

## Problem 1:

1a:

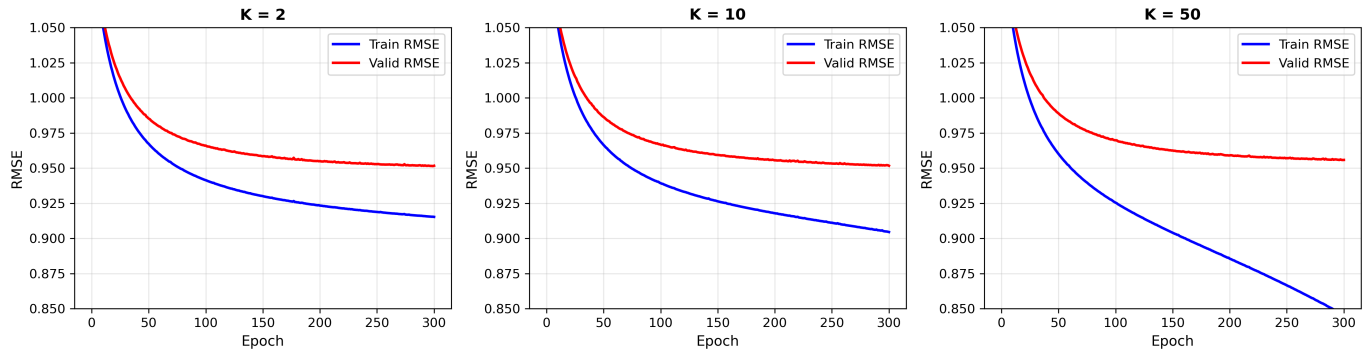


Figure 1: Train and Validation RMSE across epochs. Models were trained with batch size 1000 and step size 0.1 for 300 epochs. As  $K$  increases, train RMSE trends to zero faster, however the validation RMSE doesn't drop below 0.95. At  $K = 50$ , validation RMSE is highest after 300 epochs. The increasing difference between train and validation RMSE suggests greater overfitting as  $K$  increases.  $K = 2$  and  $K = 10$  both provided a min RMSE of 0.9517 which was the lower than the 0.9558 of  $K = 50$ . We selected a step size of 0.1, chosen from  $\{0.01, 0.05, 0.1, 0.5\}$ . The chosen step size balanced the speed of convergence with stability, allowing all models to converge within 300 epochs.

1b:

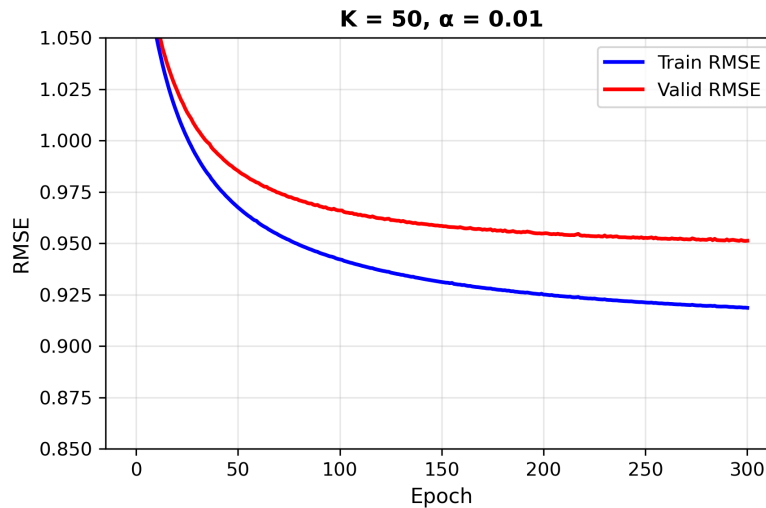


Figure 2: Train and Validation RMSE with  $K = 50$  and  $\alpha = 0.01$ . We selected  $\alpha$  of 0.01 from  $\{0.001, 0.005, 0.01, 0.05, 0.1\}$ . This value gave the lowest validation RMSE of all values tested. Smaller values showed significant overfitting with high validation RMSE, while values greater than 0.01 overregularized the model and constrained it too much to learn the patterns of the data set. We kept the same step size of 0.1 because it continued to be consistent with speed of convergence and stability of the model. The regularization did help the validation RMSE getting 0.9512 compared to 0.9558 with  $\alpha = 0$ . Additionally, the regularized graph shows a smaller gap between train and validation RMSE, indicating better generalization.

Model	Train		Validation		Test	
	RMSE	MAE	RMSE	MAE	RMSE	MAE
LF K = 2, $\alpha = 0$	0.9153	0.7252	0.9517	0.7542	0.9455	0.747
LF K = 10, $\alpha = 0$	0.9045	0.7161	0.9517	0.753	0.946	0.7469
LF K = 50, $\alpha = 0$	0.8453	0.6701	0.9558	0.756	0.9512	0.749
LF K = 50, $\alpha = 0.01$	0.9186	0.7274	0.9512	0.7534	0.9451	0.7463

Table 1: Performance comparison of models trained with batch size 1000, step size 0.1 for 300 epochs. RMSE and MAE reported for train validation and test.

1c:

Based on validation RMSE, K = 10 gives strong results without a super complex model. While the K = 50 model achieved an RMSE that was slightly lower, the increase in model complexity and training time is not worth the minor improvement. This model's train RMSE is also closer to the validation RMSE than K = 2, indicating it generalizes better. Looking at MAE over RMSE, the K = 10 model outperforms all other models on validation, suggesting it is still the strongest pick. No model showed any significant difference in RMSE versus MAE, however the relative ordering changes slightly, favoring the K = 10 model.

1d:

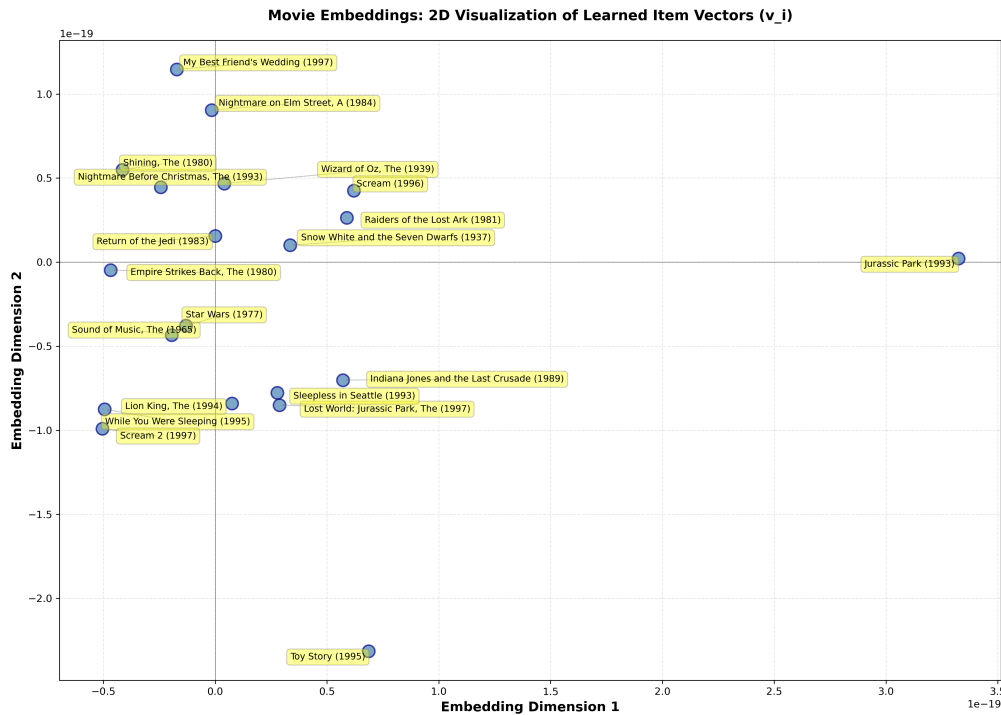


Figure 3: There does not seem to be any strong correlation between the points in the scatterplot. The only connection is all of the starwars movies being near each other, and the movies with scary titles being located near the top left of the graph. The lack of clustering suggests that the semantic meaning of the data lies in higher dimensions that cannot be captured in just 2 dimensions. The model uses all 50 dimensions for predictions so the lack of structure in this figure is not representative of poor performance overall.

## Problem 2:

### 2a:

We implemented a collaborative filtering approach using matrix factorization with the Singular Value Decomposition (SVD) algorithm from the Surprise library. This method decomposes the user-item rating matrix into two lower-dimensional matrices: user factors and item factors. We performed systematic hyperparameter tuning using 3-fold cross-validation on the combined train+validation set. Our grid search explored three hyperparameters: `n_factors` (latent dimension: 2, 10, 50, 100, 120, 150), `lr_all` (learning rate: 0.001 to 0.1), and `reg_all` (L2 regularization:  $10^{-4}$  to 10). The model was trained using stochastic gradient descent to minimize regularized squared error. After identifying optimal hyperparameters via cross-validated MAE, we retrained the final model on the full train+valid set and evaluated on the held-out test split. This approach balances model expressiveness (through latent factors) with generalization (through regularization).

### 2b:

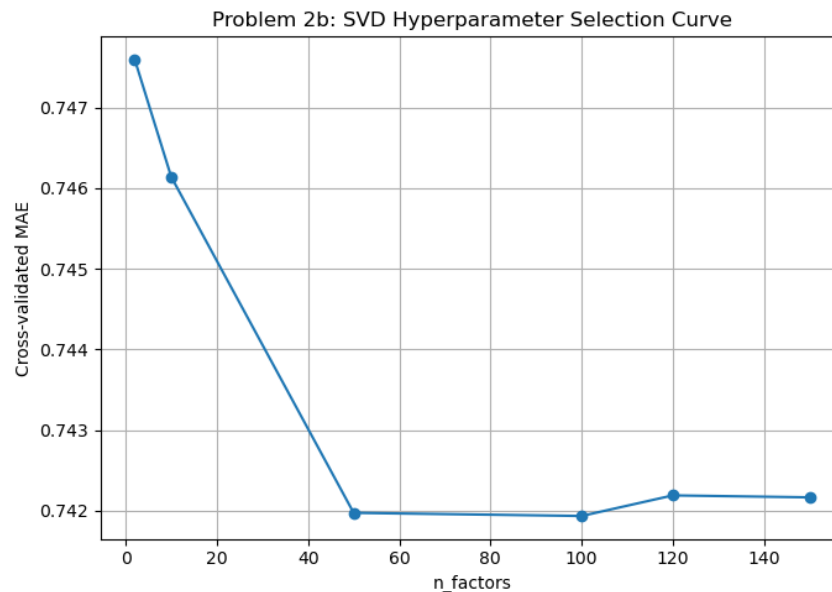


Figure 4: Hyperparameter selection curve showing minimum cross-validated MAE as a function of `n_factors`. The curve demonstrates the bias-variance tradeoff: very low `n_factors` (2–10) underfit the data, resulting in high MAE due to insufficient model capacity to capture user-item interaction patterns. As `n_factors` increases to 50–100, MAE decreases as the model gains expressiveness. Beyond the optimal point, further increases in `n_factors` show diminishing returns or slight increases in MAE, suggesting potential overfitting. The sweet spot balances model complexity with generalization, achieving optimal performance while avoiding both under and overfitting. Each point represents the best MAE achieved across all learning rate and regularization combinations for that `n_factors` value.

### 2c:

Method	Test Split MAE	Leaderboard MAE
SVD (Problem 2)	0.721	0.718
K = 10 Baseline	0.753	—

Table 2: Performance comparison: Mean Absolute Error (MAE) on test split and leaderboard set.

**(i) Leaderboard vs Test Split Comparison:** The leaderboard MAE (0.718) is very close to the test split MAE (0.721), with a difference of only 0.003. This tight agreement indicates excellent generalization as our model performs consistently across both the development test set and the unseen leaderboard set. The slightly better leaderboard performance suggests that the leaderboard data distribution is similar to our training data, and there is no evidence of overfitting to the development set. This validates our hyperparameter selection and confirms that the model captures genuine user-item preference patterns rather than random correlations specific to the train set.

**(ii) Problem 1 vs Problem 2 Comparison:** The SVD approach achieves an MAE of 0.721, substantially outperforming the K=10 collaborative filtering baseline from Problem 1 (MAE of 0.753) by 0.032 points, representing a 4.2% relative improvement. While the Problem 1 approach used matrix factorization trained with SGD for a fixed latent dimensionality (K=10), Problem 2's hyperparameter search explored a wider range of latent dimensions (2-150) along with learning rates and regularization strengths. This comprehensive grid search allowed us to identify optimal model complexity that better balances expressiveness and generalization. The superior performance demonstrates that properly tuned model complexity is critical as the K=10 baseline underfits the data with insufficient latent factors to capture the full semantic meaning of user-item interactions, while our optimized SVD model finds the optimum that maximizes predictive accuracy without overfitting.

**2d:**