1.Variance and Bias (With Diagram, Overfitting & Underfitting Explanation)

Introduction to Bias and Variance

In Machine Learning, when we train a model, our main goal is to make it predict accurately on new unseen data. However, models can make two types of errors:

- Bias Error
- Variance Error

Understanding bias and variance helps us choose the best fit model.

What is Bias?

Bias is the error due to overly simple assumptions in the learning algorithm.

- High bias → Model is too simple
- It ignores important patterns
- Leads to underfitting

Example:

If we use a straight line to fit curved data, the model will not capture the pattern correctly.

Characteristics of High Bias:

- High training error
- High testing error
- Model is too simple

What is Variance?

Variance is the error due to the model being too sensitive to small fluctuations in the training data.

- High variance → Model is too complex
- It memorizes training data
- Leads to overfitting

Characteristics of High Variance:

- Very low training error
- Very high testing error
- Model is too complex

Underfitting (High Bias)

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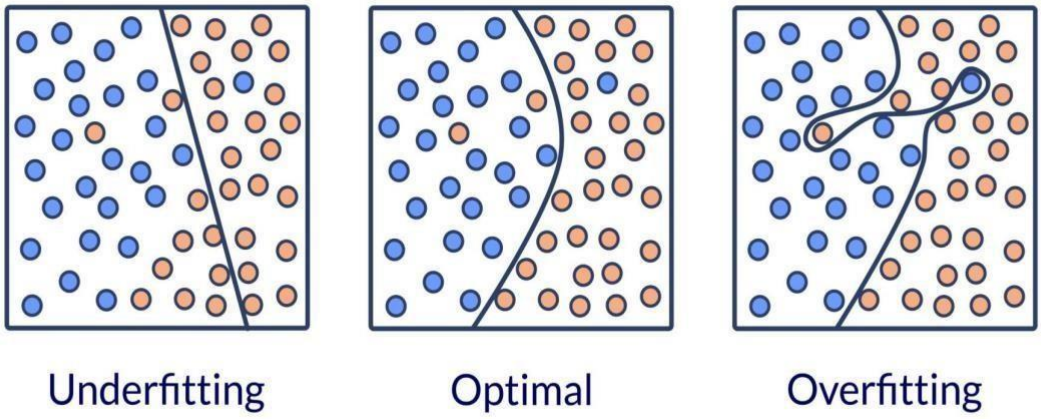
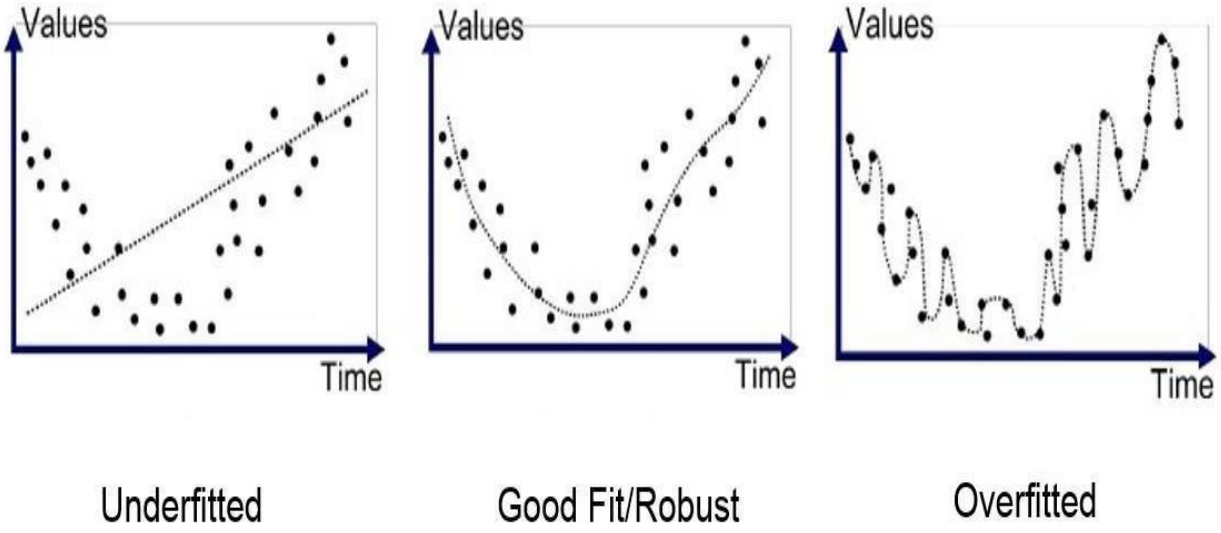
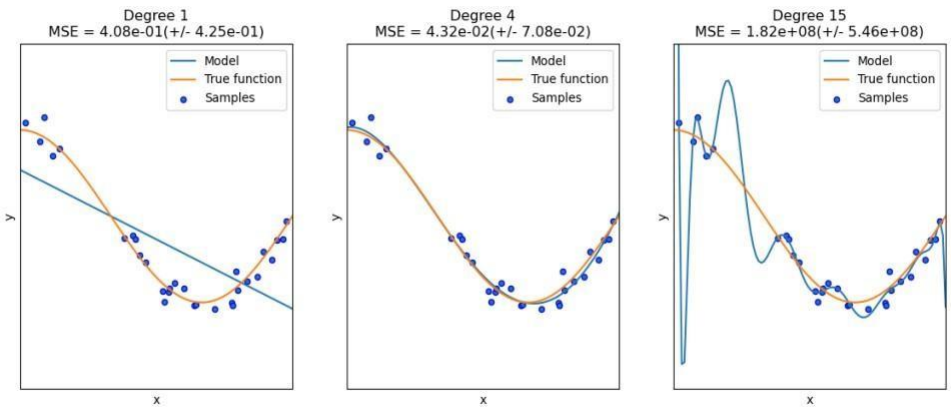






What is Underfitting?

Underfitting happens when:

- The model is too simple
- It cannot capture the underlying trend of data

Cause:

- High Bias
- Low Variance

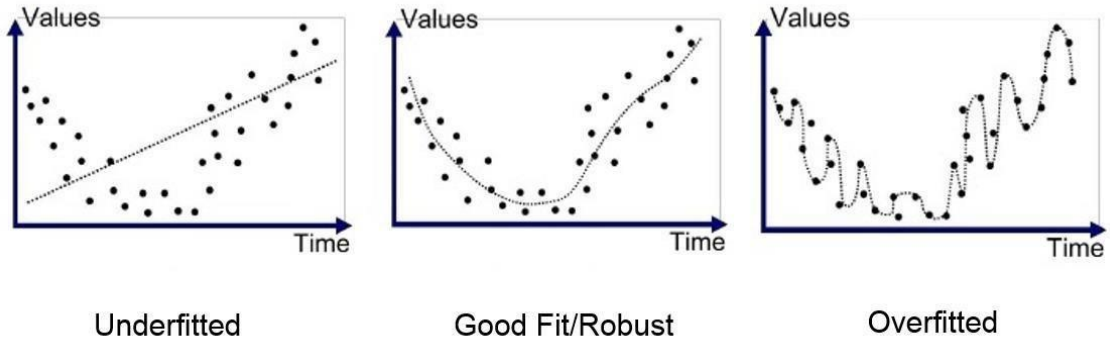
Example:

Using a linear model for non-linear data.

Result:

- Poor performance on both training and test data.

Overfitting (High Variance)



What is Overfitting?

Bias and Variance are not just theoretical concepts — they directly influence how reliable and accurate a machine learning system becomes in real-world applications. Every predictive model, whether simple linear regression or advanced deep learning networks, is affected by these two components.

A model with high bias oversimplifies reality. It assumes that the relationship between input and output is simpler than it actually is. Because of this, it fails to learn important patterns, resulting in consistent and systematic errors. Such models are stable but inaccurate. This condition is known as Underfitting.

Overfitting happens when:

- The model learns noise from training data
- It performs well only on training data

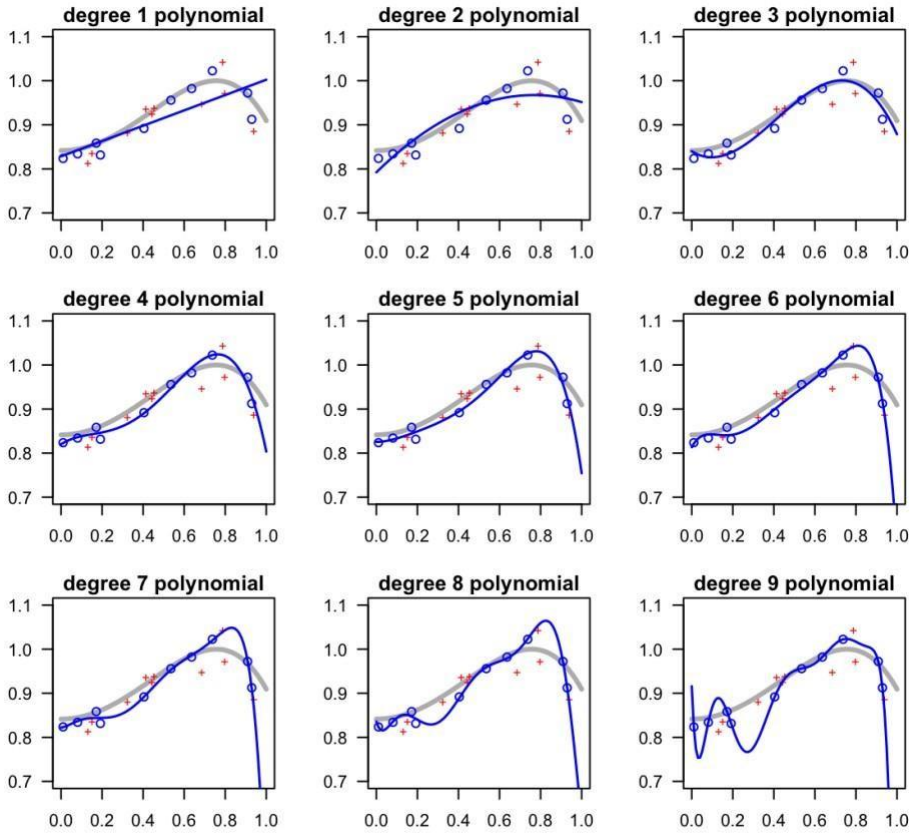
Cause**:**

- Low Bias
- High Variance Example**:**

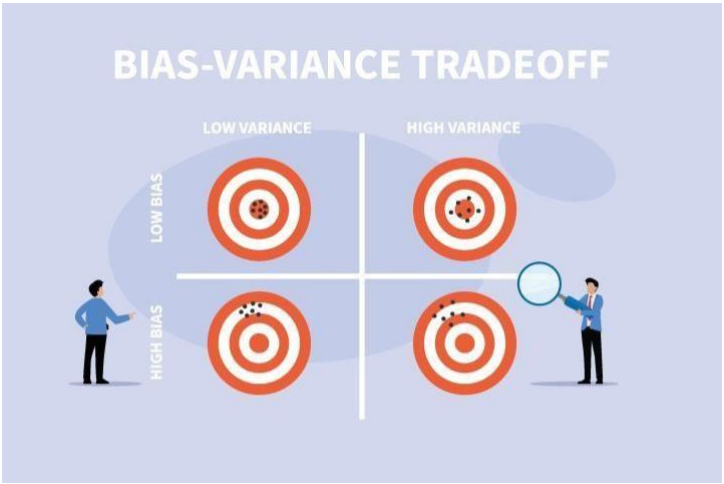
Using a very high-degree polynomial curve for simple data.

Result:

- Very low training error
- Very high testing error



Bias–Variance Tradeoff



There is a tradeoff between bias and variance.

- As model complexity increases: ○ Bias decreases ○ Variance increases
- The goal is to find a balance.

Best Fit Model – What Should It Have?

For best fit model should we have:

- Low bias or high variance
- Low bias or low variance
- High bias or high variance
- Low bias or high variance

Correct Answer:

Best Fit Model → Low Bias and Low Variance

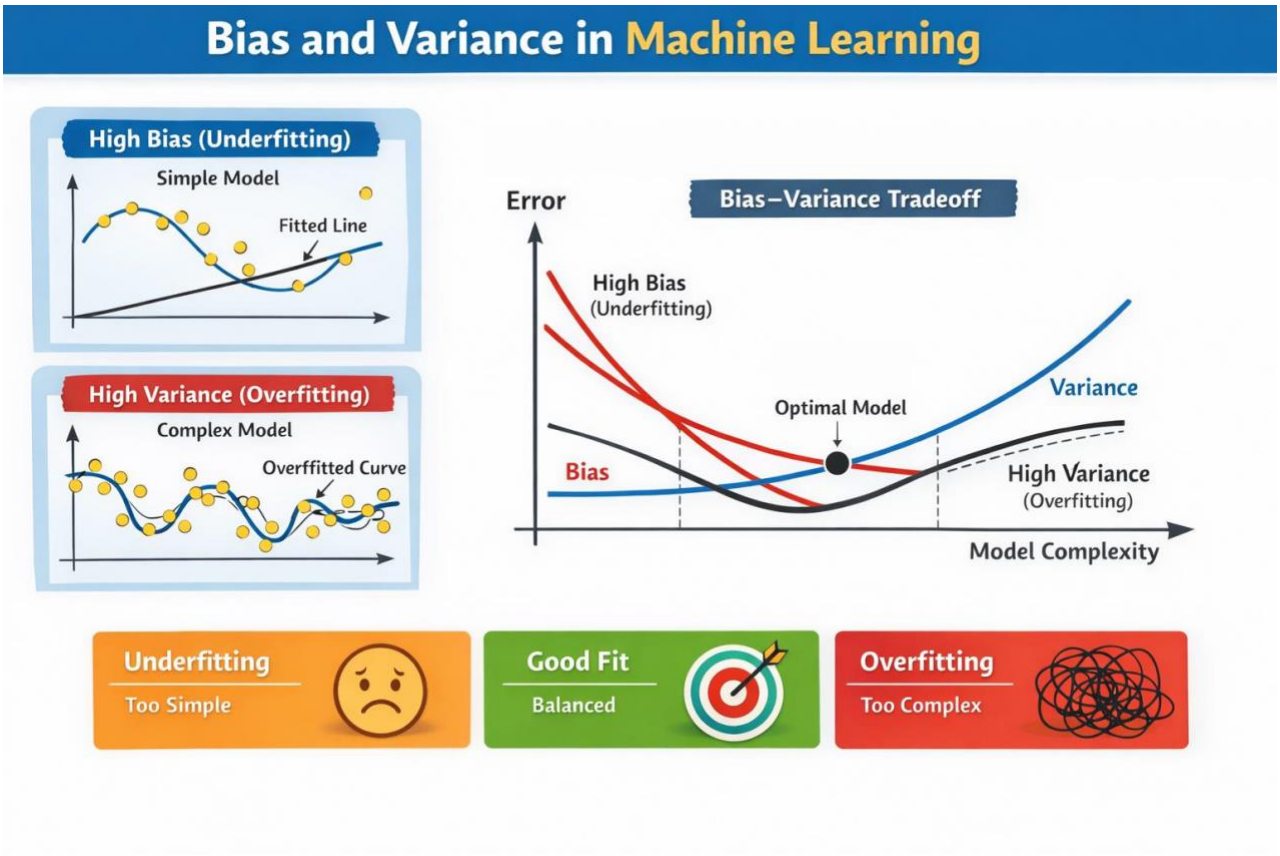
Because:

- Low bias → Model captures true pattern
- Low variance → Model generalizes well to new data

This point lies in the middle of the bias-variance trade-off curve.

Summary Table

Model Type	**Bias**	**Variance**	**Problem**
Underfitting	High	Low	Too simple
Overfitting	Low	High	Too complex
Best Fit Model	Low	Low	Balanced



Conclusion

Bias and Variance are two fundamental sources of error in machine learning models. A clear understanding of these concepts helps in building models that generalize well to unseen data rather than just performing well on training data.

High Bias leads to Underfitting, where the model is too simple to capture the underlying pattern of the data. Such models fail to learn important relationships and produce poor results on both training and testing datasets. This usually happens when the model makes overly strong assumptions or when the complexity of the model is very low.

High Variance leads to Overfitting, where the model becomes too complex and learns not only the actual pattern but also the noise in the training data. While such a model performs extremely well on training data, its performance drops significantly on new or unseen data. This means the model lacks generalization ability.

The key objective in machine learning is to find the optimal balance between bias and variance. This balance ensures:

Low training error

Low testing error

Good generalization

Stable predictions on new data
This concept is known as the Bias–Variance Tradeoff. As model complexity increases:
Bias decreases
Variance increases