Stanford University

CS 329P : Practical Machine Learning (2021 Fall)

4.2 Underfiting & Overfitting

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https://c.d2l.ai/stanford-cs329p

Who will Repay Their Loans?

- A lender hires you to investigate who will repay their loans
  - You are given all information about the 100 applicants
  - 5 defaulted within 3 years
- A Surprising Finding?!
  - All 5 people who defaulted wore blue shirts during interviews
  - Your model leverages this strong signal as well

Underfitting and Overfitting

- Training error: model error on the training data
- Generalization error: model error on new data

Training error

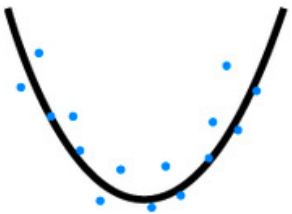
Generalization error	Low	High
Low	Good	Bug?
High	Overfitting	Underfitting

Data and Model Complexity

Model complexity \ Data complexity	Low	High
Low	Normal	Underfitting
High	Overfitting	Normal

Underfitting

Normal



Overfitting

Image credit: hackernoon.com

Model Complexity

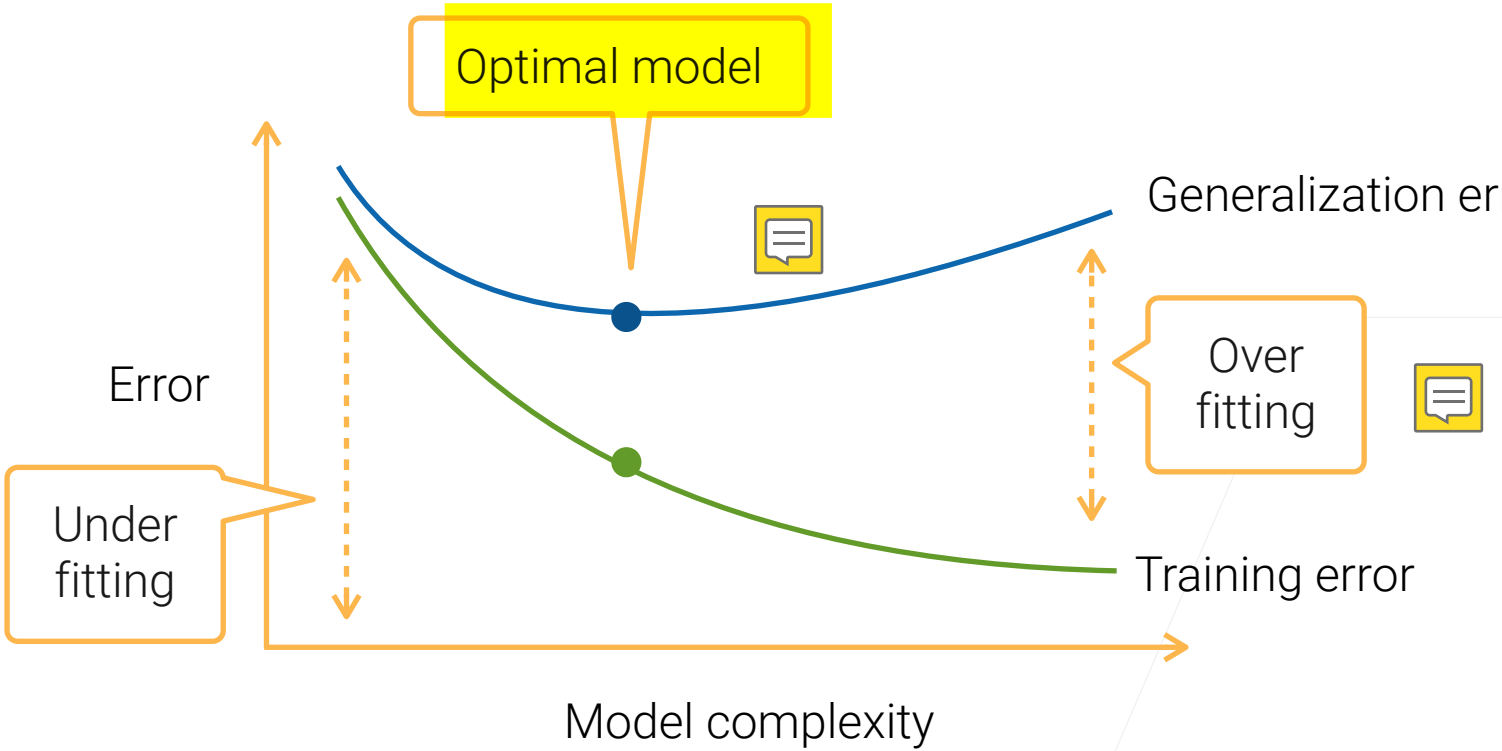
- The capacity of a set of function to fit data points

- In ML, model complexity usually refers to:
  - The number of learnable parameters
  - The value range for those parameters
- It's hard to compare between different types of ML models

  - E.g. trees vs neural network
- More precisely measure of complexity: VC dimension

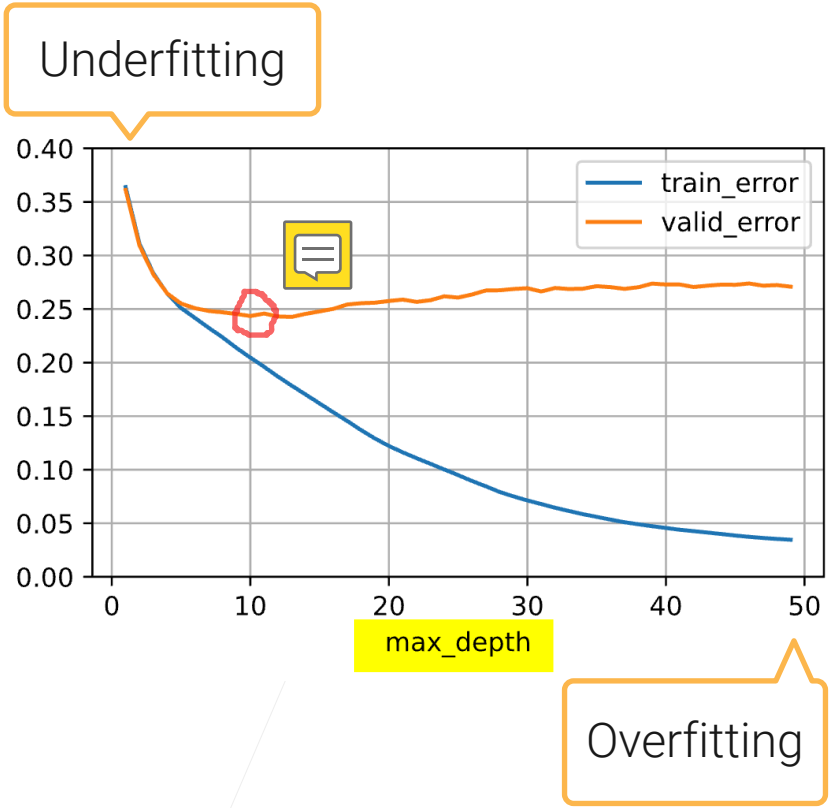
  - VC dim for classification model:
    the maximum number of examples the model can shatter

Model Complexity



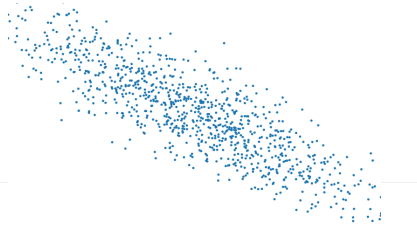
Model Complexity Example: Decision Tree

- The tree size can be controlled by the number of levels
- Use scikit-learn `DecisionTreeRegressor(max_depth=n)` on house sales data

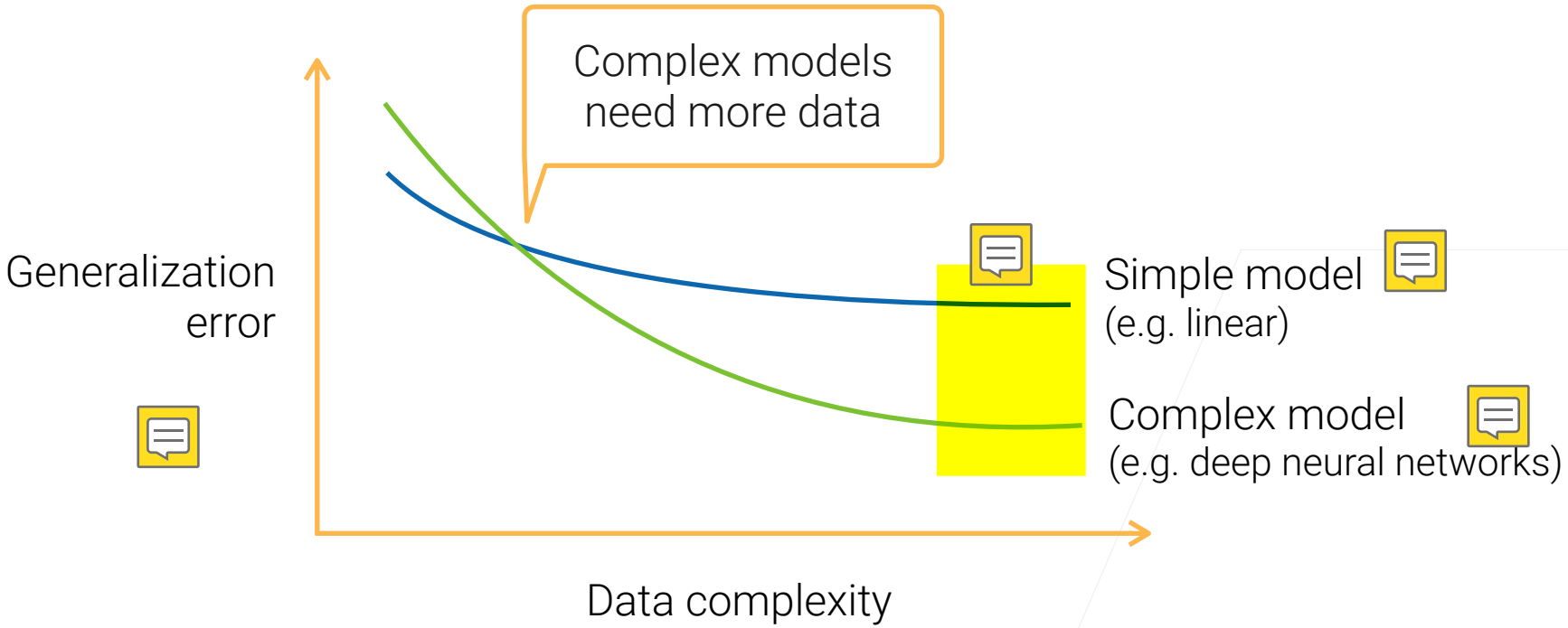


Data Complexity

- Multiple factors matters
  - # of examples
  - # of features in each example
  - the separability of the classes
- Again, hard to compare among very different data
  - E.g a char vs a pixel
- More precisely, Kolmogorov complexity
  - A data is simple if it can be generated by a short program



Model Complexity vs Data Complexity



Generalization error

- Generalization error bound (an informal statement)

$$\left|\text{errror on unseen data} - \text{training error}\right| \leq \sqrt{\frac{D}{N}\left(\log\left(\frac{2N}{D}\right)+1\right)}$$

  - D: VC-dim, M: number of training examples
- Generalization error also depends on the training algorithm
  - Adding regularization can penalize complex models
  - Model trained with stochastic gradient methods generalizes better

Model Selection

- Pick a model with a proper complexity for your data 
  - Minimize the generalization error
  - Also consider business metrics 
- Pick up a model family, then select proper hyper-parameters
  - Trees: #trees, maximal depths
  - Neural networks: architecture, depth (#layers), width (#hidden units), regularizations

Summary

- We care about generalization error
- Model complexity: the ability to fit various functions
- Data complexity: the richness of information
- Model selection: match model and data complexities