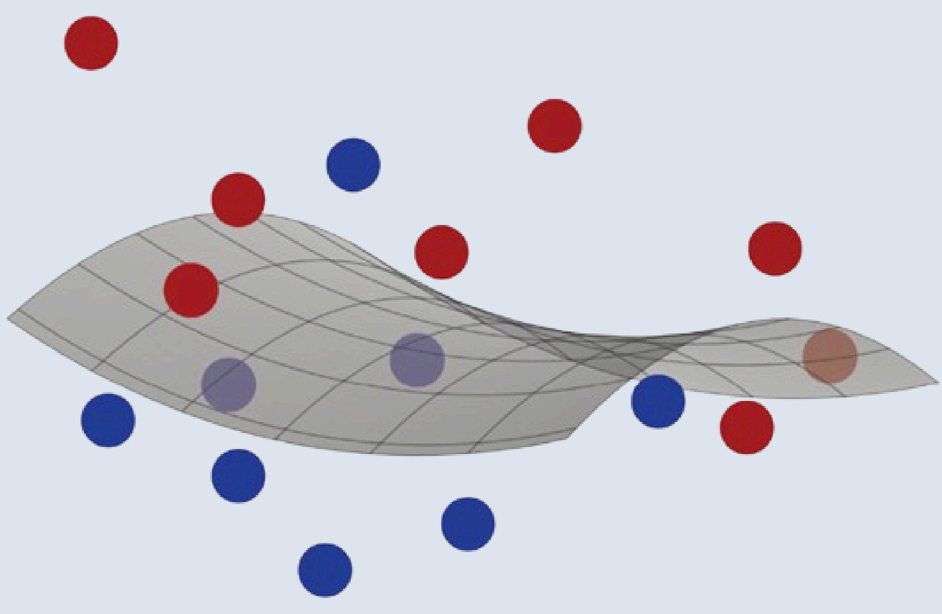
Foundations of Machine Learning

DAY - 7

Generalization



Generalization

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At the heart of machine learning lies a core goal: generalization — the ability of a model to make accurate predictions on data it hasn't seen before. It's what separates a truly intelligent system from one that just memorizes.
In supervised learning, we train a model on a finite set of labeled examples. The goal is to select a function from a defined hypothesis set — a collection of possible models — that can predict well on new, unseen inputs.
But how do we choose the right hypothesis set?

Complexity vs Accuracy: The Hypothesis Set Dilemma

- A rich (complex) hypothesis set gives the model more flexibility. It may find a function that fits every training point perfectly — achieving zero training error. But that doesn't guarantee it will perform well on new data.
- A simpler hypothesis set, on the other hand, may not be able to perfectly match every label in the training set. It might make a few mistakes, but the solution it finds could generalize better.
- This is a critical question in machine learning:
    - Should we aim for perfect training accuracy, or allow some error in favor of broader applicability?

Overfitting vs Underfitting: A Visual Intuition

- Imagine a classification problem, visualized in two ways:
    - The first solution is a zig-zag boundary that separates the training points with 100% accuracy. It's complex, rigid, and tailored to the sample — but likely to fail on unseen data.
    - The second solution is a smoother boundary. It misclassifies a few points but captures the general structure of the data more reliably.

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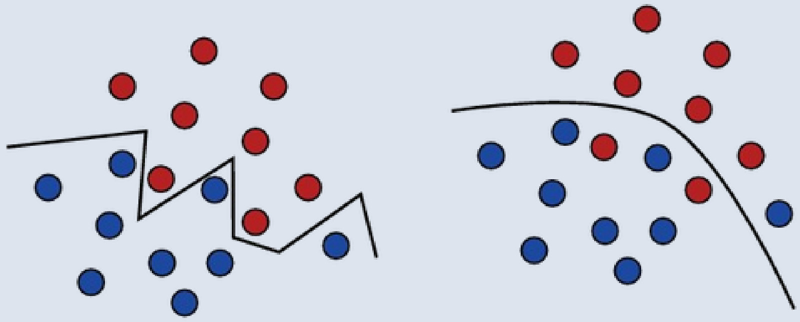

- These represent two extremes:
  - Overfitting: The model is too complex, memorizing the training data instead of learning.
  - Underfitting: The model is too simple, failing to capture patterns in the data.

The Generalization Trade-Off

- One of the most important trade-offs in machine learning is between:
  - The size of the training sample, and
  - The complexity of the hypothesis set.
- When data is limited, complex models are dangerous — they overfit easily. But if the model is too simple, even with more data, it might not achieve meaningful accuracy.
- Balancing these two — sample size and hypothesis complexity — is key to building models that generalize well.

The ability to generalize isn't just a nice-to-have — it's the whole point. Understanding how models move beyond memorization is what makes machine learning truly powerful.