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The Massive Implementation of Artificial Intelligence and Computational Methods Across Various Sectors

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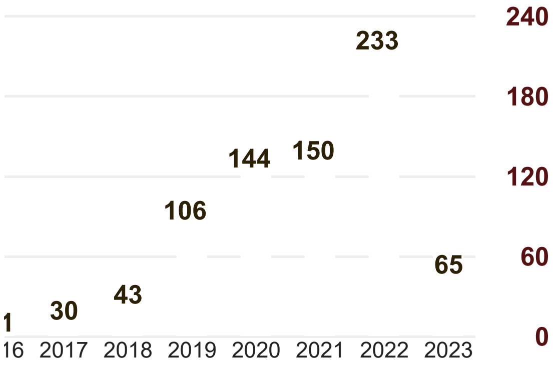

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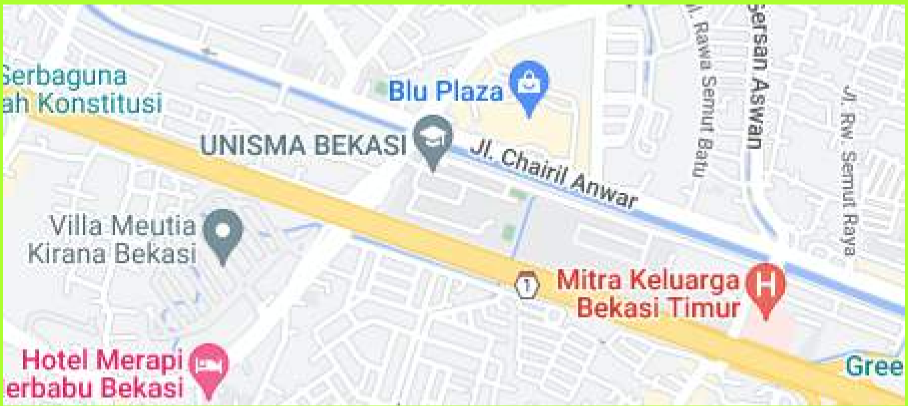

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Learning Vector Quantization, Hebbian Learning, and Self-Organizing Map for Classification

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Abstract

Deep Learning has been rapidly developed. Almost all proposed methods already have very high accuracy. Most of these methods still use techniques from the past with some modifications to adapt to existing modules. Sometimes it is necessary to understand past methods to produce new methods. Therefore, this research examines past models that have the potential to improve the performance of existing deep learning models. The methods to be examined include Learning Vector Quantization (LVQ), Hebbian learning, and Self-Organizing Map (SOM). The iris dataset available on Scikit-learn (SKlearn) is used here for testing in cases of supervised learning and unsupervised learning (especially SOM). The results show that LVQ has a good accuracy of 93%, while Hebbian learning has an accuracy of 56%. SOM fluctuates between 88% and 93%. Although the accuracy of SOM does not exceed LVQ, this model does not require labels in its training process.

Keywords: *artificial neural networks, competitive networks, CRISP-DM, suppervised learning, unsuppervised learning*

1. Introduction

The current development of Artificial Intelligence is focused on one of its components, which is Deep Learning (DL). DL is a part of Machine Learning (ML) with its main component being Neural Networks. Its applications range from prediction, projection to clustering. Unlike ML, which still requires preprocessing, DL integrates it with convolution mechanisms, such as Convolutional Neural Network (CNN) proposed by (LeCun & Bengio, 1989). Convolution is a matrix operation method that has long been known by mathematicians and is now widely applied in deep learning models.

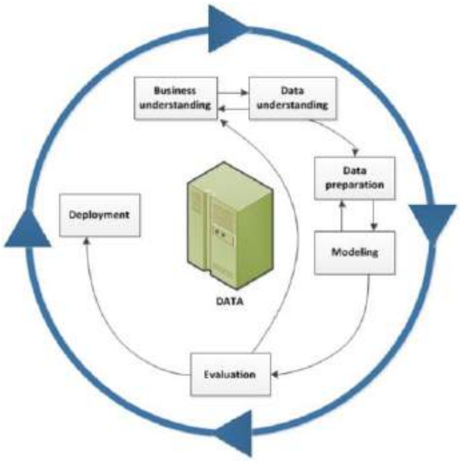
In addition to being applied in computer vision, DL is also used for other types of data such as text processing. Certain methods apply recurrent principles like in Recurrent Neural Network (RNN) (Roodschild et al., 2020) and its derivatives, such as Long Short-Term Memory (LSTM) (Hochreiter & Schmidhuber, 1997), Gated Recurrent Network (GRU) (Nayoga et al., 2021), and currently, the popular one is Generative Pre-Trained Transformer (GPT) (Radford et al., 2019). In addition to methods, their applications have also undergone development. For example, predictions in the form of classification are further divided into object detection, semantic segmentation, and instance segmentation.

Classical methods are not immediately abandoned because they can be used to improve the performance of current methods either as additional modules or hybridization. This research intends to examine the characteristics of basic neural network models, including Learning Vector Quantization (LVQ), Hebbian Learning, and Self-Organizing Maps (SOM) (Englebrecht, 2002). Accuracy and its characteristics will be examined, both from the perspective of Supervised Learning and Unsupervised Learning in the form of clustering.

After discussing the methods of LVQ, Hebbian Learning, and SOM, their implementation using Python is carried out to test the performance of these models. The results and discussion section discusses the strengths and weaknesses of each method, accompanied by the potential for future use.

2. Research Method

This research uses Cross Industry Process for Data Mining (CRISP-DM) with stages as shown in Figure 1. Starting from business understanding, the research proceeds to data understanding, and so on until deployment (IBM, 2023; Lopez, 2021; Schröer et al., 2021). The dataset uses the built-in dataset of scikit-learn, which is the IRIS dataset, with four input fields: sepal length, sepal width, petal length, and petal width, and three output classes/labels: setosa, versicolor, and virginica. Three models will be tested for their performance, namely Hebbian Learning, LVQ, and SOM. The evaluation stage compares the classification results with the real classes for the LVQ and Hebbian Learning methods, while SOM compares the clustering results with its real classes.



Source: (IBM, 2023)

Figure 1. CRISP-DM

After the evaluation stage, a prototype is created to facilitate users in utilizing the model as a deployment stage in CRISP-DM. The application is web-based and programmed in Python, which runs on the Apache web server.

2.1. Hebbian Learning

Hebbian learning is a simple and old learning rule in artificial neural networks that adjusts the strength of connections between neurons based on the correlation of their activities. The rule is motivated by Hebb's hypothesis that a neuron's ability to fire is based on its ability to cause other neurons connected to it to fire. The weight between two correlated neurons is strengthened when one neuron fires and triggers another, while it is reduced when one fires without activating the other. By modifying the weights of the connections between neurons, the network can recognize patterns in input data via unsupervised learning. However, a problem with Hebbian learning is that it can lead to saturation of weight values, which can be prevented by imposing a limit on the increase in weight values or using a nonlinear forgetting factor.

Algorithm-1: Hebbian Learning

1. Initialize all weights to zero or small random values.
2. Present an input pattern to the network.
3. Compute the output of the network using the current weights.
4. Update the weights according to the Hebbian learning rule:
   a. For each pair of neurons that are both active, increase the weight between them.

b. For each pair of neurons where only one is active, decrease the weight between them.
c. For pairs of neurons that are both inactive, leave the weight unchanged.
5. Repeat steps 2-4 for all input patterns in the training set.
6. Repeat steps 2-5 until the weights converge or a maximum number of epochs is reached.

2.2. Learning Vector Quantization (LVQ)

The learning vector quantizer (LVQ) is an unsupervised clustering algorithm commonly used to group similar input vectors based on their Euclidean distance. This research used LVQ version 1 or known as LVQ-1. In LVQ-I, each output unit represents a single cluster, and the competition among the cluster units during training is based on their closeness to the input pattern. The weight vectors of the winning unit and its neighbors are then adjusted using a learning rate that decays over time. LVQ-I can use a neighborhood function to update the weights of neighboring units, but it is not required. The number of output units should be carefully chosen to avoid underfitting or overfitting.

LVQ-I can be illustrated using a clustering problem in a two-dimensional input space, where each output unit represents a single cluster. An additional cluster unit can cause a separate cluster to learn a single input pattern, and too few or too many output units can lead to errors or overfitting.

Algorithm-2: LVQ-1

1. Initialize the weight matrix W with random small values.
2. For each input pattern zp, compute the Euclidean distance between the input and each weight vector in W.
3. Identify the neuron with the closest weight vector as the winner neuron.
4. If the winner neuron belongs to the same class as the input pattern, update its weight vector to move closer to the input pattern using the formula: $\Delta w = \varepsilon(zp - wp)$, where ε is the learning rate.
5. If the winner neuron does not belong to the same class as the input pattern, update its weight vector to move away from the input pattern using the formula: $\Delta w = -\varepsilon(zp - wp)$.
6. Repeat steps 2-5 for all input patterns in the dataset.

7. Reduce the learning rate ε and repeat steps 2-6 for a fixed number of iterations or until the weight vectors converge.
8. Classify a new input pattern by computing its Euclidean distance to each weight vector in W and assigning it to the class of the closest weight vector.

2.3. Self-Organizing Map (SOM)

The self-organizing feature map (SOM) was developed by Kohonen, inspired by the self-organization of the human cerebral cortex. SOM is a multidimensional scaling method that compresses an I-dimensional input space onto a set of codebook vectors in a discrete output space, usually a two-dimensional grid. The SOM approximates the probability density function of the input space while preserving its topological structure. The SOM performs competitive learning to cluster input vectors, and neurons are organized on a rectangular grid, updated to maintain the topological structure of the input space.

Algorithm-3: SOM

1. Initialize the network by assigning random weights to each neuron in the input layer.
2. Select an input vector from the training dataset.
3. Compute the Euclidean distance between the input vector and the weights of each neuron in the input layer.
4. Identify the neuron with the smallest distance as the "winner".
5. Update the weights of the winning neuron and its topological neighbors using the following formula:
   $w(t + 1) = w(t) + \alpha(t)(x - w(t))$
   where w(t) is the weight vector at time t, x is the input vector, α(t) is the learning rate at time t, and (x - w(t)) is the difference between the input vector and the weight vector.
6. Decrease the learning rate and the neighborhood size.
7. Repeat steps 2-6 for a fixed number of iterations or until the network converges.

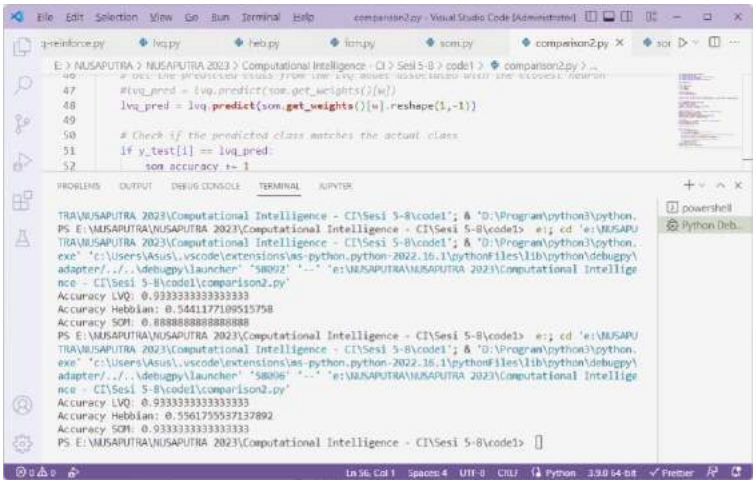
Note that this is a simplified flowchart, and there are different variations of the SOM algorithm that may have additional steps or modifications to the process. The SOM training process clusters similar patterns while preserving input space topology. To visualize cluster boundaries, the U-matrix is calculated, which shows the distance between neighboring codebook vectors. Gray-scale scheme is used to visualize the U-matrix. Ward clustering of codebook vectors is used to find cluster boundaries. The Ward distance measure decides which clusters should be merged based on the smallest distance. The resulting clusters have small variance within members and large variance between separate clusters. Two clusters can only be merged if they are adjacent and have a nonzero number of patterns associated with them to preserve topological structure.

The self-organizing map (SOM) has been applied to a wide range of real-world problems, including image analysis, speech recognition, music pattern analysis, signal processing, robotics, telecommunications, electronic-circuit design, knowledge discovery, and time series analysis. SOMs offer the advantage of easy visualization and interpretation of clusters formed by the map. The relative component values in the codebook vectors can be visualized using component planes, and the map and component planes can be used for exploratory data analysis. Additionally, a trained SOM can be used as a classifier, with clusters formed by the map manually inspected and labeled. The SOM can also be used to interpolate missing values within a pattern, either by replacing the missing value with the corresponding weight of the best matching neuron or through interpolation among a neighborhood of neurons.

3. Results and Discussion

3.1. Classification Performance

Using Visual Studio Code, three models, namely Hebbian Learning, LVQ-1, and SOM, were created using Python language. The results in the form of terminal output can be seen in Figure 2. Each run produces different results for Hebbian Learning and SOM, but not too different within the range of around 0.1 percent.



Source: Research Result (2023)

Figure 2. Experiment Result

LVQ-1 shows a stable accuracy value of 93.3%, while Hebbian Learning is far below with an accuracy of around 55%. The accuracy of SOM fluctuates between 88-93%.

3.2. Clustering Performance

Supervised learning requires a target/label in the learning process, while unsupervised learning performs grouping without a target/label. SOM, as a type of competitive neural network, has the ability to cluster datasets without labels.

SOM performs unsupervised learning processes based on the iris dataset without labels. The result is weights that are ready to be used for grouping. To test accuracy, SOM is used for the classification of the iris dataset. Considering that SOM is used for clustering, the weights resulting from SOM clustering are used as LVQ-1 weights for classification. Here, the classification results show an accuracy range of around 80% to 90% (Figure 2). Although utilizing the LVQ-1 classification process, here the weights used are the results of unsupervised learning with SOM, so the accuracy used is the accuracy of SOM. For the experiment, Apache from XAMPP version 3.3.0 with PHP version 7.4.28 running on the Windows 11 Home operating system with an i5 processor was used.

3.3. Web-Based Implementation

Figure 3 shows a web-based application as a prototype for iris dataset classification based on 4 inputs. The Python programming language used as the AI module is run with an Apache server. PHP language is required to run Python on the web application.

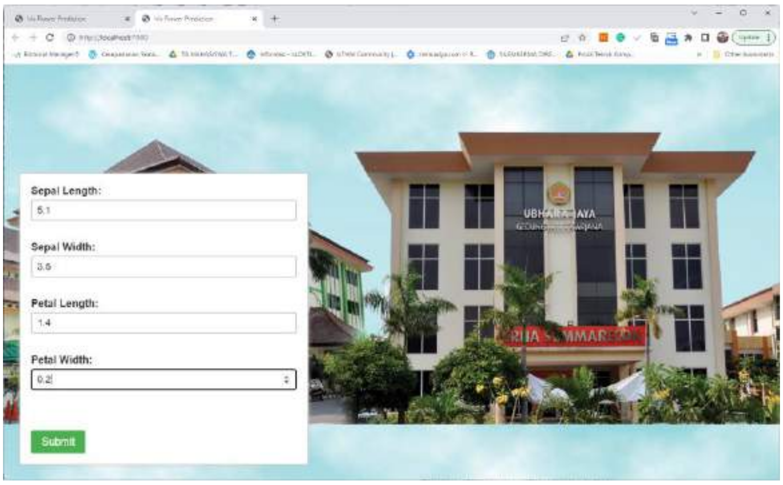


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Figure 3. Graphic User Interface

After sepal length, sepal width, petal length, and petal width are inputted, classification with LVQ-1 produces the output class 'iris setosa' accompanied by its image (Figure 4). The prototype development is a preparation for the deployment process according to the CRISP-DM standard process. However, of course, several testing stages are required in the implementation.

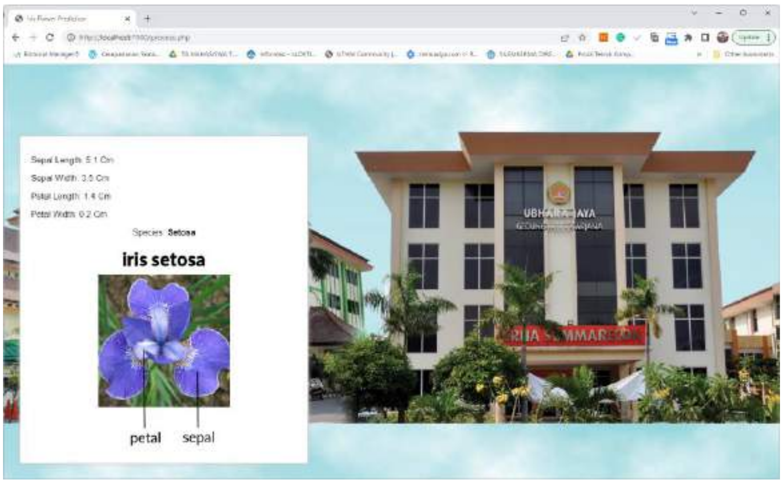

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Figure 4. Classification Result

3.4. Discussion

Hebbian Learning is a method introduced in the early development of neural networks. This method has now been replaced by current methods, such as Backpropagation and its variant modifications (Convolutional Neural

Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM)). However, some of its concepts, namely weights that have mutually reinforcing correlations and, conversely, those that are uncorrelated weaken each other, can be utilized for improving other models. Therefore, future research will investigate opportunities for utilizing this method.

Although SOM is sometimes inferior to LVQ-1 based on experimental results, it has the advantage of not requiring targets/labels in the dataset, thus it can be used as a generator of targets/labels for certain datasets. Imagine if we were asked to manually label thousands or even millions of data. The models that perform learning by generating datasets are currently being developed, including Generative Adversarial Networks (GANs), Variational Autoencoders (VAE), and Autoencoders.

4. Conclusion

The development of state-of-the-art models is closely tied to classical methods that have been modified to suit current scenarios. Although early models may have limitations, their ideas can still be implemented today, alongside other advantages such as consistency, speed, and accuracy. This study investigates variations of learning methods in machine learning, including supervised learning and unsupervised learning with competitive network-based models like Hebbian Learning, LVQ, and SOM. This study demonstrates the uniqueness of each method, from the speed and accuracy of LVQ to the classification ability of SOM integrated with LVQ for unlabeled datasets. In addition, the concept of Hebbian Learning, which focuses on the correlation between neurons, has the potential to be applied to other AI models. Future research will explore the use of classical methods to enhance the performance of current models based on specific requirements, such as those applicable to micro/mobile devices, unlabeled datasets, and other related areas.

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Author Contributions

Herlawati utilizes data, tests models, reporting, and conducts analyses to draw conclusions.

Conflicts of Interest

The author declare no conflict of interest.

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