb)))| {
                *v = w * *v + rho1 * (*x_b - *x) + rho2 * (*x_gb - *x);
            });
    }

    pub fn change_pos(&mut self) {
        self.position
            .iter_mut()
            .zip(self.speed.iter())
            .for_each(|(x, v)| {
                *x = *x + v;
            });
    }
}

pub fn gen_rho(c: f64) -> f64 {
    let mut rand = rand::thread_rng();
    let dist = Uniform::from(0.0..=1.0);
    dist.sample(&mut rand) * c
}

/// Create inital particles of MLP from layers
///
/// return: particles
pub fn init_particles(net: &Net, amount: u32) -> Vec<Individual> {
    let mut inidividuals: Vec<Individual> = vec![];
    for _ in 0..amount {
        let mut position: Vec<f64> = Vec::with_capacity(net.parameters as usize);
        for l in net.layers.iter() {
            for output in l.w.iter() {
                for _ in output.iter() {
```

```
                    // new random weight in range [-1, 1]
                    position.push(2f64 * rand::random::<f64>() - 1f64);
                }
            }
            for bias in l.b.iter() {
                position.push(*bias);
            }
        }
        inidividuals.push(Individual::new(position));
    }
    inidividuals
}

pub struct IndividualGroup {
    pub particles: Vec<Individual>,
    pub lbest_f: f64,
    pub lbest_pos: Vec<f64>,
}

impl IndividualGroup {
    pub fn add(&mut self, individual: Individual) {
        self.particles.push(individual);
    }
}

pub fn init_particles_group(net: &Net, group: usize, group_size: u32) -> Vec<IndividualGroup> {
    (0..group)
        .into_iter()
        .map(|_| {
            let particles = init_particles(&net, group_size + 1);
            IndividualGroup {
                particles: particles[1..].into(),
                lbest_f: f64::MAX,
                lbest_pos: particles[0].position.clone(),
            }
        })
        .collect()
}

#[cfg(test)]
mod tests {
    use crate::{activator, mlp::Layer};

    use super::*;

    #[test]
    fn test_update_speed() {
        fn f(pos: &Vec<f64>) -> f64 {
            pos[0].powi(2) + 2.0 * pos[1]
        }

        let mut p1 = Individual::new(vec![1.0, 1.0]);
        p1.f = 4.0;
        p1.speed = vec![0.5, 0.5];

        let gbest = vec![0.5, 1.0];

        // trainning
        let eval_result = f(&p1.position);
        if eval_result < p1.f {
            p1.f = eval_result;
            p1.best_pos = p1.position.clone();
        }

        p1.update_speed(&gbest, 1.0, 1.0);
        p1.change_pos();

        assert_eq!(p1.speed, vec![0.0, 0.5]);
        assert_eq!(p1.position, vec![1.0, 1.5]);
    }

    #[test]
    fn test_split() {
        let mut layers: Vec<Layer> = vec![];
        layers.push(Layer::new(4, 2, 1.0, activator::sigmoid()));
        layers.push(Layer::new(2, 1, 1.0, activator::sigmoid()));
```

```
        let net = Net::from_layers(layers);

        let groups = init_particles_group(&net, 3, 3);
        assert_eq!(groups.len(), 3);
        assert_eq!(groups[2].particles.len(), 3);

        let groups = init_particles_group(&net, 2, 5);
        assert_eq!(groups.len(), 2);
        assert_eq!(groups[0].particles.len(), 5);
    }
}

```

Source Code 7: utills/data.rs

```
use super::io::read_lines;
use chrono::{DateTime, Duration, TimeZone, Utc};
use rand::prelude::SliceRandom;
use serde::Deserialize;
use std::error::Error;

pub fn max(vec: &Vec<f64>) -> f64 {
    vec.iter().fold(f64::NAN, |max, &v| v.max(max))
}

pub fn min(vec: &Vec<f64>) -> f64 {
    vec.iter().fold(f64::NAN, |min, &v| v.min(min))
}

pub fn std(vec: &Vec<f64>, mean: f64) -> f64 {
    let n = vec.len() as f64;
    vec.iter()
        .fold(0.0f64, |sum, &val| sum + (val - mean).powi(2) / n)
        .sqrt()
}

pub fn mean(vec: &Vec<f64>) -> f64 {
    let n = vec.len() as f64;
    vec.iter().fold(0.0f64, |mean, &val| mean + val / n)
}

pub fn standardization(data: &Vec<f64>, mean: f64, std: f64) -> Vec<f64> {
    data.iter().map(|x| (x - mean) / std).collect()
}

pub fn minmax_norm(data: &Vec<f64>, min: f64, max: f64) -> Vec<f64> {
    data.iter().map(|x| (x - min) / (max - min)).collect()
}

#[derive(Debug, Clone)]
pub struct Data {
    pub inputs: Vec<f64>,
    pub labels: Vec<f64>,
}
#[derive(Clone)]
pub struct DataSet {
    datas: Vec<Data>,
}

impl DataSet {
    pub fn new(datas: Vec<Data>) -> DataSet {
        DataSet { datas }
    }

    pub fn cross_valid_set(&self, percent: f64) -> Vec<(DataSet, DataSet)> {
        if percent < 0.0 && percent > 1.0 {
            panic!("argument percent must be in range [0, 1]")
        }
        let k = (percent * (self.datas.len() as f64)).ceil() as usize; // fold size
        let n = (self.datas.len() as f64 / k as f64).ceil() as usize; // number of folds
        let datas = self.get_shuffled().clone(); // shuffled data before slicing it
        let mut set: Vec<(DataSet, DataSet)> = vec![];

        let mut curr: usize = 0;
        for _ in 0..n {
```

```
            let r_pt: usize = if curr + k > datas.len() {
                datas.len()
            } else {
                curr + k
            };

            let validation_set: Vec<Data> = datas[curr..r_pt].to_vec();
            let training_set: Vec<Data> = if curr > 0 {
                let mut temp = datas[0..curr].to_vec();
                temp.append(&mut datas[r_pt..datas.len()].to_vec());
                temp
            } else {
                datas[r_pt..datas.len()].to_vec()
            };

            set.push((DataSet::new(training_set), DataSet::new(validation_set)));
            curr += k
        }
        set
    }

    pub fn data_points(&self) -> Vec<f64> {
        let mut data_points: Vec<f64> = vec![];
        for mut dt in self.datas.clone() {
            data_points.append(&mut dt.inputs);
            data_points.append(&mut dt.labels);
        }
        data_points
    }

    pub fn len(&self) -> usize {
        self.datas.len()
    }

    pub fn standardization(&self, valid_set: &DataSet) -> (DataSet, DataSet) {
        let size = self.datas[0].inputs.len();
        let features: Vec<(Vec<f64>, Vec<f64>)> = (0..size)
            .into_iter()
            .map(|i| {
                let feature = self.get_feature(i);
                let v_feature = valid_set.get_feature(i);
                let mean = mean(&feature);
                let std = std(&feature, mean);
                (
                    standardization(&feature, mean, std),
                    standardization(&v_feature, mean, std),
                )
            })
            .collect();

        let datas: Vec<Data> = self
            .datas
            .iter()
            .enumerate()
            .map(|(i, dt)| Data {
                labels: dt.labels.clone(),
                inputs: features.iter().map(|x| x.0[i]).collect(),
            })
            .collect();

        let v_datas: Vec<Data> = valid_set
            .datas
            .iter()
            .enumerate()
            .map(|(i, dt)| Data {
                labels: dt.labels.clone(),
                inputs: features.iter().map(|x| x.1[i]).collect(),
            })
            .collect();

        (DataSet::new(datas), DataSet::new(v_datas))
    }

    pub fn minmax_norm(&self, valid_set: &DataSet) -> (DataSet, DataSet) {
        let size = self.datas[0].inputs.len();
        let features: Vec<(Vec<f64>, Vec<f64>)> = (0..size)
```

```
            .into_iter()
            .map(|i| {
                let feature = self.get_feature(i);
                let v_feature = valid_set.get_feature(i);
                let min = min(&feature);
                let max = max(&feature);
                (
                    minmax_norm(&feature, min, max),
                    minmax_norm(&v_feature, min, max),
                )
            })
            .collect();

        let datas: Vec<Data> = self
            .datas
            .iter()
            .enumerate()
            .map(|(i, dt)| Data {
                labels: dt.labels.clone(),
                inputs: features.iter().map(|x| x.0[i]).collect(),
            })
            .collect();

        let v_datas: Vec<Data> = valid_set
            .datas
            .iter()
            .enumerate()
            .map(|(i, dt)| Data {
                labels: dt.labels.clone(),
                inputs: features.iter().map(|x| x.1[i]).collect(),
            })
            .collect();

        (DataSet::new(datas), DataSet::new(v_datas))
    }

    pub fn get_datas(&self) -> Vec<Data> {
        self.datas.clone()
    }

    pub fn get_feature(&self, i: usize) -> Vec<f64> {
        if i >= self.datas[0].inputs.len() {
            panic!("i should not exceed inputs feature size");
        }

        self.datas.iter().map(|data| data.inputs[i]).collect()
    }

    pub fn get_label(&self, i: usize) -> Vec<f64> {
        if i >= self.datas[0].labels.len() {
            panic!("i should not exceed inputs feature size");
        }

        self.datas.iter().map(|data| data.labels[i]).collect()
    }

    pub fn get_shuffled(&self) -> Vec<Data> {
        let mut shuffled_datas = self.datas.clone();
        shuffled_datas.shuffle(&mut rand::thread_rng());
        shuffled_datas
    }
}

pub fn confusion_count(
    matrix: &mut [[i32; 2]; 2],
    result: &Vec<f64>,
    label: &Vec<f64>,
    threshold: f64,
) {
    if result[0] > threshold {
        // true positive
        if label[0] == 1.0 {
            matrix[0][0] += 1
        } else {
            // false negative
            matrix[1][0] += 1
```

```
        }
    } else if result[0] <= threshold {
        // true negative
        if label[0] == 0.0 {
            matrix[1][1] += 1
        }
        // false positive
        else {
            matrix[0][1] += 1
        }
    }
}

pub fn un_standardization(value: f64, mean: f64, std: f64) -> f64 {
    value * std + mean
}

pub fn xor_dataset() -> DataSet {
    let inputs = vec![[0.0, 0.0], [0.0, 1.0], [1.0, 0.0], [1.0, 1.0]];
    let labels = vec![[0.0], [1.0], [1.0], [0.0]];
    let mut datas: Vec<Data> = vec![];
    for i in 0..4 {
        datas.push(Data {
            inputs: inputs[i].to_vec(),
            labels: labels[i].to_vec(),
        });
    }

    DataSet::new(datas)
}

pub fn flood_dataset() -> Result<DataSet, Box<dyn Error>> {
    #[derive(Deserialize)]
    struct Record {
        s1_t3: f64,
        s1_t2: f64,
        s1_t1: f64,
        s1_t0: f64,
        s2_t3: f64,
        s2_t2: f64,
        s2_t1: f64,
        s2_t0: f64,
        t7: f64,
    }

    let mut datas: Vec<Data> = vec![];
    let mut reader = csv::Reader::from_path("data/flood_dataset.csv")?;
    for record in reader.deserialize() {
        let record: Record = record?;
        let mut inputs: Vec<f64> = vec![];
        // station 1
        inputs.push(record.s1_t3);
        inputs.push(record.s1_t2);
        inputs.push(record.s1_t1);
        inputs.push(record.s1_t0);
        // station 2
        inputs.push(record.s2_t3);
        inputs.push(record.s2_t2);
        inputs.push(record.s2_t1);
        inputs.push(record.s2_t0);

        let labels: Vec<f64> = vec![f64::from(record.t7)];
        datas.push(Data { inputs, labels });
    }
    Ok(DataSet::new(datas))
}

pub fn cross_dataset() -> Result<DataSet, Box<dyn Error>> {
    let mut datas: Vec<Data> = vec![];
    let mut lines = read_lines("data/cross.pat")?;
    while let (Some(_), Some(Ok(l1)), Some(Ok(l2))) = (lines.next(), lines.next(), lines.next()) {
        let mut inputs: Vec<f64> = vec![];
        let mut labels: Vec<f64> = vec![];
        for w in l1.split(" ") {
            let v: f64 = w.parse().unwrap();
            inputs.push(v);
```

```
        }
        for w in l2.split(" ") {
            let v: f64 = w.parse().unwrap();
            // class 1 0 -> 1
            // class 0 1 -> 0
            labels.push(v);
            break;
        }
        datas.push(Data { inputs, labels });
    }
    Ok(DataSet::new(datas))
}

pub fn wdbc_dataset() -> Result<DataSet, Box<dyn Error>> {
    let mut datas: Vec<Data> = vec![];
    let mut lines = read_lines("data/wdbc.txt")?;
    while let Some(Ok(line)) = lines.next() {
        let mut inputs: Vec<f64> = vec![];
        let mut labels: Vec<f64> = vec![]; // M (malignant) = 1.0, B (benign) = 0.0
        let arr: Vec<&str> = line.split(",").collect();
        if arr[1] == "M" {
            labels.push(1.0);
        } else if arr[1] == "B" {
            labels.push(0.0);
        }
        for w in &arr[2..] {
            let v: f64 = w.parse()?;
            inputs.push(v);
        }
        datas.push(Data { inputs, labels });
    }
    Ok(DataSet::new(datas))
}

/// Return `(desired = next five days, desired = next ten days)`
pub fn airquality_dataset() -> Result<(DataSet, DataSet), Box<dyn Error>> {
    // nx is not used
    #[derive(Deserialize, Debug)]
    struct Record {
        #[serde(rename = "Date")]
        date: String,
        #[serde(rename = "Time")]
        time: String,
        #[serde(rename = "PT08.S1(CO)")]
        pt_s1: i32,
        #[serde(rename = "C6H6(GT)")]
        benzene: f64,
        #[serde(rename = "PT08.S2(NMHC)")]
        pt_s2: i32,
        #[serde(rename = "PT08.S3(NOx)")]
        pt_s3: i32,
        #[serde(rename = "PT08.S4(NO2)")]
        pt_s4: i32,
        #[serde(rename = "PT08.S5(O3)")]
        pt_s5: i32,
        #[serde(rename = "T")]
        temp: f64,
        #[serde(rename = "RH")]
        rh: f64,
        #[serde(rename = "AH")]
        ah: f64,
    }
    #[derive(Debug)]
    struct RecData {
        datetime: DateTime<Utc>,
        input: Vec<f64>,
        output: Vec<f64>,
        pub okay: bool,
    }
    /// add to input if input is true else add to output
    fn rec_add(recdata: &mut RecData, v: f64, input: bool) {
        if v == -200.0 {
            recdata.okay = false;
        }
        if input {
            recdata.input.push(v);
```

```
        } else {
            recdata.output.push(v)
        };
    }

    impl RecData {
        pub fn new(record: &Record) -> RecData {
            let datetime_str = format!("{} {}", record.date, record.time);
            let datetime = Utc
                .datetime_from_str(&datetime_str, "%-m/%-d/%Y %-H:%M:%S")
                .unwrap();

            let mut recdata = RecData {
                datetime,
                input: vec![],
                output: vec![],
                okay: true,
            };
            rec_add(&mut recdata, record.pt_s1 as f64, true);
            rec_add(&mut recdata, record.pt_s2 as f64, true);
            rec_add(&mut recdata, record.pt_s3 as f64, true);
            rec_add(&mut recdata, record.pt_s4 as f64, true);
            rec_add(&mut recdata, record.pt_s5 as f64, true);
            rec_add(&mut recdata, record.temp, true);
            rec_add(&mut recdata, record.rh, true);
            rec_add(&mut recdata, record.ah, true);
            rec_add(&mut recdata, record.benzene, false);
            recdata
        }
    }

    let mut reader = csv::Reader::from_path("data/AirQualityUCI.csv")?;
    let mut rec_datas: Vec<RecData> = vec![];
    for record in reader.deserialize() {
        let rec_data = RecData::new(&record.unwrap());
        if rec_data.okay {
            rec_datas.push(rec_data)
        };
    }

    // Duration::days(5)
    let mut datas_five: Vec<Data> = vec![];
    let mut datas_ten: Vec<Data> = vec![];

    for (i, x) in rec_datas.iter().enumerate() {
        let next_five_days = x.datetime + Duration::days(5);
        let next_ten_dats = x.datetime + Duration::days(10);

        let mut labels_five: Vec<f64> = vec![];
        let mut labels_ten: Vec<f64> = vec![];

        for y in &rec_datas[i..] {
            if y.datetime == next_five_days {
                labels_five = y.output.clone();
            }
            if y.datetime == next_ten_dats {
                labels_ten = y.output.clone();
                break;
            }
        }

        if labels_five.len() == 0 && labels_ten.len() == 0 {
            break;
        }
        if labels_five.len() != 0 {
            datas_five.push(Data {
                inputs: x.input.clone(),
                labels: labels_five,
            });
        }
        if labels_ten.len() != 0 {
            datas_ten.push(Data {
                inputs: x.input.clone(),
                labels: labels_ten,
            });
        }
```

```
    }
    Ok((DataSet::new(datas_five), DataSet::new(datas_ten)))
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn test_airquality() -> Result<(), Box<dyn Error>> {
        let (dt5, _) = airquality_dataset().unwrap();

        let dt = &dt5.cross_valid_set(0.1)[0];
        let (train, _) = dt.0.minmax_norm(&dt.1);

        for dt in train.get_datas().iter() {
            for v in dt.inputs.iter() {
                print!("{:.3e} ", v);
            }
            print!("{:.3e}\n", dt.labels[0]);
        }
        println!("{}", train.len());
        Ok(())
    }

    #[test]
    fn test_minmax_norm() {
        let datas: Vec<Data> = (0..=10)
            .into_iter()
            .map(|i| Data {
                labels: vec![0.0],
                inputs: vec![i as f64 * 10.0],
            })
            .collect();
        let v_datas: Vec<Data> = (0..=10)
            .into_iter()
            .map(|i| Data {
                labels: vec![0.0],
                inputs: vec![i as f64 * 5.0],
            })
            .collect();

        let (t, v) = DataSet::new(datas).minmax_norm(&DataSet::new(v_datas));

        let expected = vec![0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0];
        for (i, x) in t.get_feature(0).iter().enumerate() {
            assert_eq!(*x, expected[i]);
        }
        let v_expected = vec![
            0.0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50,
        ];
        for (i, x) in v.get_feature(0).iter().enumerate() {
            assert_eq!(*x, v_expected[i])
        }
    }
}

```

Source Code 8: utills/graph/mod.rs

```
use plotters::coord::Shift;
use plotters::prelude::*;
use std::error::Error;

pub mod hist;

const FONT: &str = "Roboto Mono";
const CAPTION: i32 = 70;
const SERIE_LABEL: i32 = 32;
const AXIS_LABEL: i32 = 40;

pub struct LossGraph {
    loss: Vec<Vec<f64>>,
    valid_loss: Vec<Vec<f64>>,
}
```

```rust

impl LossGraph {
    pub fn new() -> LossGraph {
        let loss: Vec<Vec<f64>> = vec![];
        let valid_loss: Vec<Vec<f64>> = vec![];
        LossGraph { loss, valid_loss }
    }

    pub fn add_loss(&mut self, training: Vec<f64>, validation: Vec<f64>) {
        self.loss.push(training);
        self.valid_loss.push(validation);
    }
    /// Draw training loss and validation loss at each epoch (x_vec)
    pub fn draw_loss(
        &self,
        idx: u32,
        root: &DrawingArea<BitMapBackend, Shift>,
        loss_vec: &Vec<f64>,
        valid_loss_vec: &Vec<f64>,
        max_loss: f64,
    ) -> Result<(), Box<dyn Error>> {
        let min_loss1 = loss_vec.iter().fold(f64::NAN, |min, &val| val.min(min));
        let min_loss2 = valid_loss_vec
            .iter()
            .fold(f64::NAN, |min, &val| val.min(min));
        let min_loss = if min_loss1.min(min_loss2) > 0.0 {
            0.0
        } else {
            min_loss1.min(min_loss2)
        };

        let mut chart = ChartBuilder::on(&root)
            .caption(
                format!("Loss {}", idx),
                ("Hack", 44, FontStyle::Bold).into_font(),
            )
            .margin(20)
            .x_label_area_size(50)
            .y_label_area_size(60)
            .build_cartesian_2d(0..loss_vec.len(), min_loss..max_loss)?;

        chart
            .configure_mesh()
            .y_desc("Loss")
            .x_desc("Epochs")
            .axis_desc_style(("Hack", 20))
            .draw()?;

        chart.draw_series(LineSeries::new(
            loss_vec.iter().enumerate().map(|(i, x)| (i + 1, *x)),
            &RED,
        ))?;

        chart.draw_series(LineSeries::new(
            valid_loss_vec.iter().enumerate().map(|(i, x)| (i + 1, *x)),
            &BLUE,
        ))?;

        root.present()?;
        Ok(())
    }

    pub fn max_loss(&self) -> f64 {
        f64::max(
            self.loss.iter().fold(f64::NAN, |max, vec| {
                let max_loss = vec.iter().fold(f64::NAN, |max, &val| val.max(max));
                f64::max(max_loss, max)
            }),
            self.valid_loss.iter().fold(f64::NAN, |max, vec| {
                let max_loss = vec.iter().fold(f64::NAN, |max, &val| val.max(max));
                f64::max(max_loss, max)
            }),
        )
    }

    pub fn draw(&self, path: String) -> Result<(), Box<dyn Error>> {
```

```
        let root = BitMapBackend::new(&path, (2000, 1000)).into_drawing_area();
        root.fill(&WHITE)?;
        // hardcode for 10 iteraions
        let drawing_areas = root.split_evenly((2, 5));

        let mut loss_iter = self.loss.iter();
        let mut valid_loss_iter = self.valid_loss.iter();
        let max_loss = self.max_loss();
        for (drawing_area, idx) in drawing_areas.iter().zip(1..) {
            if let (Some(loss_vec), Some(valid_loss_vec)) =
                (loss_iter.next(), valid_loss_iter.next())
            {
                self.draw_loss(idx, drawing_area, loss_vec, valid_loss_vec, max_loss)?;
            }
        }
        Ok(())
    }
}

/// Draw confusion matrix
pub fn draw_confustion(matrix_vec: Vec<[[i32; 2]; 2]>, path: String) -> Result<(), Box<dyn Error>> {
    let root = BitMapBackend::new(&path, (2000, 1100)).into_drawing_area();
    root.fill(&WHITE)?;

    let (top, down) = root.split_vertically(1000);

    let mut chart = ChartBuilder::on(&down)
        .margin(20)
        .margin_left(40)
        .margin_right(40)
        .x_label_area_size(40)
        .build_cartesian_2d(0i32..50i32, 0i32..1i32)?;
    chart
        .configure_mesh()
        .disable_y_axis()
        .disable_y_mesh()
        .x_labels(3)
        .label_style((FONT, 40))
        .draw()?;

    chart.draw_series((0..50).map(|x| {
        Rectangle::new(
            [(x, 0), (x + 1, 1)],
            HSLColor(
                240.0 / 360.0 - 240.0 / 360.0 * (x as f64 / 50.0),
                0.7,
                0.1 + 0.4 * x as f64 / 50.0,
            )
            .filled(),
        )
    }))?;
    // hardcode for 10 iteraions
    let drawing_areas = top.split_evenly((2, 5));
    let mut matrix_iter = matrix_vec.iter();
    for (drawing_area, idx) in drawing_areas.iter().zip(1..) {
        if let Some(matrix) = matrix_iter.next() {
            let mut chart = ChartBuilder::on(&drawing_area)
                .caption(
                    format!("Iteration {}", idx),
                    (FONT, 40, FontStyle::Bold).into_font(),
                )
                .margin(20)
                .build_cartesian_2d(0i32..2i32, 2i32..0i32)?
                .set_secondary_coord(0f64..2f64, 2f64..0f64);

            chart
                .configure_mesh()
                .disable_axes()
                .max_light_lines(4)
                .disable_x_mesh()
                .disable_y_mesh()
                .label_style(("Hack", 20))
                .draw()?;

            chart.draw_series(
                matrix
```

```
                    .iter()
                    .zip(0..)
                    .map(|(l, y)| l.iter().zip(0..).map(move |(v, x)| (x, y, v)))
                    .flatten()
                    .map(|(x, y, v)| {
                        Rectangle::new(
                            [(x, y), (x + 1, y + 1)],
                            HSLColor(
                                240.0 / 360.0 - 240.0 / 360.0 * (*v as f64 / 50.0),
                                0.7,
                                0.1 + 0.4 * *v as f64 / 50.0,
                            )
                            .filled(),
                        )
                    }),
            )?;

            chart.draw_secondary_series(
                matrix
                    .iter()
                    .zip(0..)
                    .map(|(l, y)| l.iter().zip(0..).map(move |(v, x)| (x, y, v)))
                    .flatten()
                    .map(|(x, y, v)| {
                        let text: String = if x == 0 && y == 0 {
                            format!["TP:{}", v]
                        } else if x == 1 && y == 0 {
                            format!["FP:{}", v]
                        } else if x == 0 && y == 1 {
                            format!["FN:{}", v]
                        } else {
                            format!["TN:{}", v]
                        };

                        Text::new(
                            text,
                            ((2.0 * x as f64 + 0.7) / 2.0, (2.0 * y as f64 + 1.0) / 2.0),
                            FONT.into_font().resize(30.0).color(&WHITE),
                        )
                    }),
            )?;
        }
    }
    root.present()?;
    Ok(())
}

/// Receive each cross-validation vector of each individual fitness value.
pub fn draw_ga_progress(
    cv_fitness: &Vec<Vec<(i32, f64)>>,
    path: String,
    max_y: f64,
) -> Result<(), Box<dyn Error>> {
    let root = BitMapBackend::new(&path, (2000, 1000)).into_drawing_area();
    root.fill(&WHITE)?;

    let max_x = cv_fitness[0]
        .iter()
        .reduce(|m, x| if m.0 > x.0 { m } else { x })
        .unwrap()
        .0;

    // This is mostly hardcoded
    let drawing_areas = root.split_evenly((2, 5));
    for ((drawing_area, idx), fitness) in drawing_areas.iter().zip(1..).zip(cv_fitness.iter()) {
        let mut chart = ChartBuilder::on(&drawing_area)
            .caption(
                format!("Iteration {}", idx),
                (FONT, 40, FontStyle::Bold).into_font(),
            )
            .margin(40)
            .x_label_area_size(20)
            .y_label_area_size(30)
            .build_cartesian_2d(0i32..max_x, 0.0..max_y)?;

        chart
```

```
            .configure_mesh()
            .x_labels(3)
            .y_labels(2)
            .label_style((FONT, 30))
            .max_light_lines(4)
            .draw()?;

        chart.draw_series(
            fitness
                .iter()
                .map(|x| Circle::new((x.0, x.1), 1, BLUE.mix(0.25).filled())),
        )?;
    }
    root.present()?;
    Ok(())
}

```

Source Code 9: utills/graph/hist.rs

```
use plotters::prelude::*;
use std::error::Error;

use crate::utills::{graph::*, data};

pub struct Histogram2 {
    datas: [Vec<f64>; 2],
    title: String,
    axes_desc: (String, String),
}

impl Histogram2 {
    pub fn new(datas: [Vec<f64>; 2],title: &str, axes_desc: (&str, &str)) -> Histogram2 {
        Histogram2 {
            datas,
            title: title.into(),
            axes_desc: (axes_desc.0.into(), axes_desc.1.into()),
        }
    }

    pub fn mean(&self) -> Vec<f64> {
        self.datas
            .iter()
            .map(|l| {
                l.iter()
                    .fold(0f64, |mean, &val| mean + val / l.len() as f64)
            })
            .collect()
    }

    pub fn max_x(&self) -> f64 {
        self.datas
            .iter()
            .fold(0f64, |max, l| max.max(l.len() as f64))
    }

    pub fn max_y(&self) -> f64 {
        self.datas
            .iter()
            .fold(f64::MIN, |max, l| {
                let l_max = data::max(l);
                if l_max > max {
                    l_max
                }
                else {
                    max
                }
            })
    }

    pub fn draw_hist(&self, path: String, max_y: f64) -> Result<(), Box<dyn Error>> {
        let root = BitMapBackend::new(&path, (1024, 768)).into_drawing_area();
        root.fill(&WHITE)?;

        let n = self.max_x();
```

```
        let mut chart = ChartBuilder::on(&root)
            .caption(&self.title, (FONT, CAPTION, FontStyle::Bold).into_font())
            .margin(20)
            .x_label_area_size(70)
            .y_label_area_size(90)
            .build_cartesian_2d((1..n as u32).into_segmented(), 0.0..max_y)?
            .set_secondary_coord(0.0..n, 0.0..max_y);

        chart
            .configure_mesh()
            .disable_x_mesh()
            .y_max_light_lines(0)
            .y_desc(&self.axes_desc.1)
            .x_desc(&self.axes_desc.0)
            .axis_desc_style((FONT, AXIS_LABEL))
            .y_labels(3)
            .label_style((FONT, AXIS_LABEL - 10))
            .draw()?;


        let colors = [&RED, &BLUE];

        for (i, dt) in self.datas.iter().enumerate() {
            let color = colors[i % 2];
            let offset = i as f64 * 0.4;
            chart.draw_secondary_series(dt.iter().zip(0..).map(|(y, x)| {
                Rectangle::new(
                    [(x as f64 + 0.1 + offset, *y), (x as f64 + 0.5 + offset, 0f64)],
                    Into::<ShapeStyle>::into(color.mix(0.5)).filled(),
                )
            }))?;
        }

        let v: Vec<usize> = (0..(n + 1.0) as usize).collect();
        let mean = self.mean();
        for (j, m) in mean.iter().enumerate() {
            let color = colors[j % 2];
            chart
                .draw_secondary_series(LineSeries::new(
                    v.iter().map(|i| (*i as f64, *m)),
                    color.filled().stroke_width(2),
                ))?
                .label(format!("mean: {:.3}", m))
                .legend(move |(x, y)| PathElement::new(vec![(x, y), (x + 20, y)], color.filled()));
        }

        chart
            .configure_series_labels()
            .label_font((FONT, SERIE_LABEL).into_font())
            .background_style(&WHITE)
            .border_style(&BLACK)
            .draw()?;

        root.present()?;
        Ok(())
    }
}

/// Draw histogram of given datas
/// axes_desc - (for x, for y)
pub fn draw_acc_hist(
    datas: &Vec<f64>,
    title: &str,
    axes_desc: (&str, &str),
    path: String,
) -> Result<(), Box<dyn Error>> {
    let n = datas.len();
    let mean = datas
        .iter()
        .fold(0.0f64, |mean, &val| mean + val / n as f64);

    let root = BitMapBackend::new(&path, (1024, 768)).into_drawing_area();
    root.fill(&WHITE)?;

    let mut chart = ChartBuilder::on(&root)
        .caption(title, ("Hack", 44, FontStyle::Bold).into_font())
```

```
        .margin(20)
        .x_label_area_size(50)
        .y_label_area_size(60)
        .build_cartesian_2d((1..n).into_segmented(), 0.0..1.0)?
        .set_secondary_coord(1..n, 0.0..1.0);

    chart
        .configure_mesh()
        .disable_x_mesh()
        .y_max_light_lines(0)
        .y_desc(axes_desc.1)
        .x_desc(axes_desc.0)
        .axis_desc_style(("Hack", 20))
        .y_labels(3)
        .draw()?;

    let hist = Histogram::vertical(&chart)
        .style(RED.mix(0.5).filled())
        .margin(10)
        .data(datas.iter().enumerate().map(|(i, x)| (i + 1, *x)));

    chart.draw_series(hist)?;

    chart
        .draw_secondary_series(LineSeries::new(
            datas.iter().enumerate().map(|(i, _)| (i + 1, mean)),
            BLUE.filled().stroke_width(2),
        ))?
        .label(format!("mean: {:.3}", mean))
        .legend(|(x, y)| PathElement::new(vec![(x, y), (x + 20, y)], &BLUE));

    chart
        .configure_series_labels()
        .label_font(("Hack", 14).into_font())
        .background_style(&WHITE)
        .border_style(&BLACK)
        .draw()?;

    root.present()?;
    Ok(())
}

pub fn draw_acc_2hist(
    datas: [&Vec<f64>; 2],
    title: &str,
    axes_desc: (&str, &str),
    path: String,
) -> Result<(), Box<dyn Error>> {
    let hist2 = Histogram2::new([datas[0].clone(), datas[1].clone()], title, axes_desc);
    hist2.draw_hist(path, 1.0)
}

pub fn draw_2hist(
    datas: [&Vec<f64>; 2],
    title: &str,
    axes_desc: (&str, &str),
    path: String,
) -> Result<(), Box<dyn Error>> {
    let hist2 = Histogram2::new([datas[0].clone(), datas[1].clone()], title, axes_desc);
    hist2.draw_hist(path, hist2.max_y())
}
```