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Convexity, Robustness, and Stability: A Mathematical Investigation of MSE and Huber Loss in Machine Learning

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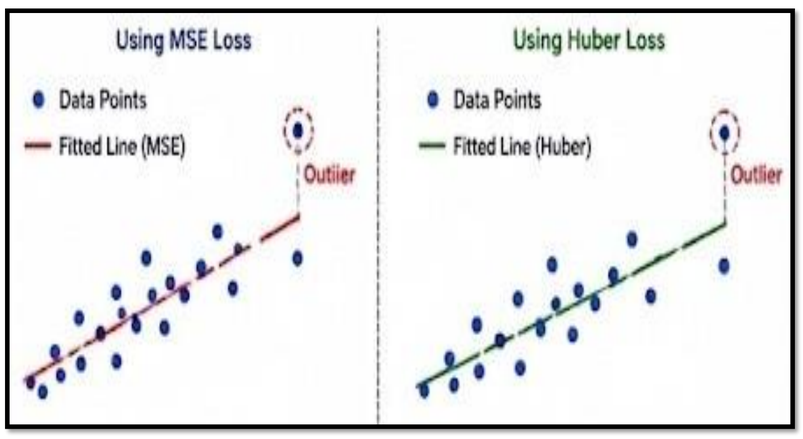
INTRODUCTION & AIM

- Raw data is processed by a model to generate predictions, and the resulting errors are used to optimize model performance.

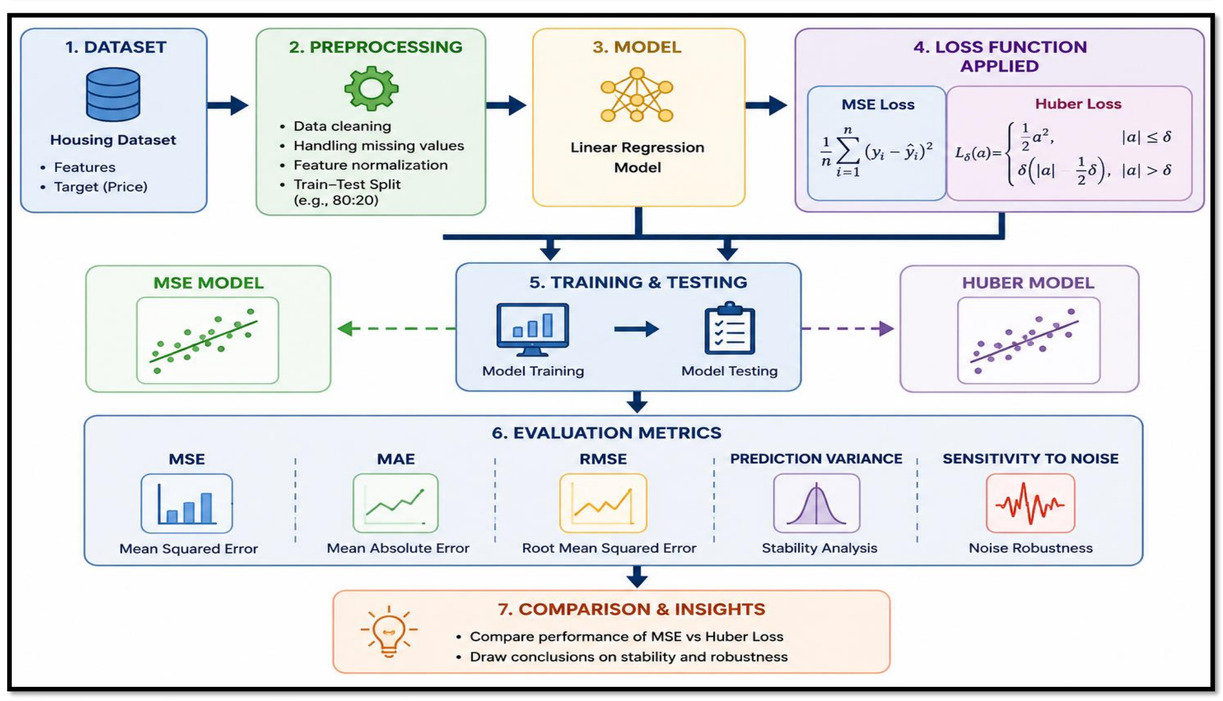


- Different loss functions respond differently to outliers, where Huber Loss provides a more stable fitted line than MSE Loss.

Aim

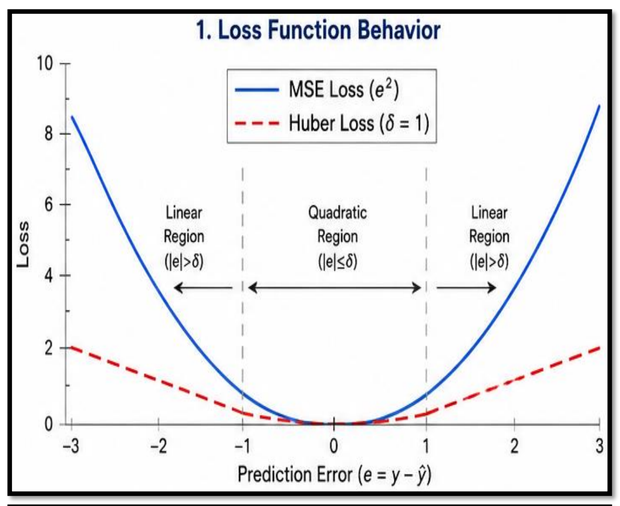
- ➢ To reduce the influence of outliers in predictive modeling
- ➢ To improve model robustness and prediction accuracy
- ➢ To compare Huber Loss performance with MSE Loss

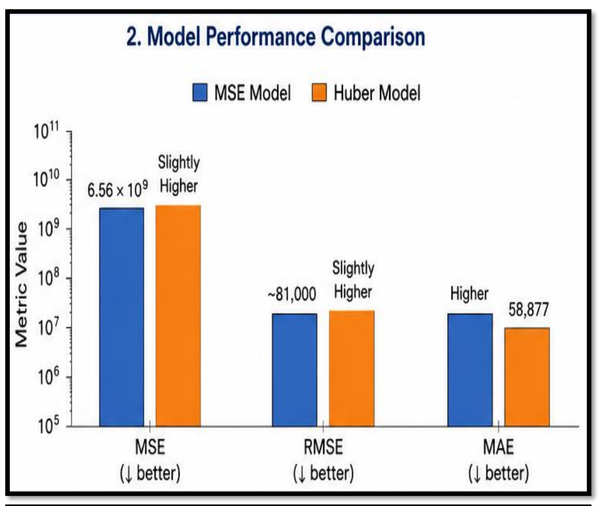
METHOD

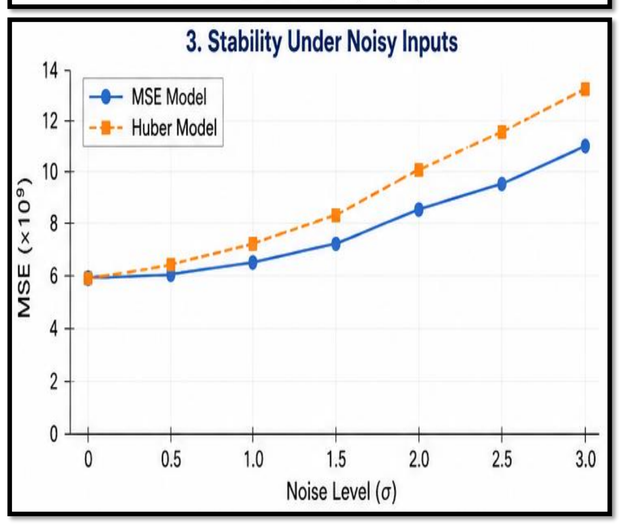


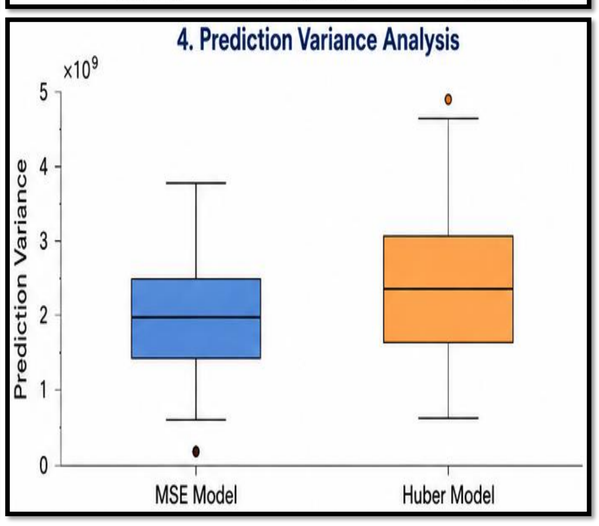
RESULTS & DISCUSSION

- MSE produced lower overall prediction error and better stability.
- Huber Loss achieved lower MAE, indicating stronger robustness to outliers.
- Both models (MSE/ Huber Loss) showed performance degradation under noisy conditions.
- Huber Loss reduced the influence of large prediction errors through its piecewise structure.
- Mathematical properties of loss functions affect model behavior.









CONCLUSION/ FUTURE WORK

Huber Loss Equation

$$L_\delta(a) = \begin{cases} \frac{1}{2}a^2 & |a| \le \delta \\ \delta(|a| - \frac{1}{2}\delta) & |a| > \delta \end{cases}$$

- Combines quadratic and linear error behavior.
- Reduces sensitivity to outliers.
- Improves robustness in noisy datasets.

MSE Equation

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

- Penalizes large errors quadratically.

Experimental Setup

- Housing dataset → regression analysis
- Linear regression models trained using MSE & Huber Loss.
- Performance evaluation → MSE, MAE, RMSE.
- Prediction variance & Noise sensitivity analysis.

Conclusion

- ➢ Loss functions significantly affect model accuracy, robustness, and stability.
- ➢ MSE performs well on datasets with lower prediction error.
- ➢ Huber Loss provides better resistance to noise and outliers, improving model reliability.

Future Work

- ➢ Explore additional robust loss functions (Tukey, Cauchy).
- ➢ Extend the study to deep learning models under noisy conditions.
- ➢ Develop adaptive or hybrid loss functions for improved performance on real-world datasets.

References

- *Deep Learning, MIT Press, 2016.*
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- *Robust Estimation of a Location Parameter, Annals of Mathematical Statistics, 35(1), 73–101.*