

Classifying Human Driving Behavior via Deep Neural Networks

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June 8, 2017

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Problem Statement

This is problem statement

Project Background

This is project background

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Neural Networks - Introduction

- The concept of artificial neurons was introduced by Warren McCullock and Walter Pitts
- Neural network consists of many artificial neurons

Neural Networks - Introduction

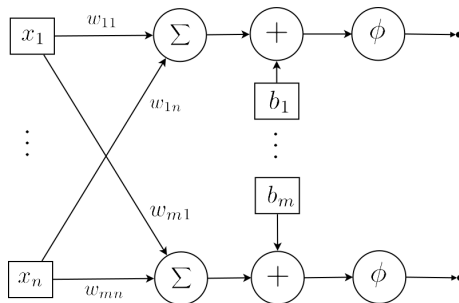


Figure: Example of a Neural Network

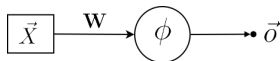


Figure: Simplified Neural Network

Neural Networks - Forward Propagation

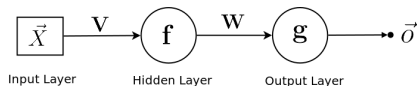


Figure: One Hidden Layer MLP

$$\vec{h} = f(\vec{x}v + \vec{c}) = f(\vec{X}V)$$

$$\vec{o} = g(\vec{h}w + \vec{b}) = g(\vec{H}W)$$

$$\vec{o} = g(h(\vec{x}v + \vec{c})w + \vec{b}) = g(h(\vec{X}V)W)$$

Neural Networks - Back Propagation

Error Function:

$$J(V, W) = \frac{1}{2} \sum_i (y_i - o_i)^2 = \frac{1}{2} \sum_i (y_i - g(h(\vec{X}V)W_i))^2$$

Update W_{ij} - i th neuron for j th input:

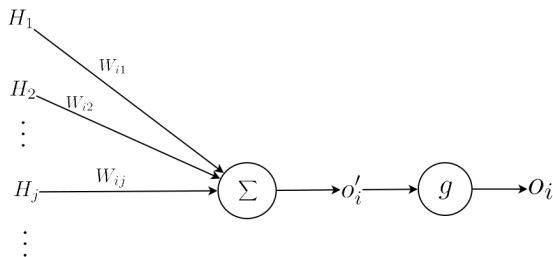


Figure: Back-propagation for W_{ij}

Neural Networks - Back Propagation

Update W_{ij} - i th neuron for j th input:

$$W_{ij}^{next} = W_{ij} - \eta \frac{\partial J}{\partial W_{ij}} = W_{ij} - \eta \frac{\partial J}{\partial o_i} \frac{\partial o_i}{\partial o'_i} \frac{\partial o'_i}{\partial W_{ij}} = W_{ij} + \eta (y_i - o_i) o_i (1 - o_i) H_j$$

Let

$$\delta_i = \frac{\partial J}{\partial o'_i} = \frac{\partial J}{\partial o_i} \frac{\partial o_i}{\partial o'_i}$$

Neural Networks - Back Propagation

Update W_{ij} - i th neuron for j th input:

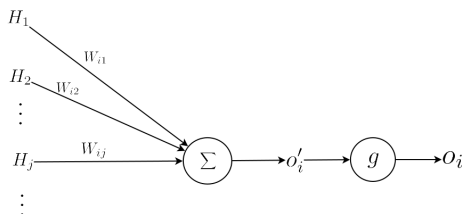


Figure: Back-propagation for W_{ij}

$$W_{ij}^{next} = W_{ij} - \eta \frac{\partial J}{\partial W_{ij}} = W_{ij} - \eta \frac{\partial J}{\partial o_i} \frac{\partial o_i}{\partial o'_i} \frac{\partial o'_i}{\partial W_{ij}} = W_{ij} + \eta (y_i - o_i) o_i (1 - o_i) H_j$$

Let

$$\delta_i = \frac{\partial J}{\partial o'_i} = \frac{\partial J}{\partial o_i} \frac{\partial o_i}{\partial o'_i}$$

Neural Networks - Back Propagation

Update V_{ij} - i th neuron for j th input:

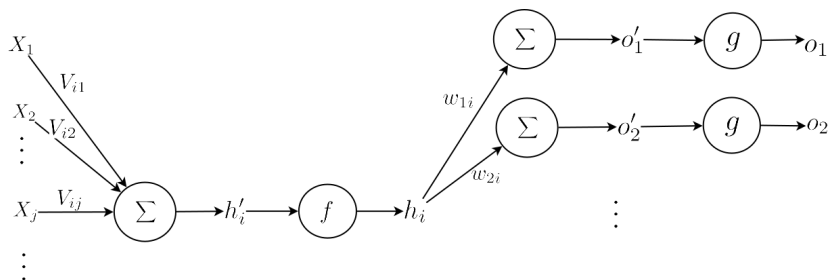


Figure: Back-propagation for V_{ij}

$$V_{ij}^{next} = V_{ij} - \eta \frac{\partial J}{\partial V_{ij}} = V_{ij} - \eta \frac{\partial J}{\partial h_i} \frac{\partial h_i}{\partial h'_i} \frac{\partial h'_i}{\partial V_{ij}} = V_{ij} - \eta \sum_k (\delta_k w_{ki}) h_i (1 - h_i) X_j$$

Long Short Term Memory Networks (LSTM)

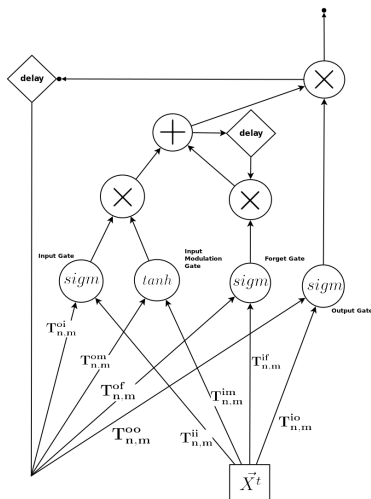


Figure: LSTM

- Recurrent Neural Network
- Four gates and Memory Cells handle long term dependencies

Long Short Term Memory Networks (LSTM)

Input gate:

$$\vec{i}^t = \text{sigm}(\vec{X}^t T_{n,m}^{ii} + H^{t-1} T_{m,m}^{oi})$$

Input modulation gate:

$$\vec{m}^t = \tanh(\vec{X}^t T_{n,m}^{im} + H^{t-1} T_{m,m}^{om})$$

Forget gate:

$$\vec{f}^t = \text{sigm}(\vec{X}^t T_{n,m}^{if} + H^{t-1} T_{m,m}^{of})$$

Output gate:

$$\vec{o}^t = \text{sigm}(\vec{X}^t T_{n,m}^{io} + H^{t-1} T_{m,m}^{oo})$$

Memory cells:

$$\vec{c}^t = \vec{i}^t * \vec{m}^t + \vec{f}^t * \vec{c}^{t-1}$$

Result:

$$\vec{h}^t = \vec{c}^t * \vec{o}^t$$

Auto-encoder (AE) - Single layer AE

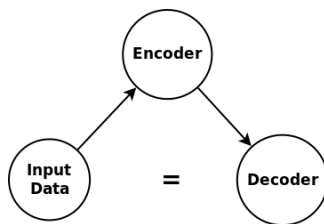


Figure: Abstract structure of Auto-encoder

Auto-encoder is a neural network to attempt to copy its inputs to its outputs

Auto-encoder (AE) - Single layer AE

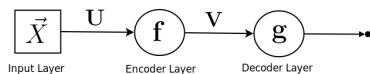


Figure: Basic Auto-encoder

$$\vec{e} = f(\vec{X}U)$$

$$\vec{d} = g(\vec{E}V)$$

$$E(\vec{x}, \vec{d}) = E(\vec{x}, g(\vec{E}V)) = E(\vec{x}, g(f(\vec{x}u + \vec{b}_e)v + \vec{b}_d))$$

Auto-encoder (AE) - Multiple layer AE

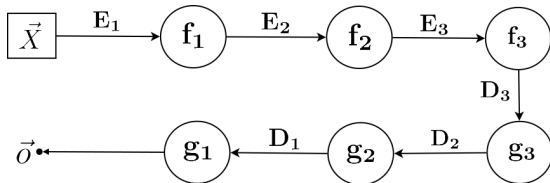


Figure: Multilayer Auto-encoder Example

Auto-encoder (AE) - Multiple layer AE

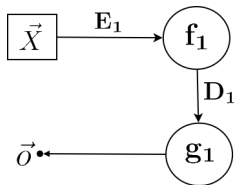


Figure: Pretraining First Step

Auto-encoder (AE) - Multiple layer AE

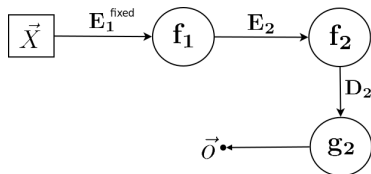


Figure: Pretraining Second Step

Auto-encoder (AE) - Multiple layer AE

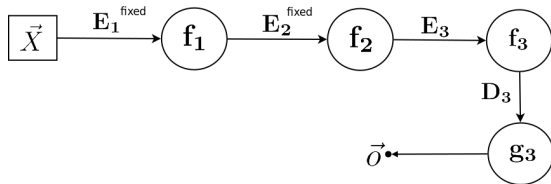


Figure: Pretraining Thrid Step

Auto-encoder (AE) - Multiple layer AE

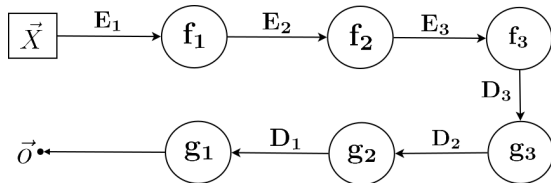


Figure: Multilayer Auto-encoder Example

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- Collected in the high-fidelity simulator of the Center for Injury Research Prevention Studies at the *Children's Hospital of Philadelphia* (CHOP)
- 16 traces = 4 tracks \times (2 expert drivers + 2 inexperienced drivers)
- 100 features collected at 60Hz
 - Car status: velocity, steer, Brake, throttle and etc.
 - Environment status: current speed limit, and etc.
 - instruction: left turn, right turn, and etc.
- Two datasets
 - *raw dataset*: 98 features without time stamps
 - *filtered dataset*: 23 features - more important features from 100 features

Table: Length of each of the traces

<i>Trace</i>	<i>Driver</i>	<i>Track</i>	<i>Length</i>
Trace0	Expert0	Track0	50029
Trace1	Expert0	Track1	26375
Trace2	Expert0	Track2	29629
Trace3	Expert0	Track3	26298
Trace4	Expert1	Track0	51295
Trace5	Expert1	Track1	26674
Trace6	Expert1	Track2	29680
Trace7	Expert1	Track3	27075
Trace8	Inexpert0	Track0	49691
Trace9	Inexpert0	Track1	30058
Trace10	Inexpert0	Track2	26441
Trace11	Inexpert0	Track3	27373
Trace12	Inexpert1	Track0	47658
Trace13	Inexpert1	Track1	29380
Trace14	Inexpert1	Track2	26684
Trace15	Inexpert1	Track3	27255

- Min: 26298
(about 7 minutes 18 seconds)
- Max: 51295
(about 14 minutes 15 seconds)
- Average: 33224.6875
(about 9 minutes 13 seconds)

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Cross Validation & Normalization

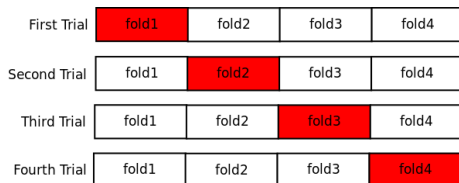


Figure: 4 Folds Cross Validation

- Cross Validation

- To validate experiment models when data is not large enough
- Divides a data set into K folds
- Uses the i th fold as the test set and other folds as the training set

- Normalization

- Normalize training set (mean 0, std 1)
- Normalize test set by mean and standard deviation of training set

First Model

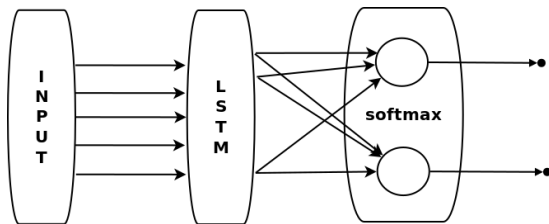


Figure: First experiment NN

- Hidden neurons in LSTM: 16, 32, 64, 128, and 256
- Without Auto-encoder on *filtered dataset*

Second Model

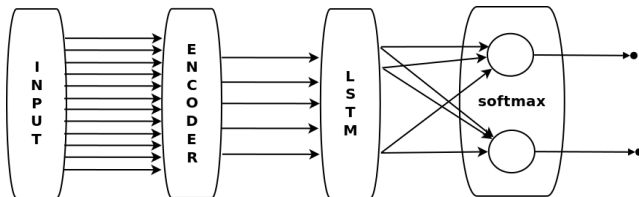


Figure: Second experiment NN

- Hidden neurons in LSTM: 16, 32, 64, 128, and 256
- With Single layer Auto-encoder on *raw dataset*:
98 features \rightarrow 25 features

Third Model

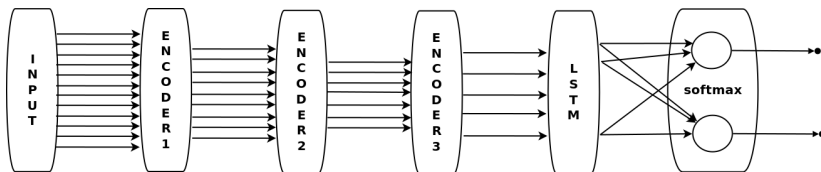


Figure: Third experiment NN

- Hidden neurons in LSTM: 16, 32, 64, 128, and 256
- With Three layer Auto-encoder on *raw dataset*:
98 features \rightarrow 75 features \rightarrow 50 features \rightarrow 25 features

- Period
 - 1 over 10
 - 1 over 20
 - 1 over 50
- Sampling Methods
 - Last sample from each period
 - Mean of each period
 - Gaussian filtered value of each period

Table: Sampling and Models

Period	Method	Model
1 over 10	last	<i>first, second, third</i>
	mean	<i>first</i>
	gaussian	<i>first</i>
1 over 20	last	<i>first</i>
	mean	<i>first</i>
	gaussian	<i>first</i>
1 over 50	last	<i>first</i>
	mean	<i>first</i>
	gaussian	<i>first</i>

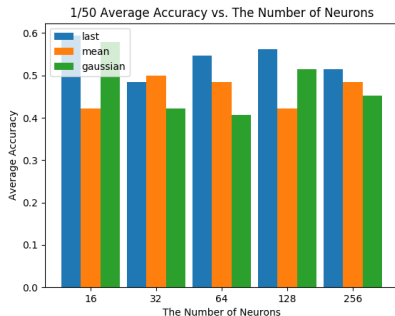
Tux

- Processors:
- Memory:
- Tensorflow 0.12.1

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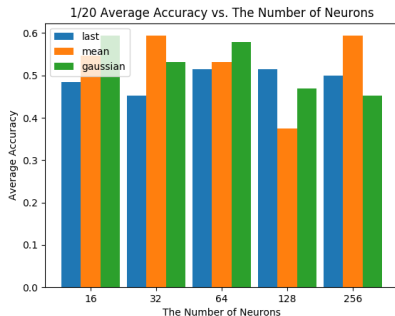
First Model with 1 over 50



- Best: 0.59375 (59.375%) on *last* and 16 neurons
- Worst: 0.40625 (40.625%) on *gaussian* and 64 neurons
- Average: 0.492708 (49.2708%)

Figure: Result of first model with 1 over 50 *filtered dataset*

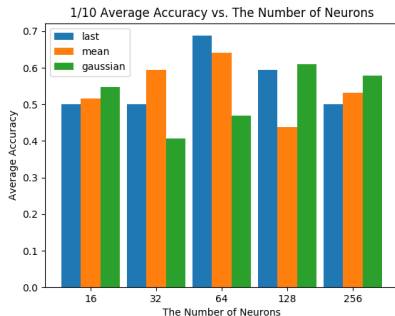
First Model with 1 over 20



- Best: 0.59375 (59.375%) on *mean* and 32 and 256 neurons
- Worst: 0.375 (37.5%) on *mean* and 128 neurons
- Average: 0.515625 (51.5625%)

Figure: Result of first model with 1 over 20 *filtered dataset*

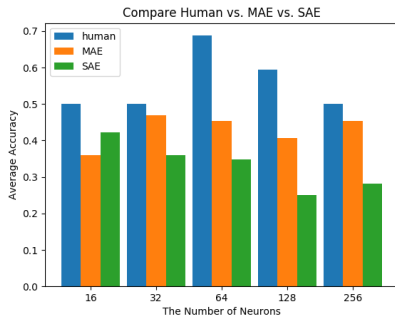
First Model with 1 over 10



- Best: 0.6875 (68.75%) on *last* and 64 neurons
- Worst: 0.40625 (40.625%) on *gaussian* and 32 neurons
- Average: 0.540625 (54.00625%)

Figure: Result of first model with 1 over 10 *filtered dataset*

Comparison of three models with 1 over 10, *last* method



Models with Auto-encoder show worse performance

Figure: Result of three models with 1 over 10, *last* method

Comparison of three models with 1 over 10, *last* method

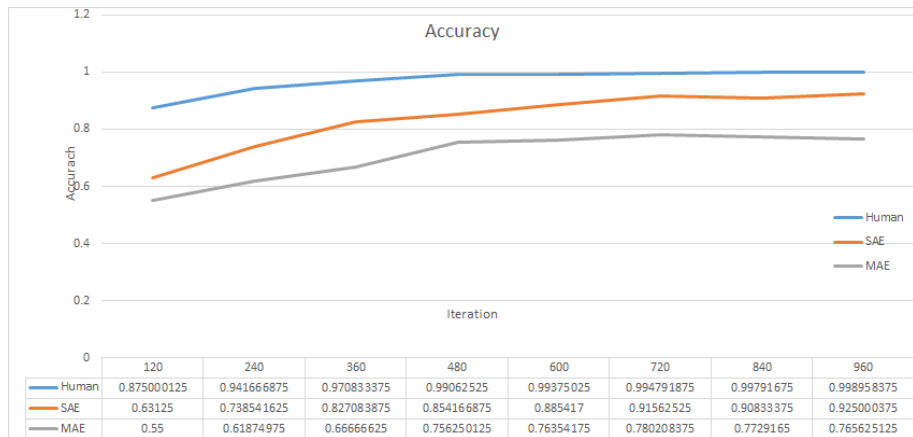


Figure: Three Models Training Accuracy

Comparison of three models with 1 over 10, *last* method



Figure: Three Models Training Loss

Problems with second and third models

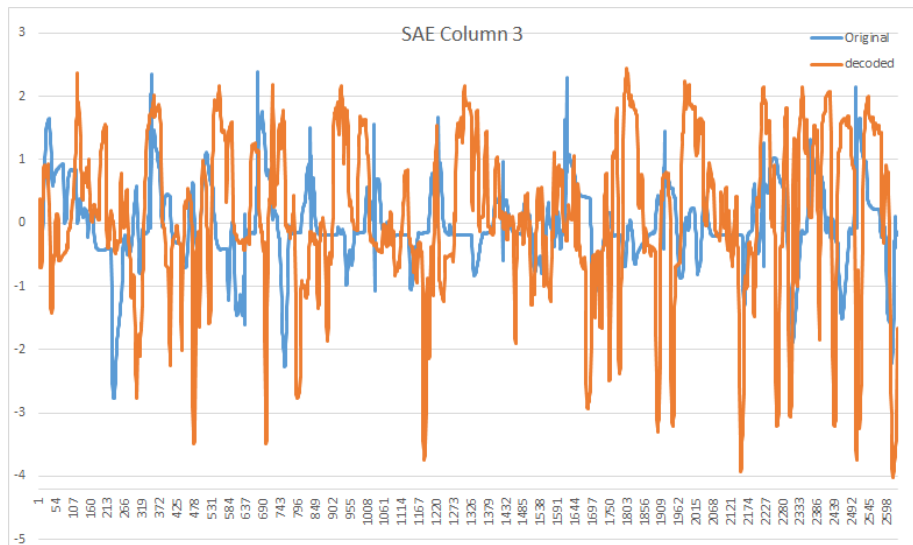


Figure: SAE, AE Error for Column 3

Problems with second and third models

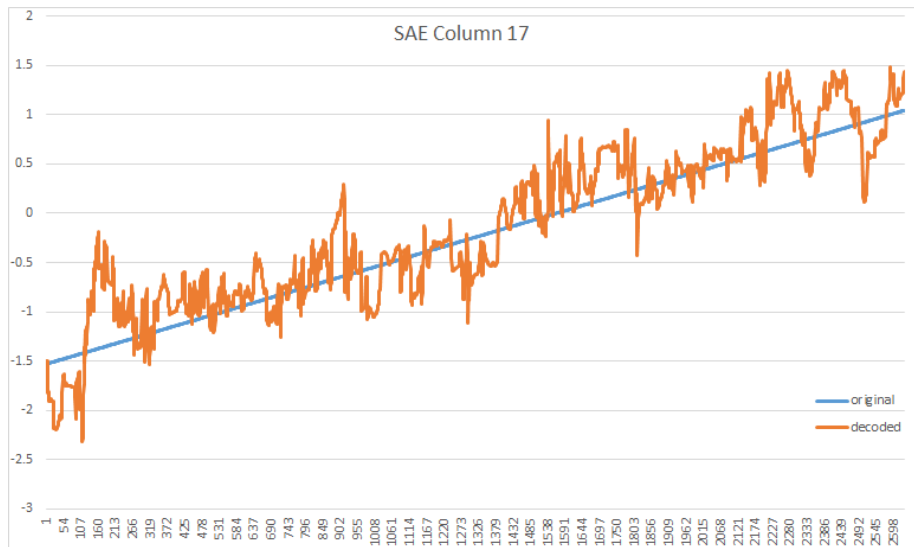


Figure: SAE, AE Error for Column 17

Problems with second and third models

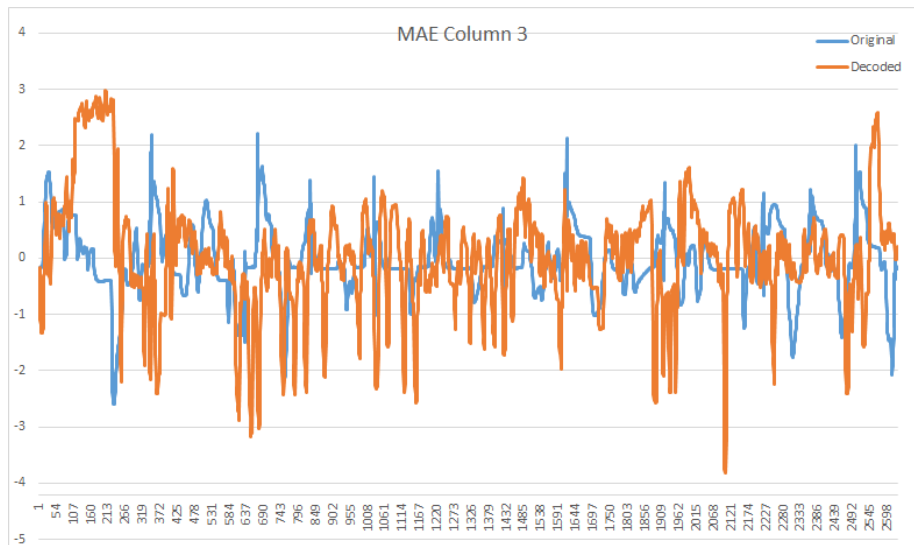


Figure: MAE, AE Error for Column 3

Problems with second and third models

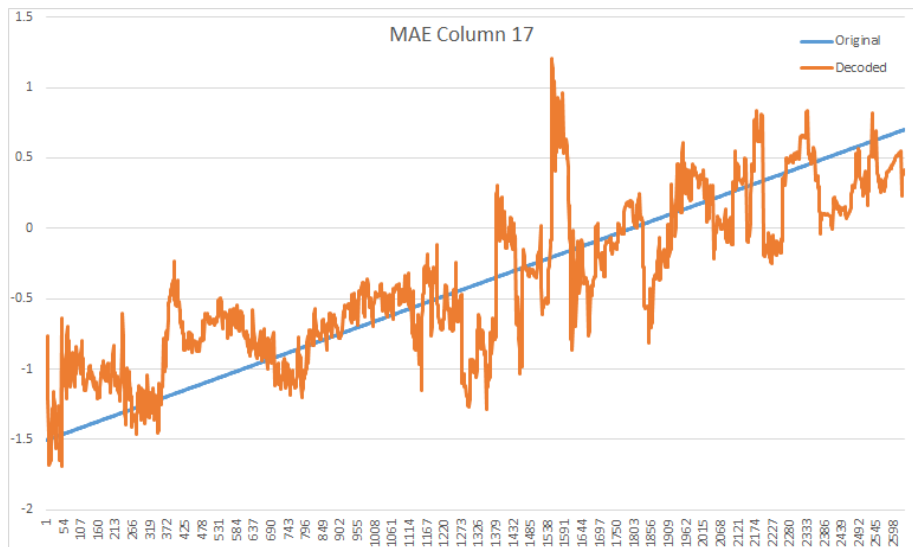


Figure: MAE, AE Error for Column 17

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Conclusion - Data Size

- The number of samples in trace
From result of experiment with different re-sampled periods, more densely re-sampled data gives better performance
- The number of traces
12 traces are not enough to train proposed neural networks

Conclusion - Limitation of Auto-encoders

- No optimize transfer matrices
When Auto-encoder tries to reduce dimensions, if encoder and decoder transfer matrices are not exist, encoded data has noise. It can make hard to train following neural networks.
- Always try to keep all information
Auto-encoder does not ignore or exclude unimportant features

Conclusion - Problem in training MAE

- Training time
Processing of pretraining takes long time
- Learn error from previous layer during pretraining
Fix previous layer while follow auto-encoder layer is trained

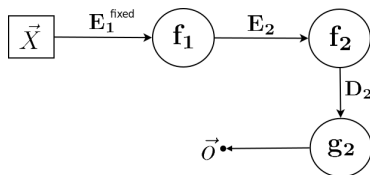


Figure: Pretraining Second Step

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- Experiment with more traces
- Research auto-encoder that accept some form of supervision and reduce dimensions with the ability to ignore unimportant features and keep information from the important features
- Try different way to train MAE

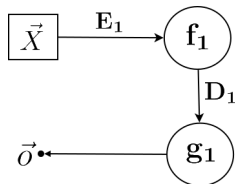


Figure: First Step of New Way to train MAE

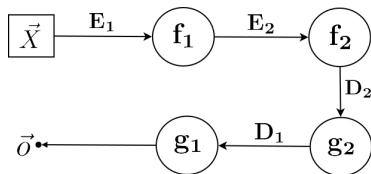


Figure: Second Step of New Way to train MAE

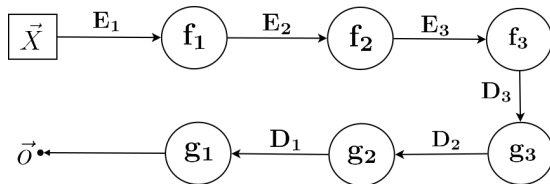


Figure: Thrid Step of New Way to train MAE

Thank You