Firefly Algorithm for Hyperparameter Tuning of CBOW Word2Vec Embeddings Models

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Swarm Intelligence

Swarm intelligence algorithms are inspired by the collective behavior of social creatures.

Figure 1: Swarm intelligence: Birds

Firefly Algorithm

The **Firefly Algorithm (FA)**, introduced by Xin-She Yang, is inspired by the flashing behavior of fireflies.

Figure 2: Fireflies flashing at night

Firefly Algorithm

The Firefly Algorithm is based on three key hypotheses:

- **All-Attractiveness**: All fireflies are attracted to each other regardless of their gender.
- **Brightness-Based Attraction**: Attractiveness is proportional to brightness, meaning less bright fireflies move towards brighter ones.
- **Random Movement**: If no brighter fireflies are nearby, a firefly moves randomly.

Firefly Algorithm

The main equation for the Firefly Algorithm:

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2} \left(x_j^t - x_i^t\right) + \alpha \epsilon_i^t \tag{1}$$

where r_{ij} denotes the Cartesian distance between firefly i and firefly j, given by

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{n} \left(x_{i,k} - x_{j,k}\right)^2}$$

Firefly Algorithm

The attractiveness β is inversely proportional to the distance, which is given by the formula:

$$\beta = \beta_0 e^{-\gamma r^2}$$

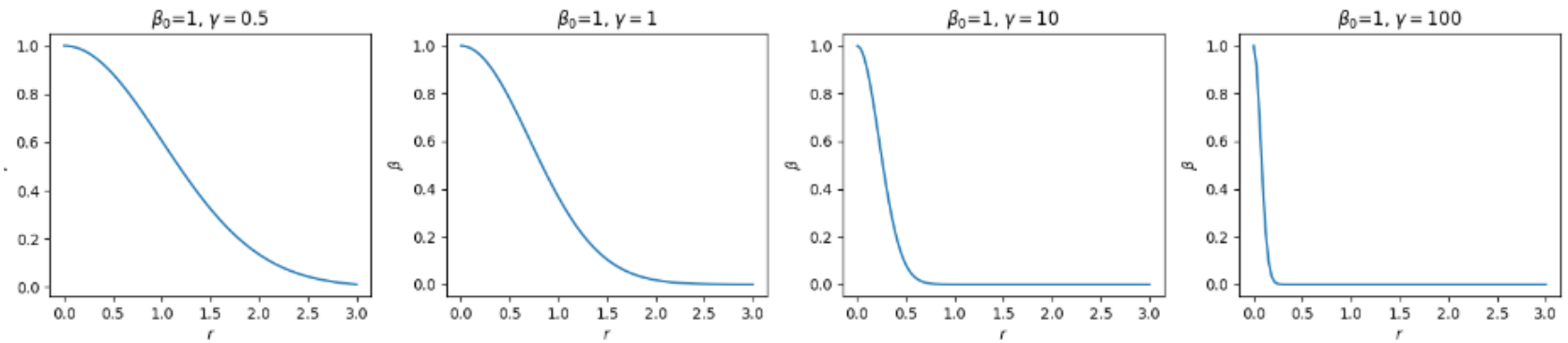

Figure 3: Effect of Gamma parameter

Note: As $r \to +\infty$, $\beta \to 0$.

Firefly Algorithm

Algorithm 1 FireFly Algorithm

Require: Light absorption coefficient γ, maximum generation $MaxGeneration$
Require: Initial population of fireflies x_i $(i = 1, 2, ..., n)$
Generate initial population of fireflies x_i $(i = 1, 2, ..., n)$
Evaluate light intensity I_i at x_i using objective function $f(x)$
Initialize iteration counter $t = 0$
while $t < MaxGeneration$ **do**
  for $i = 1$ **to** n **do**
    for $j = 1$ **to** n **do**
      if $I_j > I_i$ **then**
        Move firefly i towards j in d-dimension
      end if
      Attractiveness varies with distance r via $\exp[-\gamma r^2]$
      Evaluate new solutions and update light intensity
    end for
  end for
  Rank the fireflies and find the current best
  $t = t + 1$
end while

Overview of the CBoW Model

CBoW stands for **Continuous Bag of Words**. It is a **Word2Vec** model based on a neural network architecture, which learns to represent **words** with continuous vectors.

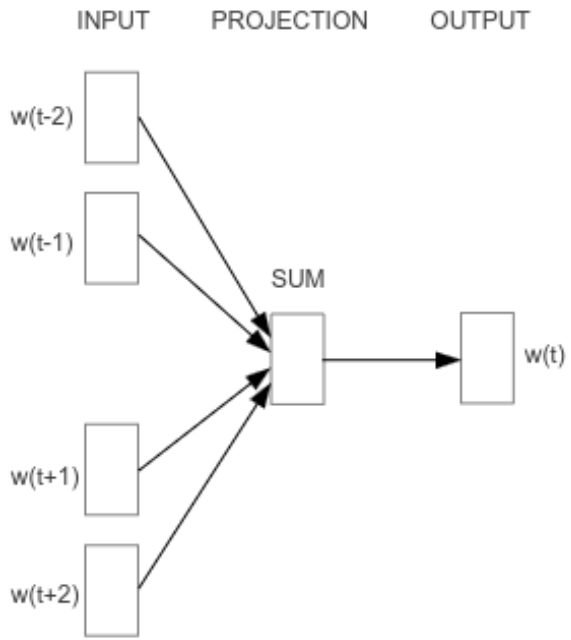

Figure 4: CBoW Model Architecture

CBoW Model Architecture

The following figure represents the model's architecture used in the experiment results:

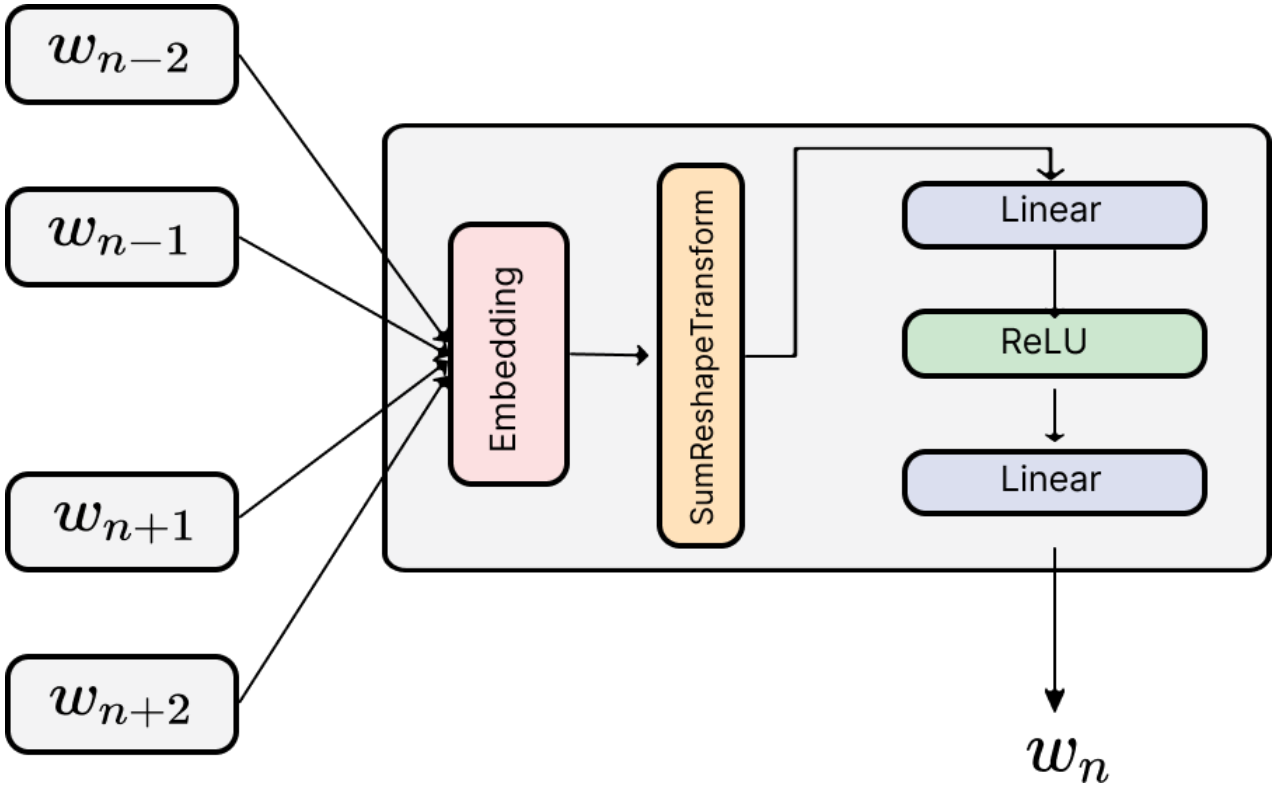

Figure 5: CBoW Model Architecture

How It Works

The CBoW model has a basic idea: given a larger corpus of text and a window of words w, it tries to predict the word in the middle.

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Hyperparameter Tuning Workflow

The following figure represents the workflow of hyperparameters tuning using the Firefly Algorithm.

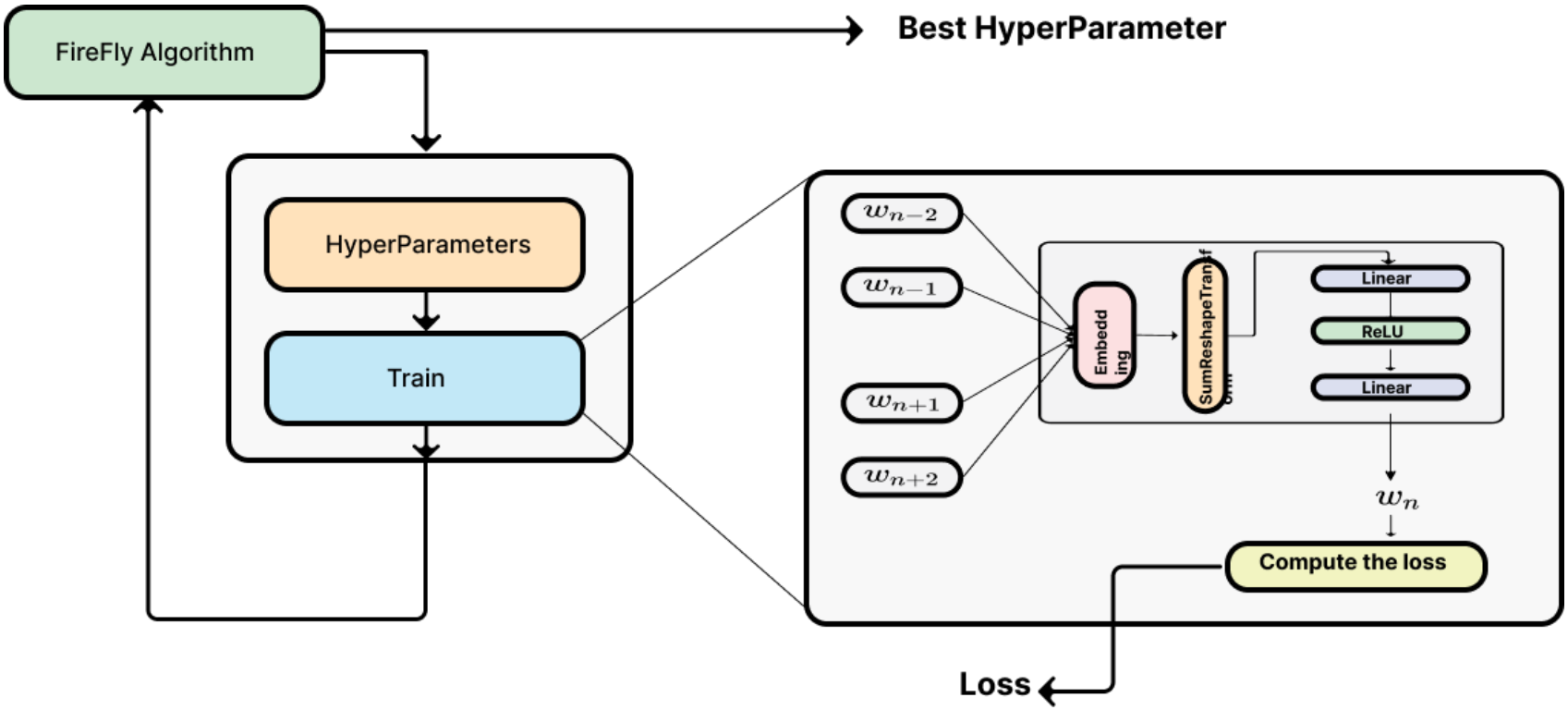


Figure 6: Workflow of Hyperparameters Tuning with the Firefly Algorithm

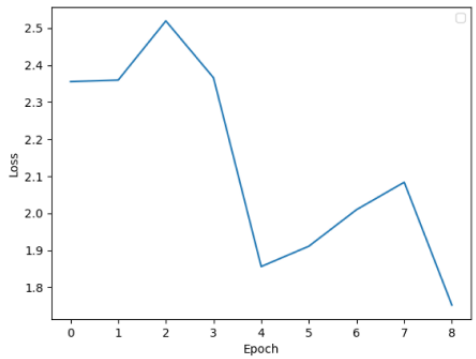
Hyperparameter Tuning Experiment

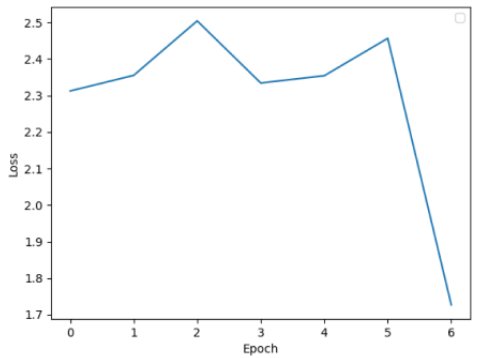
The figure below shows the script execution process for hyperparameter tuning using the Firefly Algorithm.

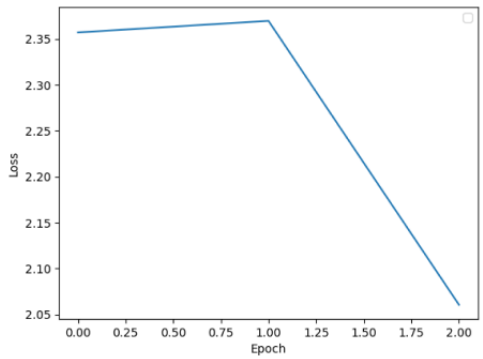
```
⊗ → FireFly-Optimizer-Deep-Learning git:(main) ✗ python3 hyperparam.py --numtest=1 --popsize=5 --maxiters=3 --gamma=0
.1 --alpha=2
/home/moussa/.local/lib/python3.11/site-packages/matplotlib/projections/__init__.py:63: UserWarning: Unable to impor
t Axes3D. This may be due to multiple versions of Matplotlib being installed (e.g. as a system package and as a pip
package). As a result, the 3D projection is not available.
  warnings.warn("Unable to import Axes3D. This may be due to multiple versions of "
/home/moussa/.local/lib/python3.11/site-packages/torch/nn/init.py:412: UserWarning: Initializing zero-element tensor
s is a no-op
  warnings.warn("Initializing zero-element tensors is a no-op")
Loss: 3.63418: 100%|| 10/10 [00:01<00:00,  8.48it/s]
/home/moussa/.local/lib/python3.11/site-packages/torch/nn/init.py:412: UserWarning: Initializing zero-element tensor
s is a no-op
  warnings.warn("Initializing zero-element tensors is a no-op")
Loss: 5.79429: 100%|| 10/10 [00:01<00:00,  8.65it/s]
Loss: 4.82992: 100%|| 10/10 [00:01<00:00,  8.34it/s]
Loss: 6.45045: 100%|| 10/10 [00:01<00:00,  8.69it/s]
Loss: 4.12953: 100%|| 10/10 [00:01<00:00,  8.44it/s]
Loss: 2.18995:  60%|| 6/10 [00:00<00:00,  7.39it/s]
Loss: 2.18995:  60%|| 6/10 [00:01<00:00,  5.75it/s]
```

Figure 7: Execution of the Hyperparameter Tuning Script

Experiment HyperParamerts tuning







Parameter	Figure 1	Figure 2	Figure 3
Learning Rate (lr)	0.0093	0.0100	0.0100
β_1	0.899	0.9003	0.901
β_2	0.9981	0.9989	0.9991
Embedding Dimension	2	4	5
Window Size (w)	3	3	2
Best Intensity	1.83	**1.72**	2.06

Table 1: Hyperparameters and Best Intensities for Different Figures

Training with Optimized Hyperparameters

The figure below illustrates the process of running training scripts using the hyperparameters found through the tuning process.

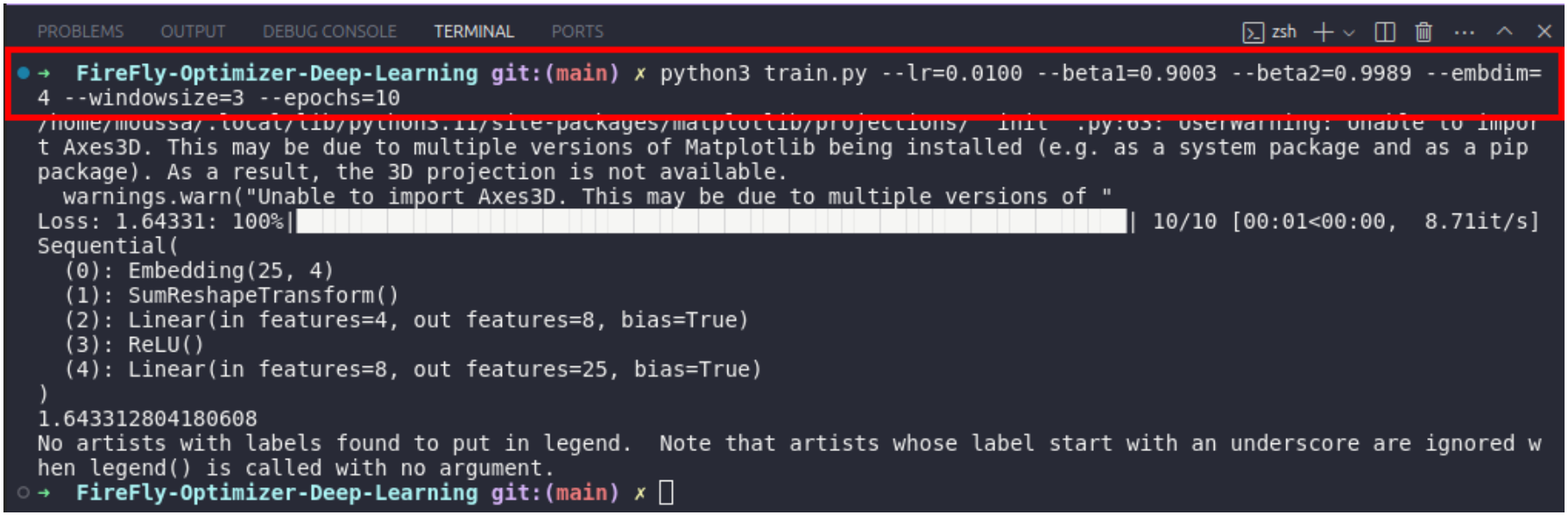


Figure 8: Execution of Training Scripts with Optimized Hyperparameters

Training with Optimized Hyperparameters

The figure below shows the training loss and the plot of words in 2D space. **PCA** is used for dimensionality reduction.

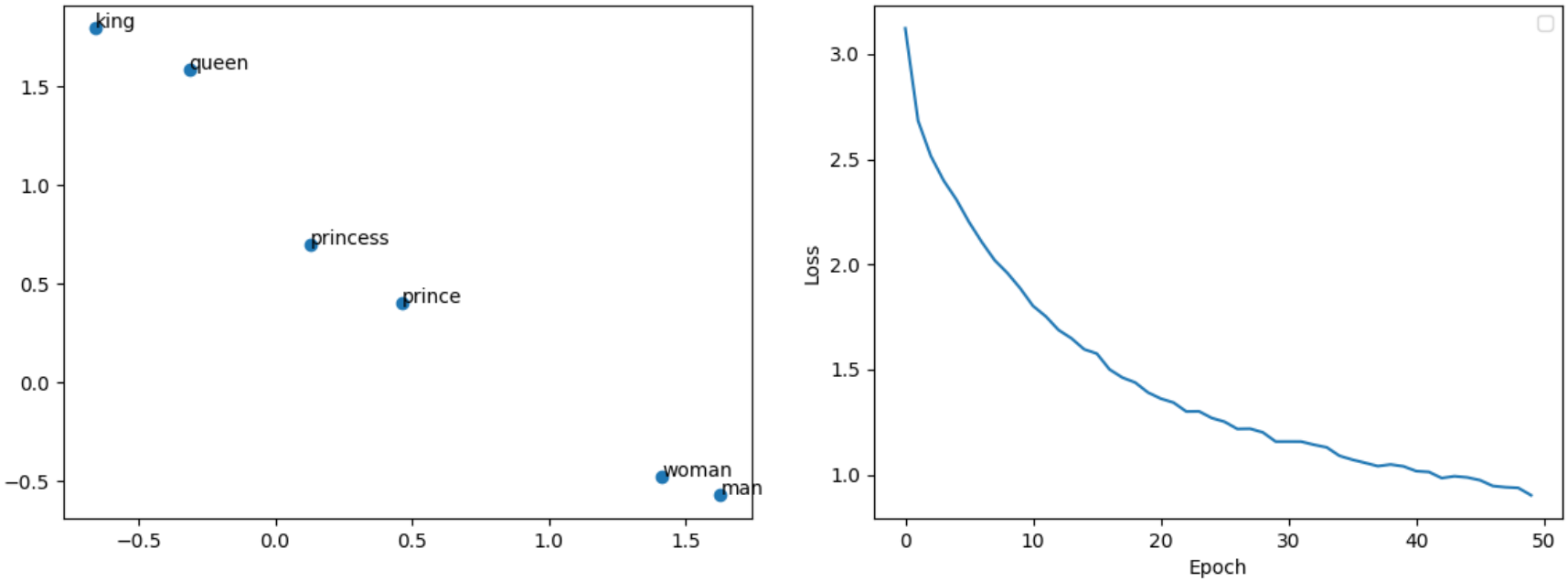


Figure 9: Training Loss and Words Plot in 2D Space