Model Validation and Selection

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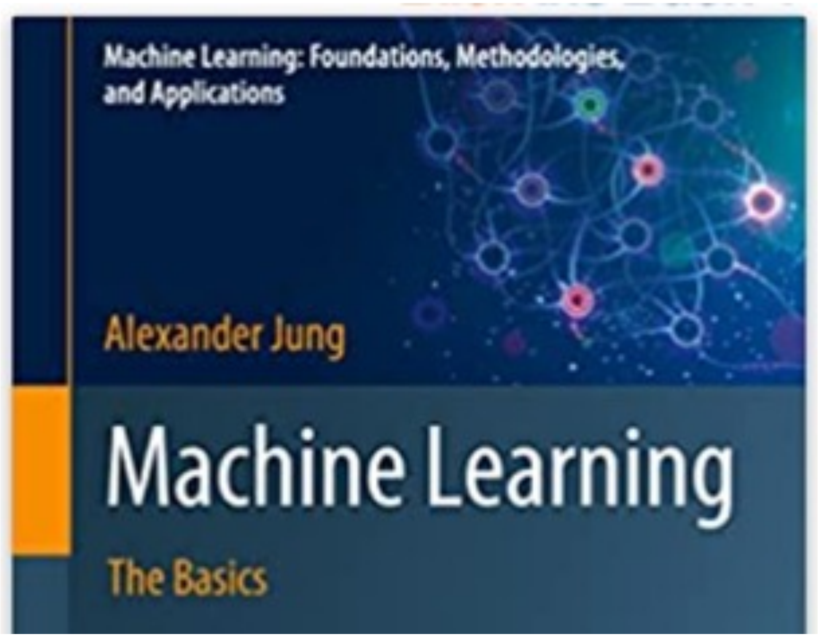
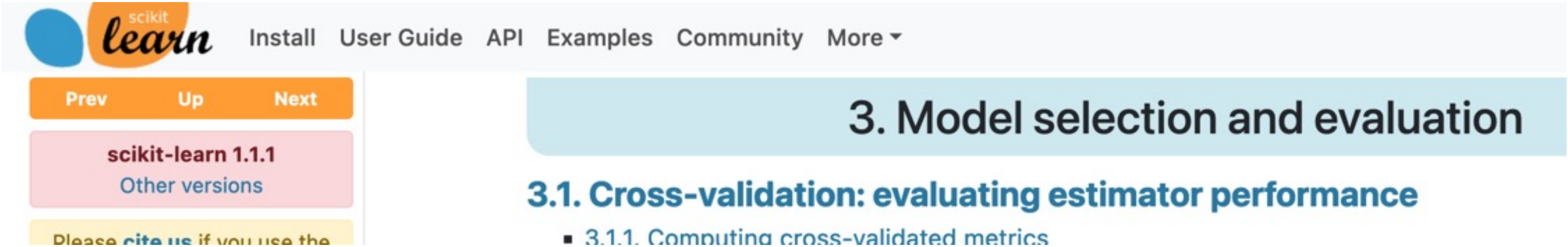
Reading.

Ch. 6 of https://mlbook.cs.aalto.fi





https://scikit-learn.org/stable/model_selection.html

”Model”

=

Hypothesis Space

Learning Goals

- know train err is bad quality measure for ML method

- val.err. is more useful as quality measure for a ML model

- basic idea of k-fold CV

- hyper-parameter tuning = model selection

- Python implementations of k-fold CV / gridsearch

ML – In a Nutshell

- learn hypothesis h(.) out of model such that for any data point $h(x) \approx y$
- approximation quality measured by loss $L((x,y),h)$
- approximate "any data point" by a training set

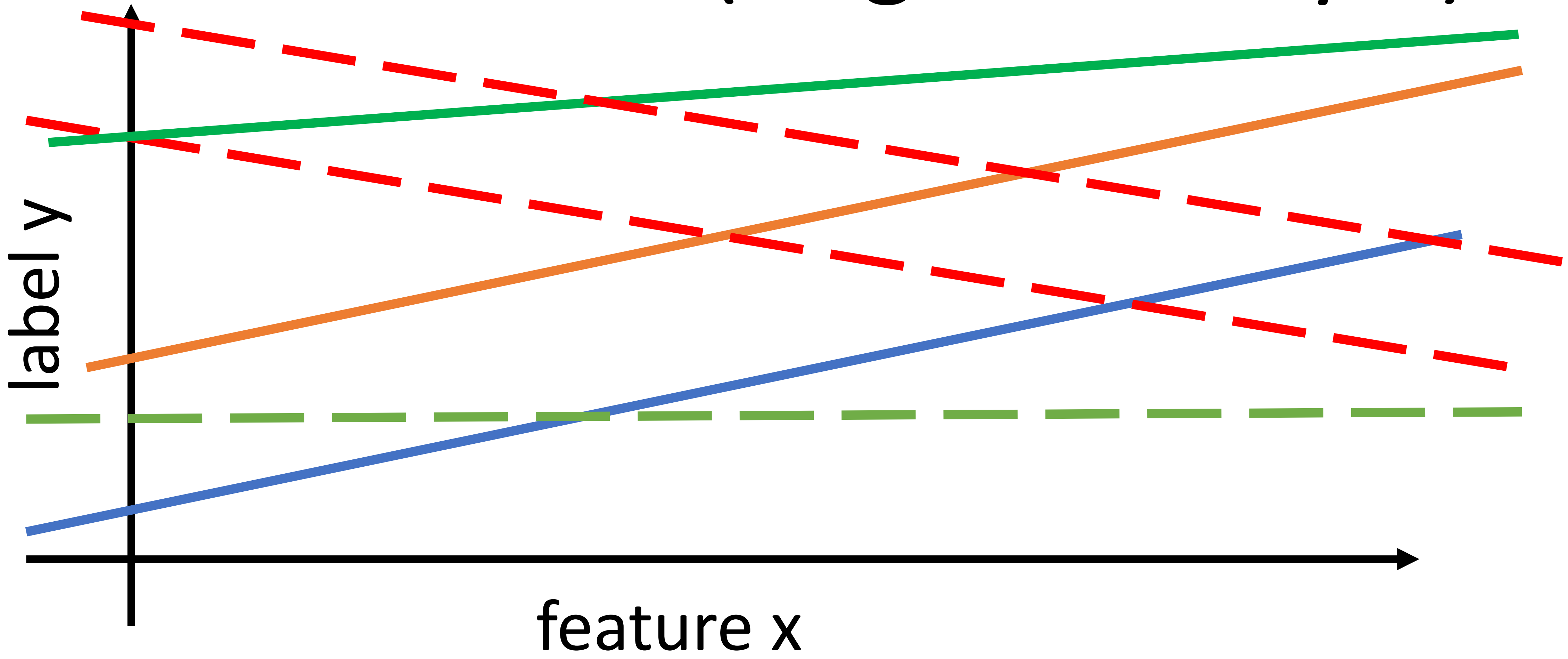
Model Validation

How do we know a model is any good ?

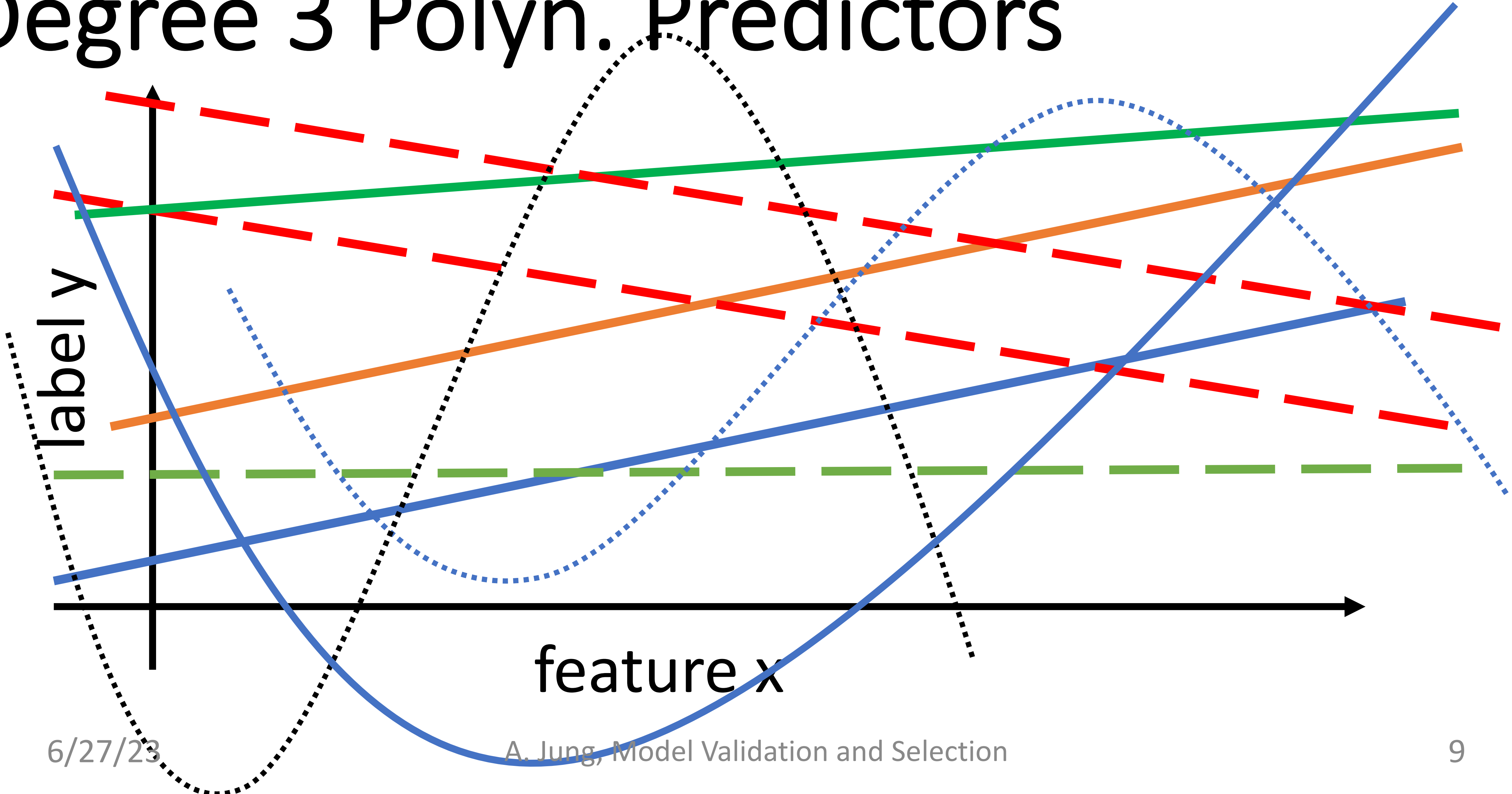
Model Selection

How to choose between different alternative models?

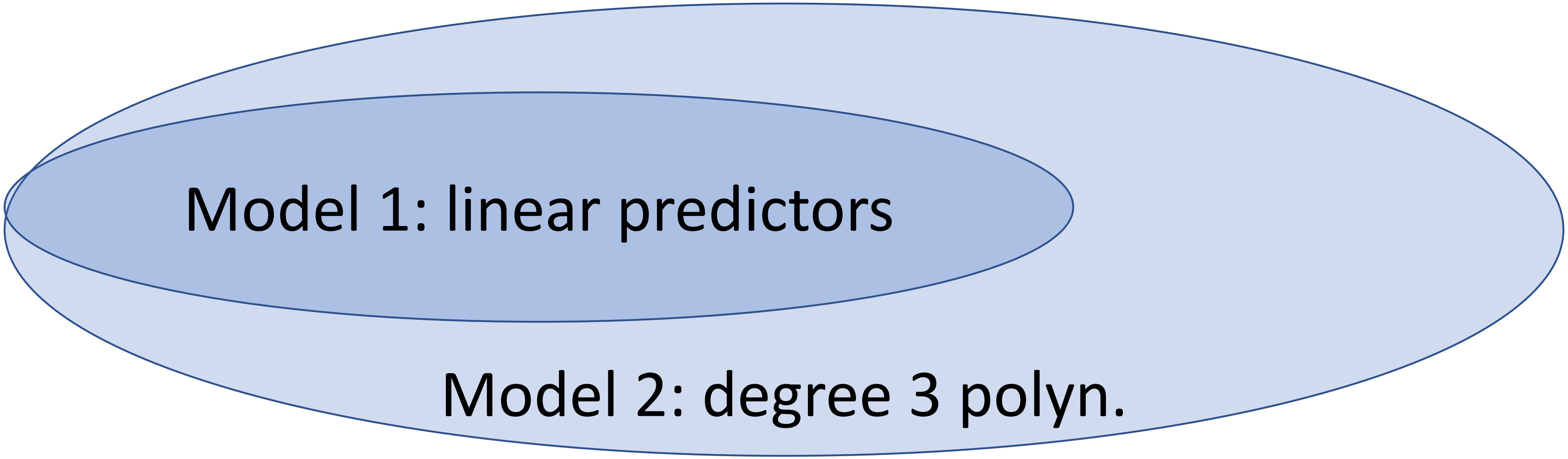
Model 1:
Linear Predictors (Degree 1 Polyn.)



Model 2:
Degree 3 Polyn. Predictors



Nested Models – I



Math Notation

$$\mathcal{H}^{(n)} = \left\{ h(x) = \sum_{l=0}^{n} w_l x^l \; with\ some\ w_l \right\}$$

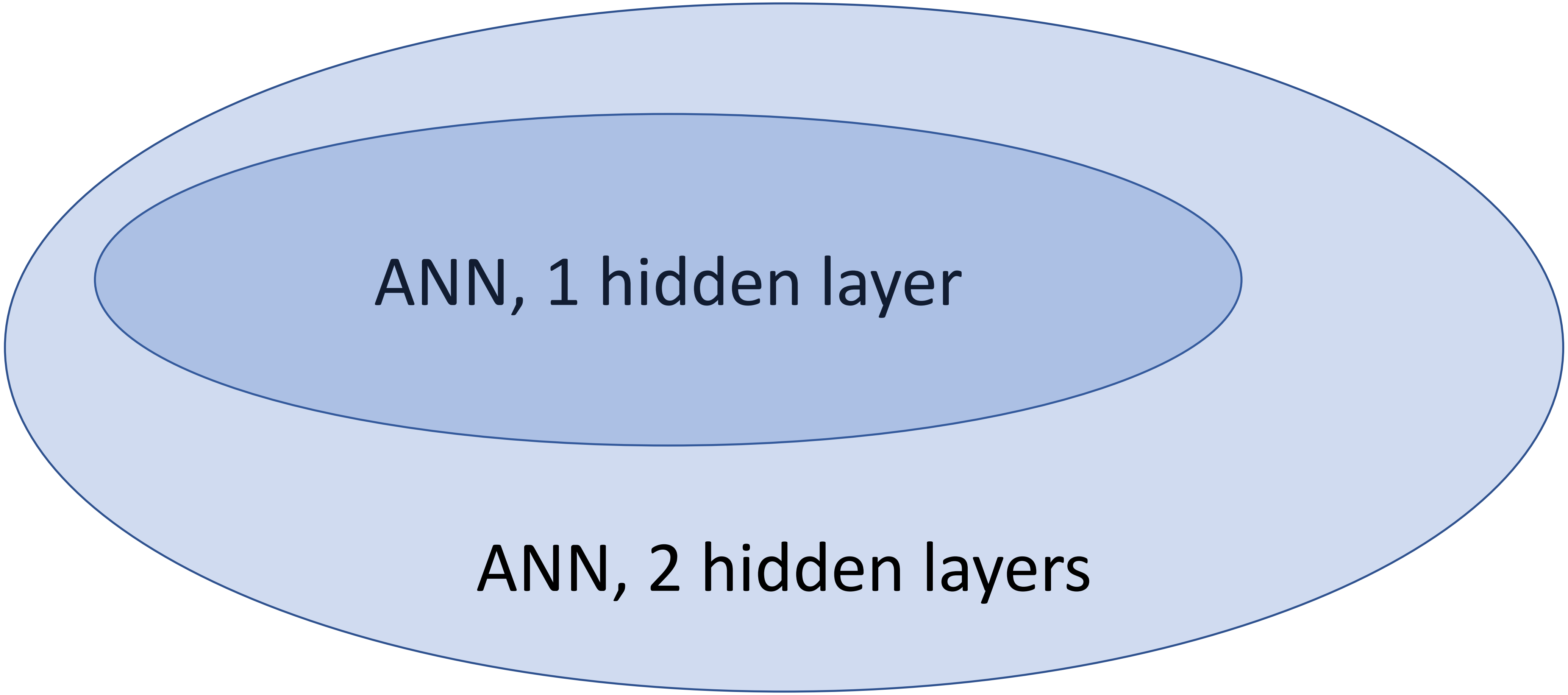
$\mathcal{H}^{(0)}$ … constant prediction (ignores feature)

$\mathcal{H}^{(1)}$ … linear hypotheses

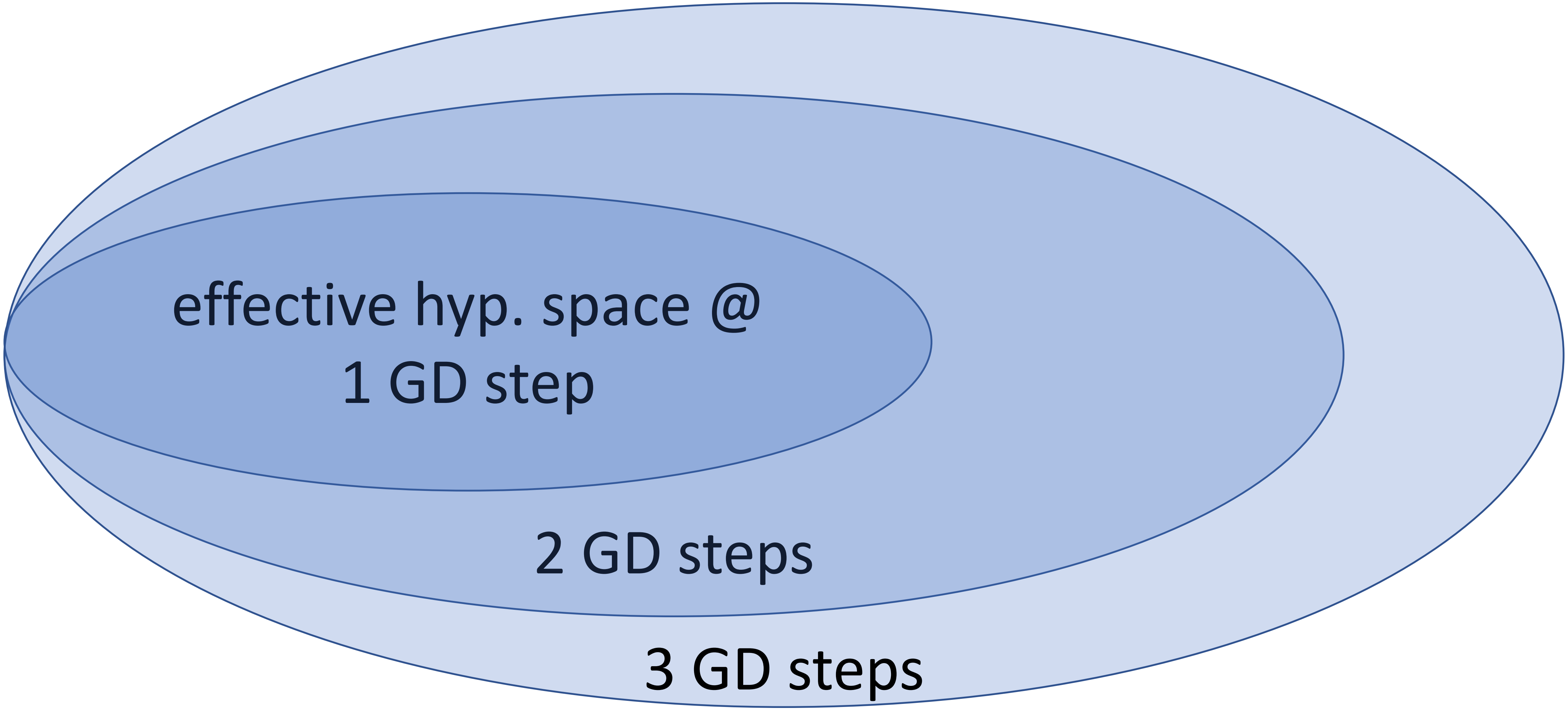
$\mathcal{H}^{(3)}$ … degree 3 polyn.

$$\mathcal{H}^{(0)} \subseteq \mathcal{H}^{(1)} \subseteq \mathcal{H}^{(2)} \subseteq \mathcal{H}^{(3)} \subseteq \ldots$$

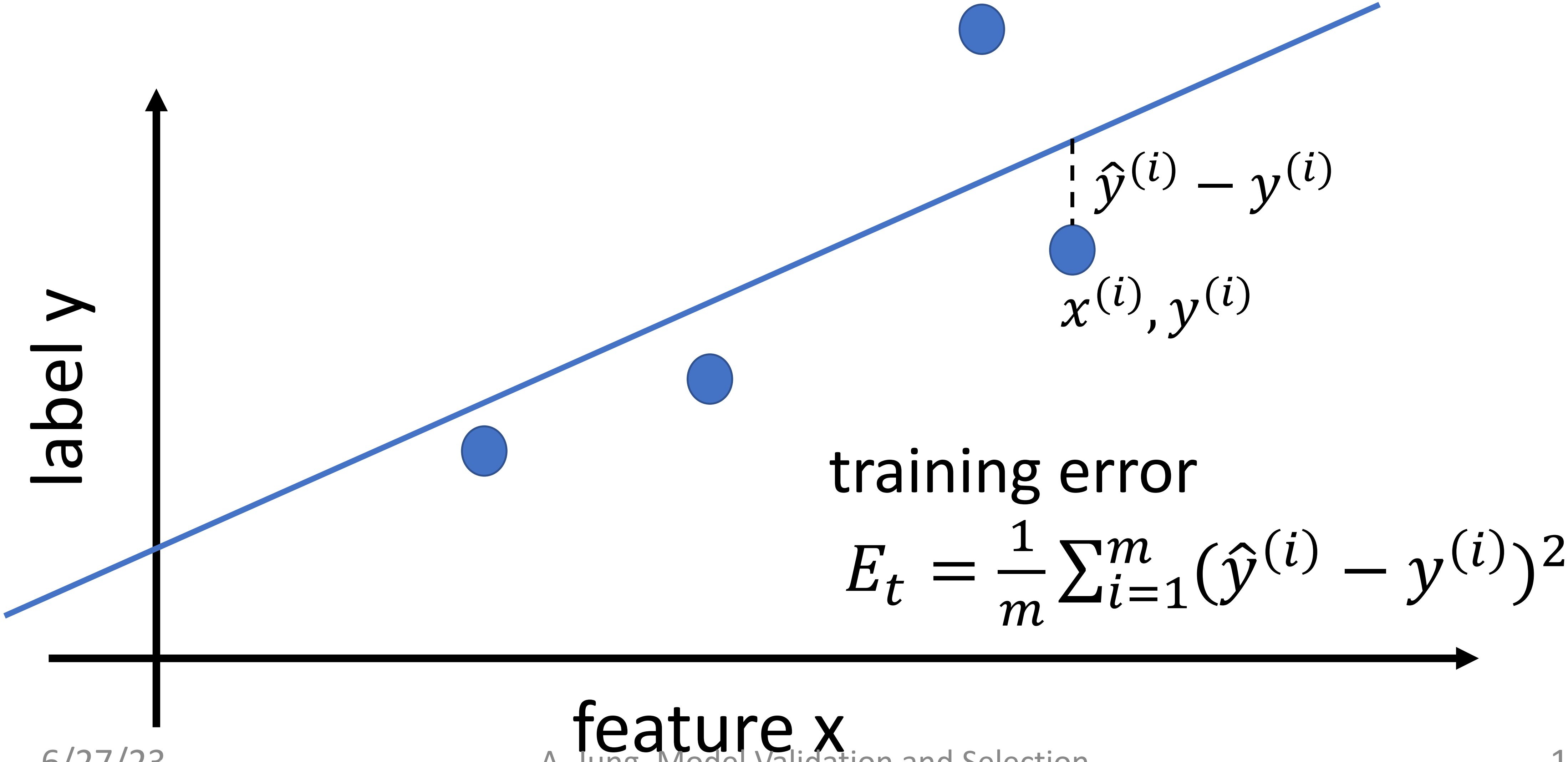
Nested Models - II



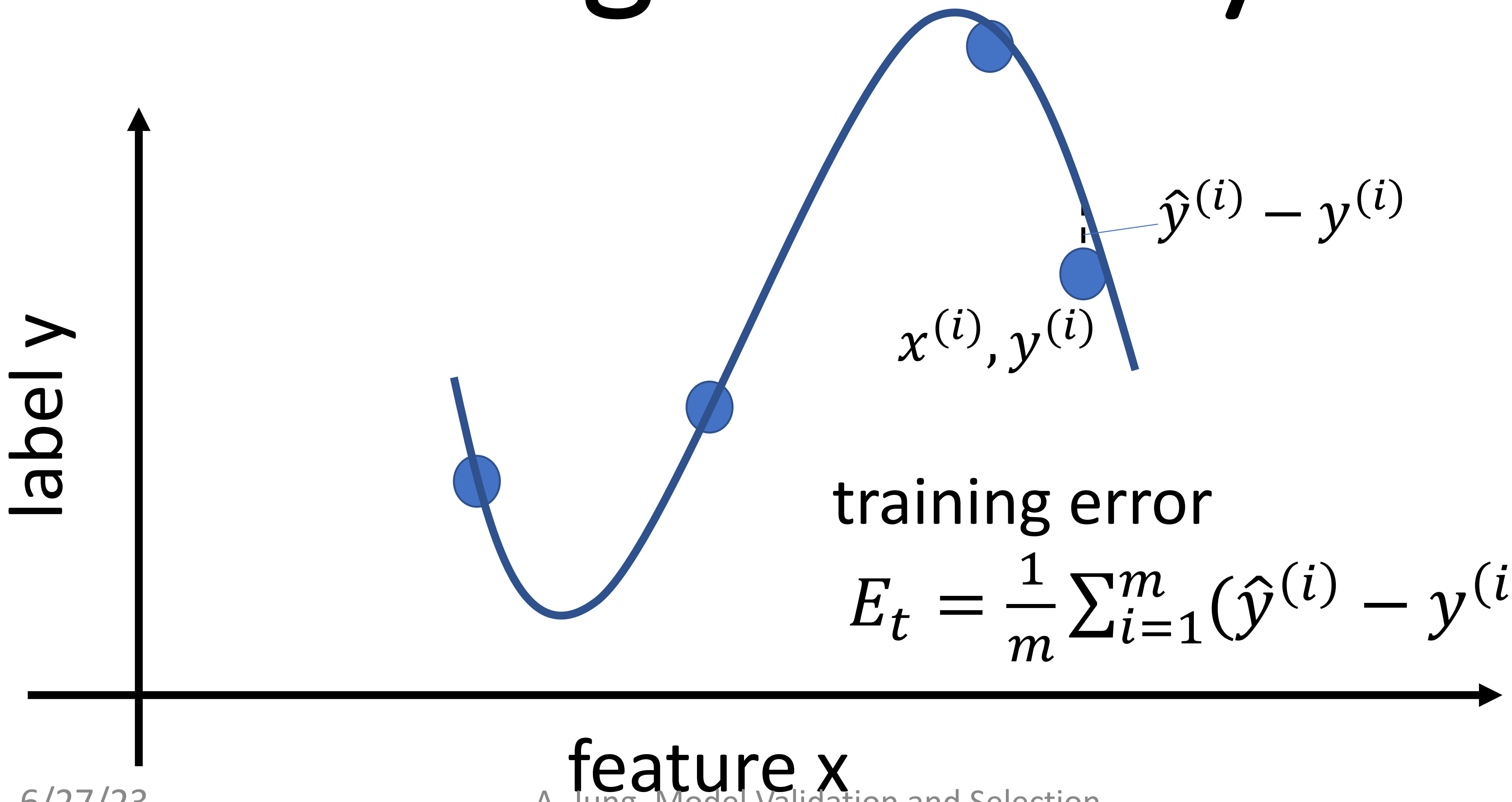
Nested Models - III



Learn Linear Predictor



Learn Degree 3 Polyn.



training error

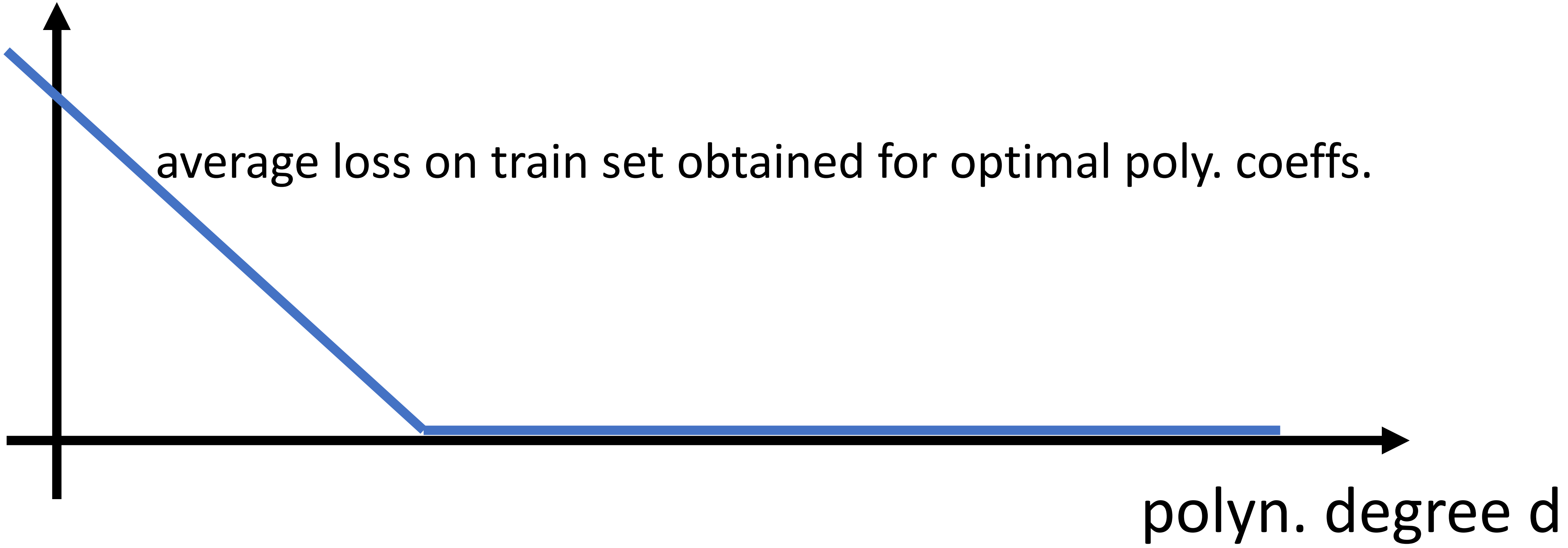
$$E_t = \frac{1}{m}\sum_{i=1}^{m}(\hat{y}^{(i)} - y^{(i)})^2$$

Training Errors

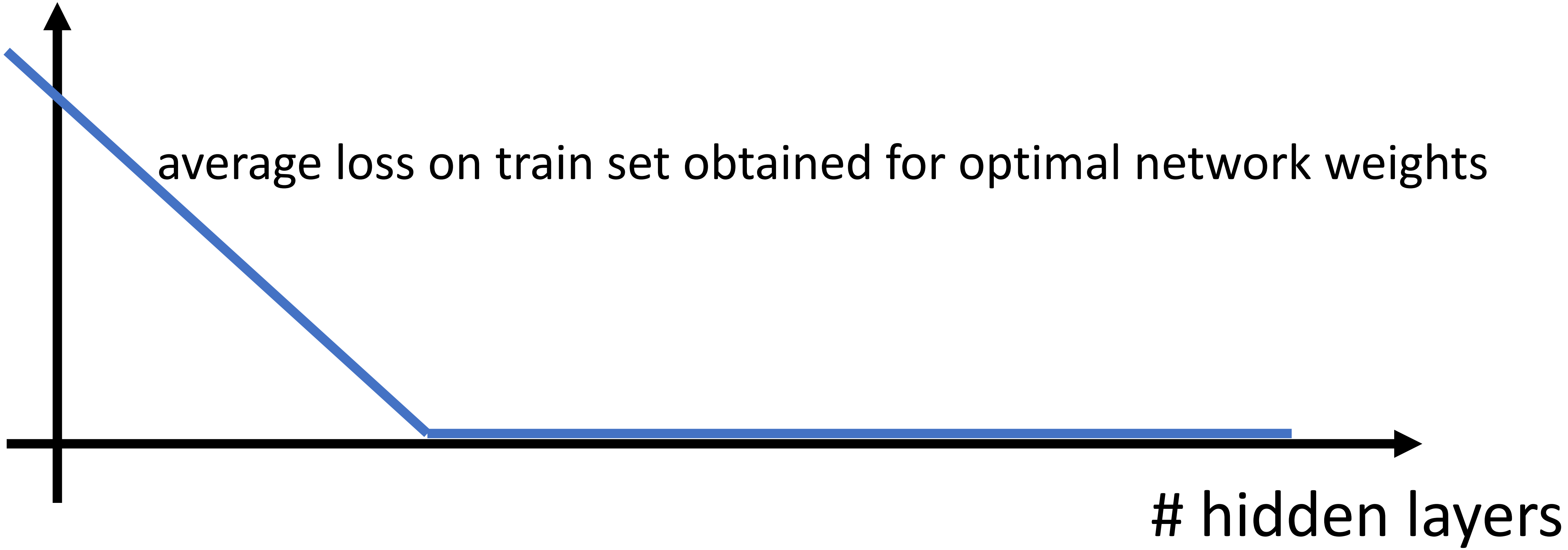
model 1
linear predictors

model 2:
degree 3 polyn.

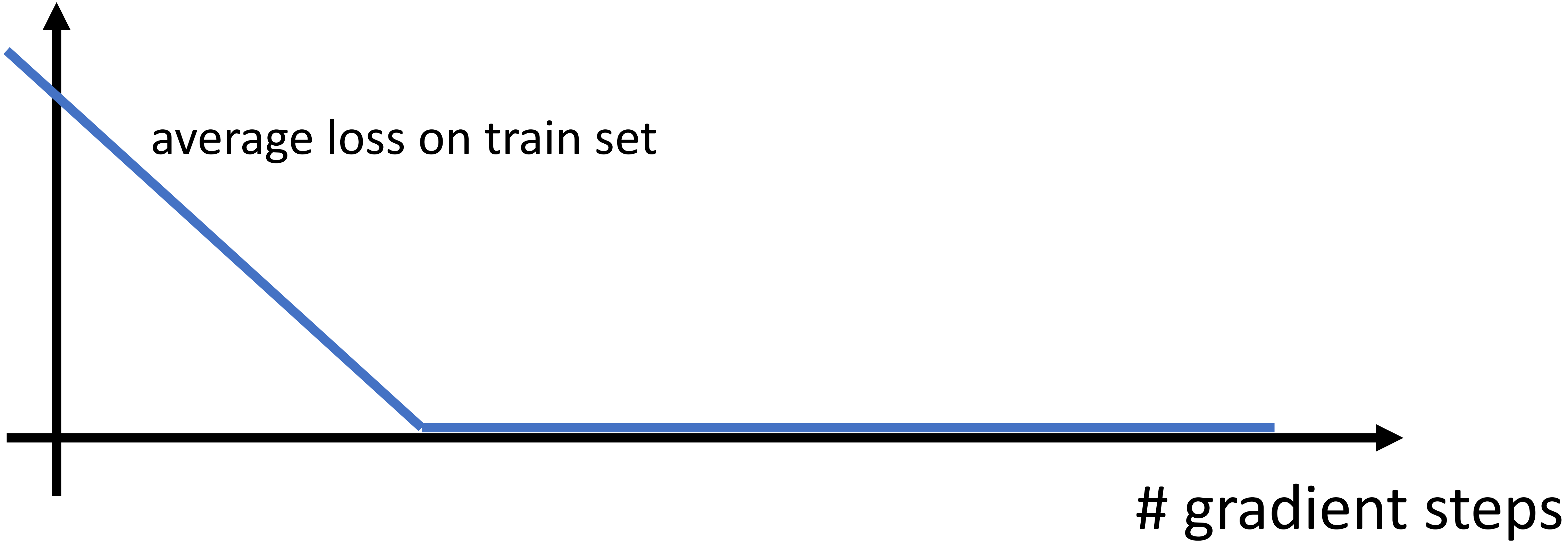
Train Error vs. Degree



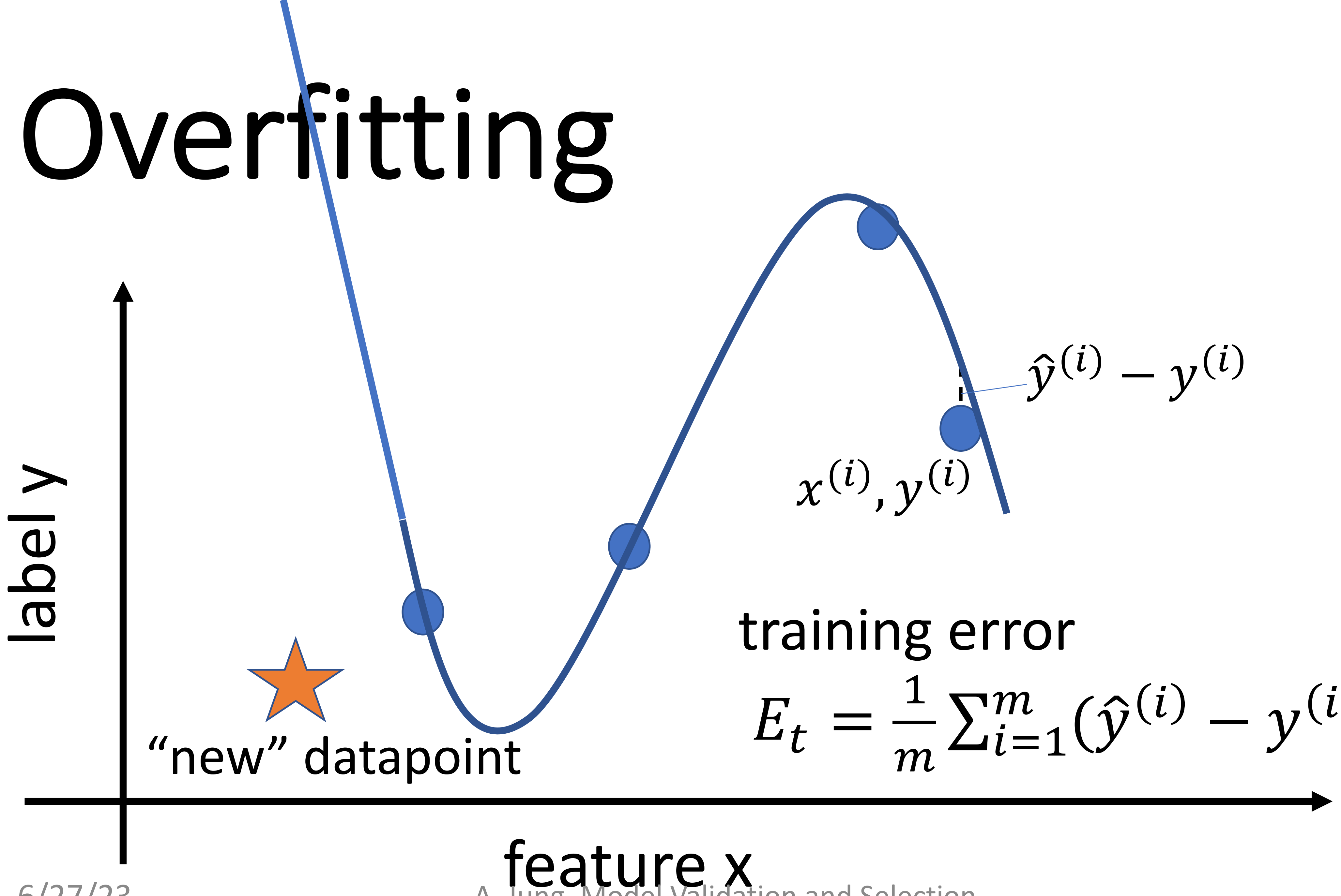
Train Error vs. ANN Layers



Train Error vs. Gradient Steps



Overfitting



training error

$$E_t = \frac{1}{m} \sum_{i=1}^{m} (\hat{y}^{(i)} - y^{(i)})^2$$

small training error does not imply good performance on new data points!

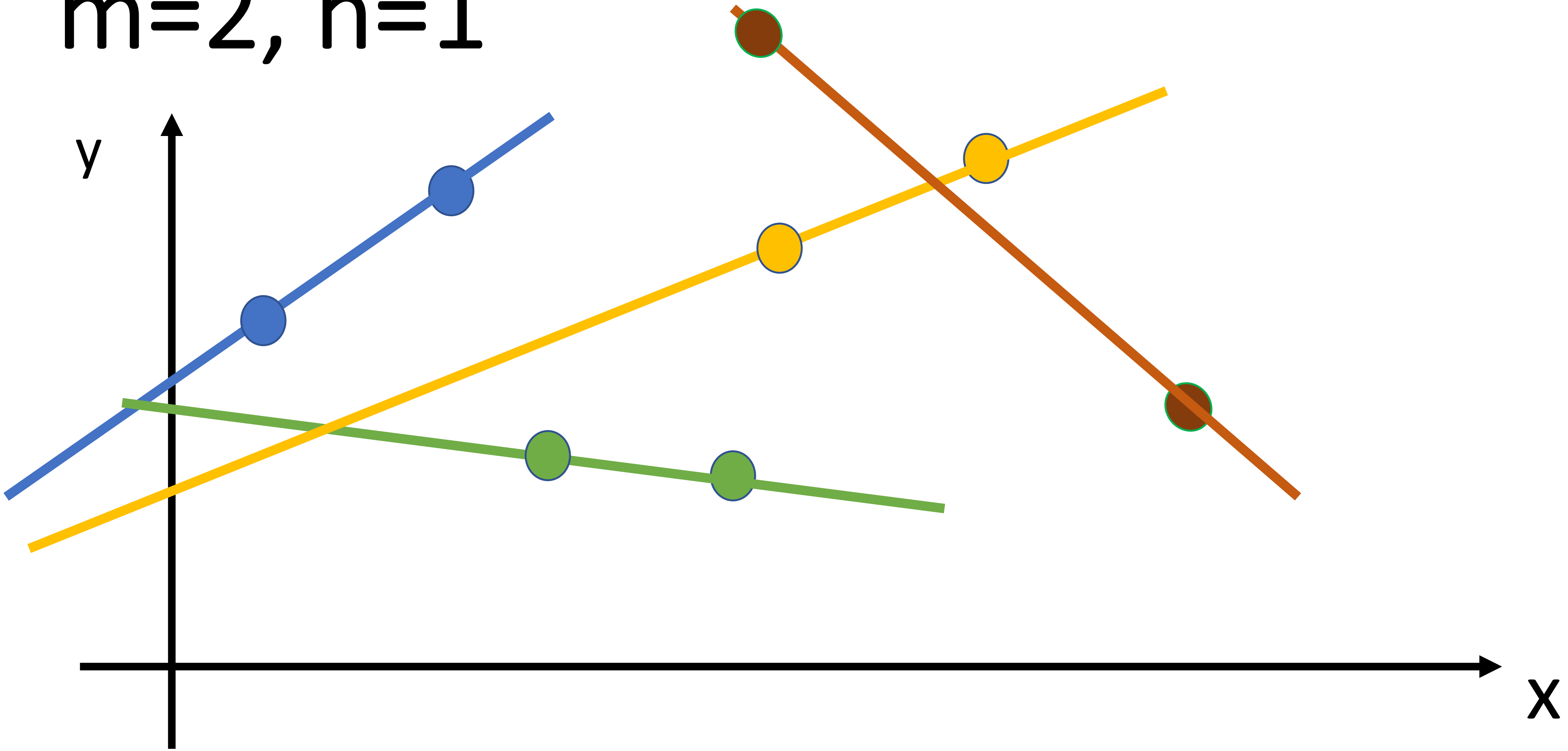
small training error merely indicates that training algorithm has been implemented correctly

A Case in Point

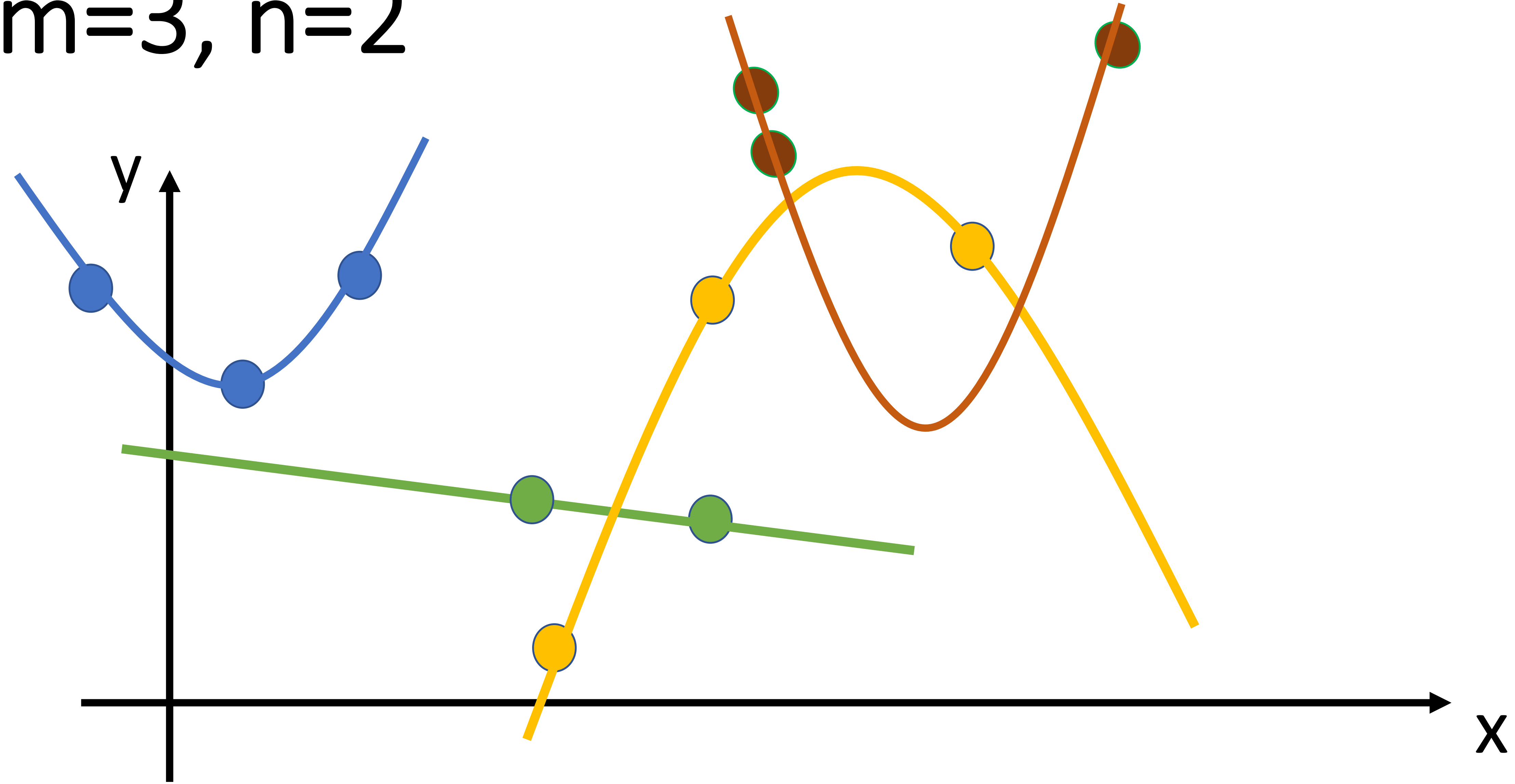
we can perfectly fit (almost) any m data points using polynomials of degree n as soon as

$$n \geq m\text{-}1$$

m=2, n=1



m=3, n=2



Reminder: Probabilistic Model

- data points are realizations of RVs
- joint pdf p(x,y) of features and label
- training set is a RV
- learnt hypothesis h(.) is a RV
- prediction h(x) is a RV

Why Can Train. Err. Mislead?

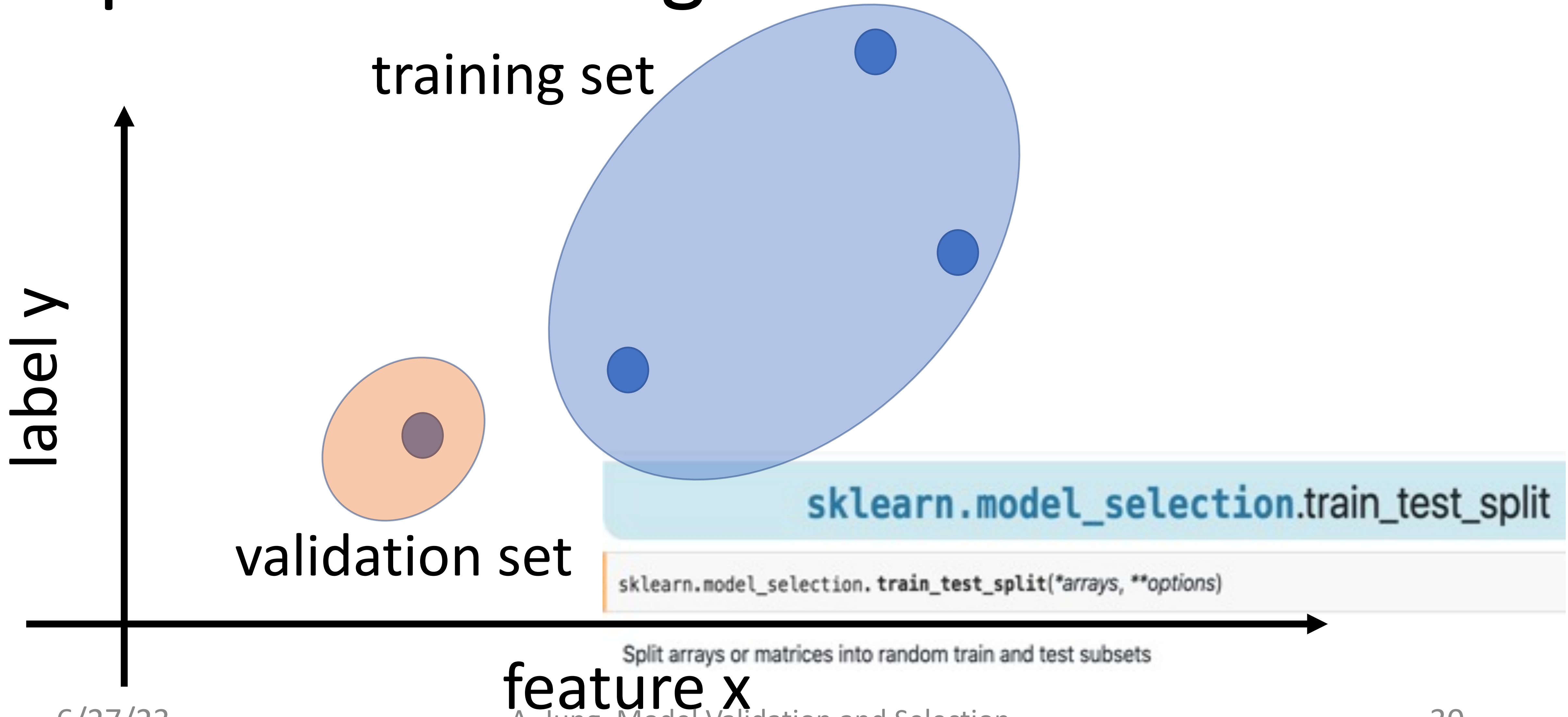
- consider expected loss of hypothesis
- estimate expectation using sample average
- this only works if hypothesis does not depends on data points used in average
- does not hold for training error

Model Validation

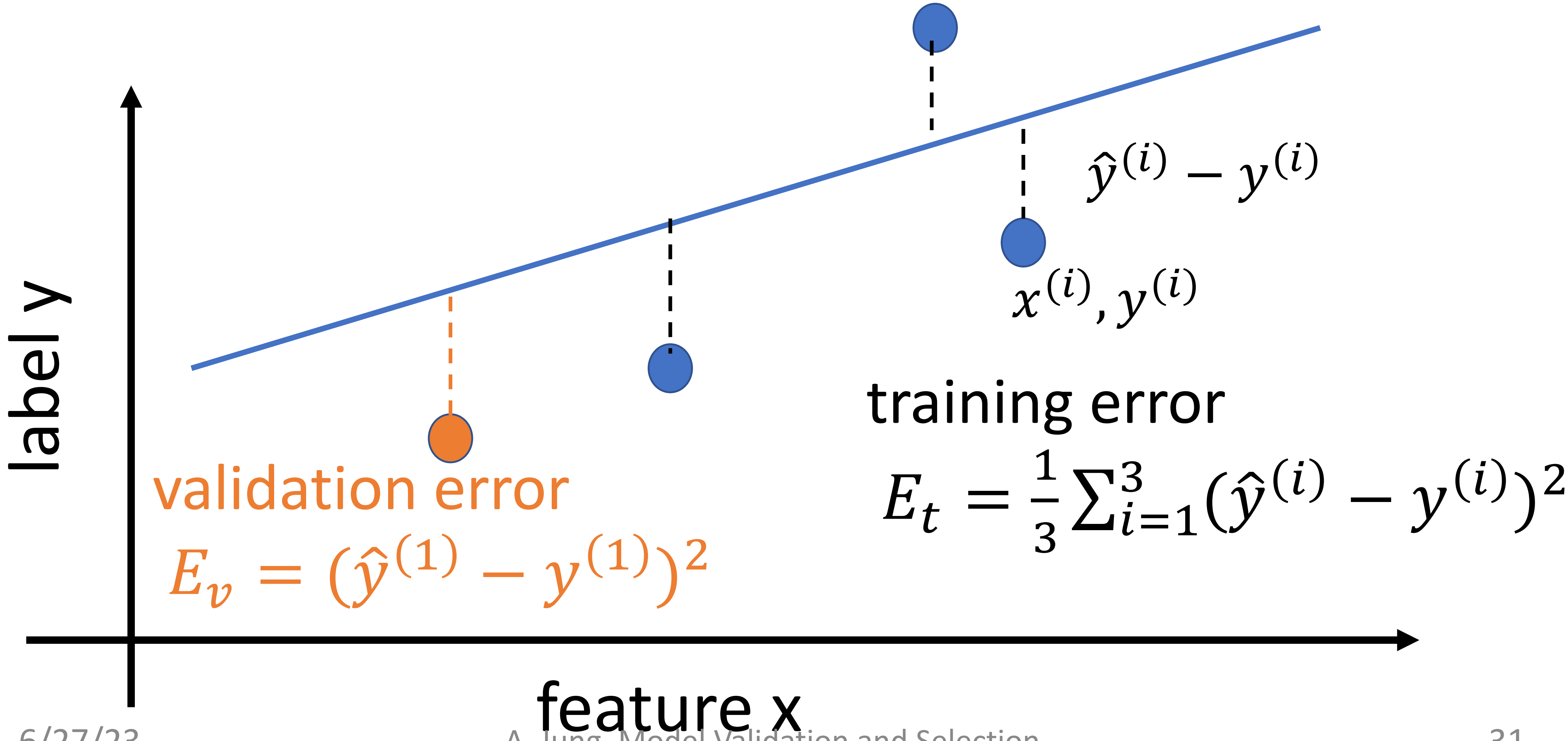
Basic Idea of Validation

- divide data points into two subsets
- use training set to learn predictor
- use validation set to estimate loss

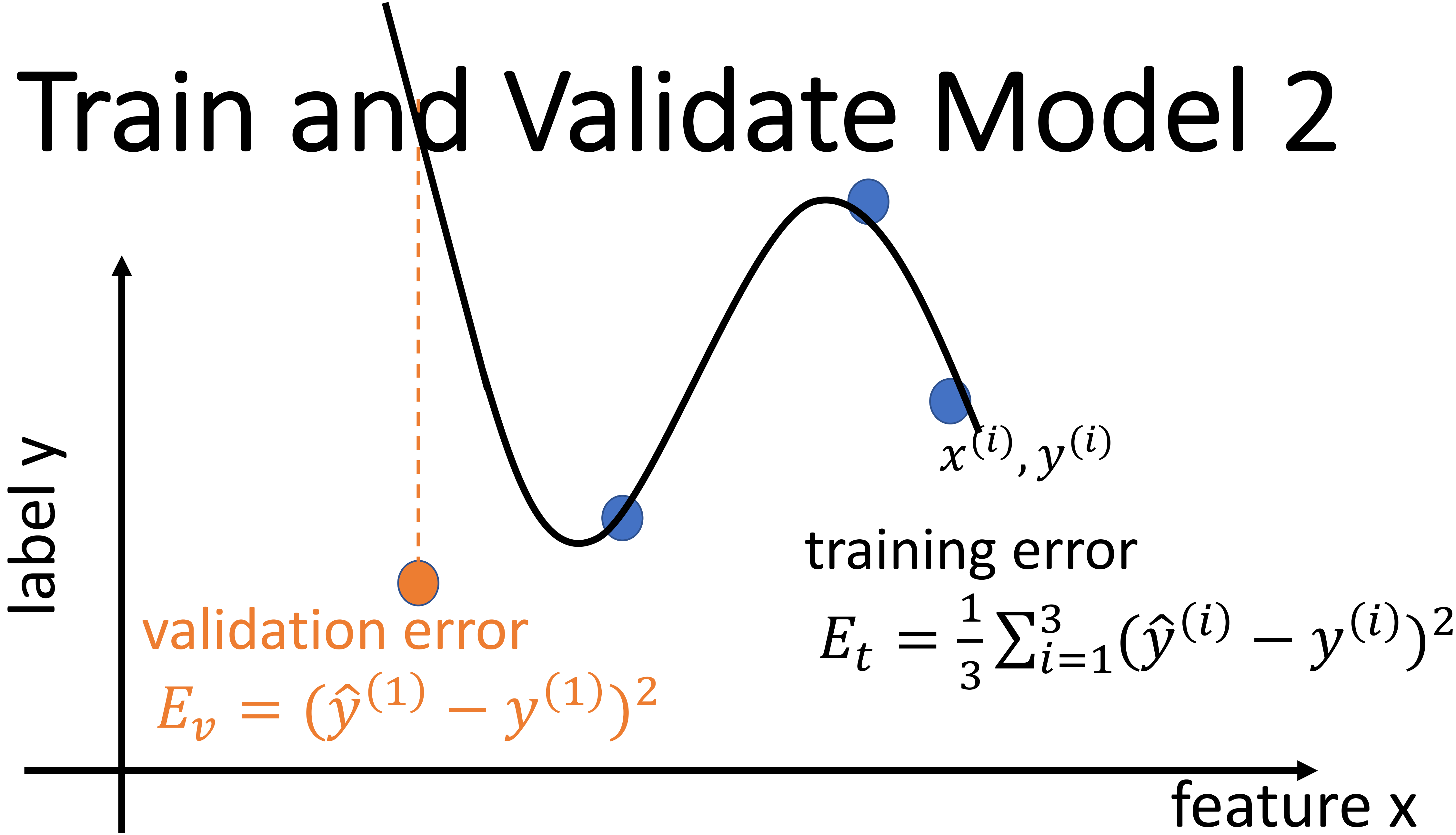
Split into Training and Validation Set



Train and Validate Model 1

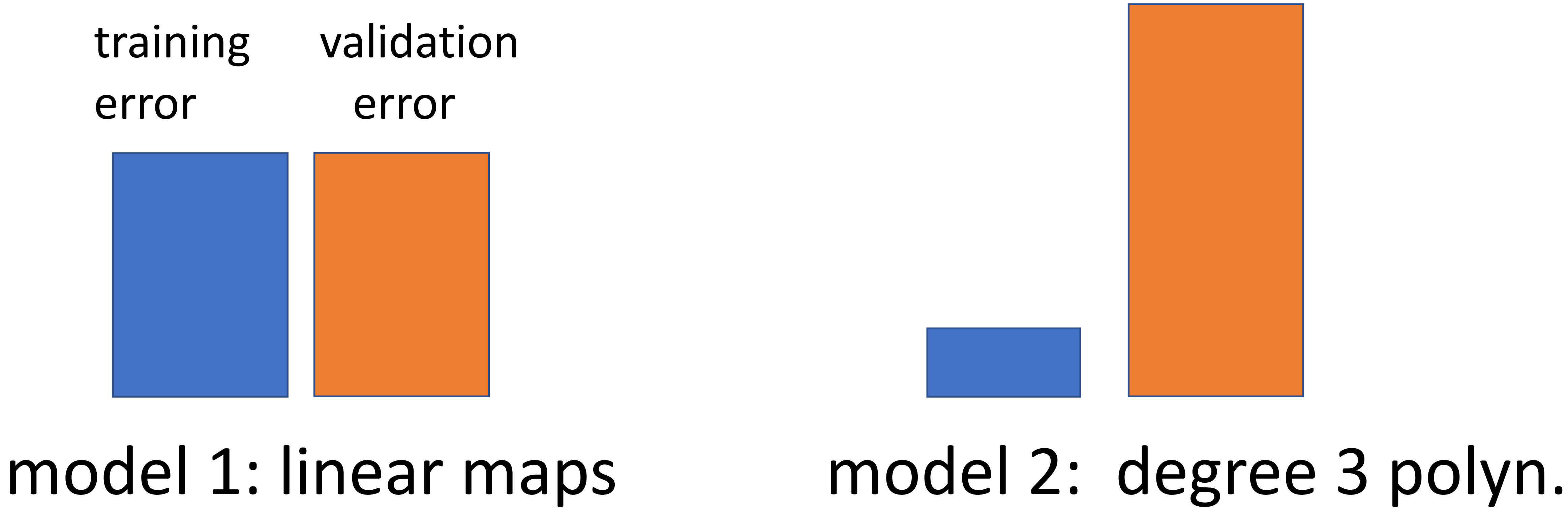


Train and Validate Model 2



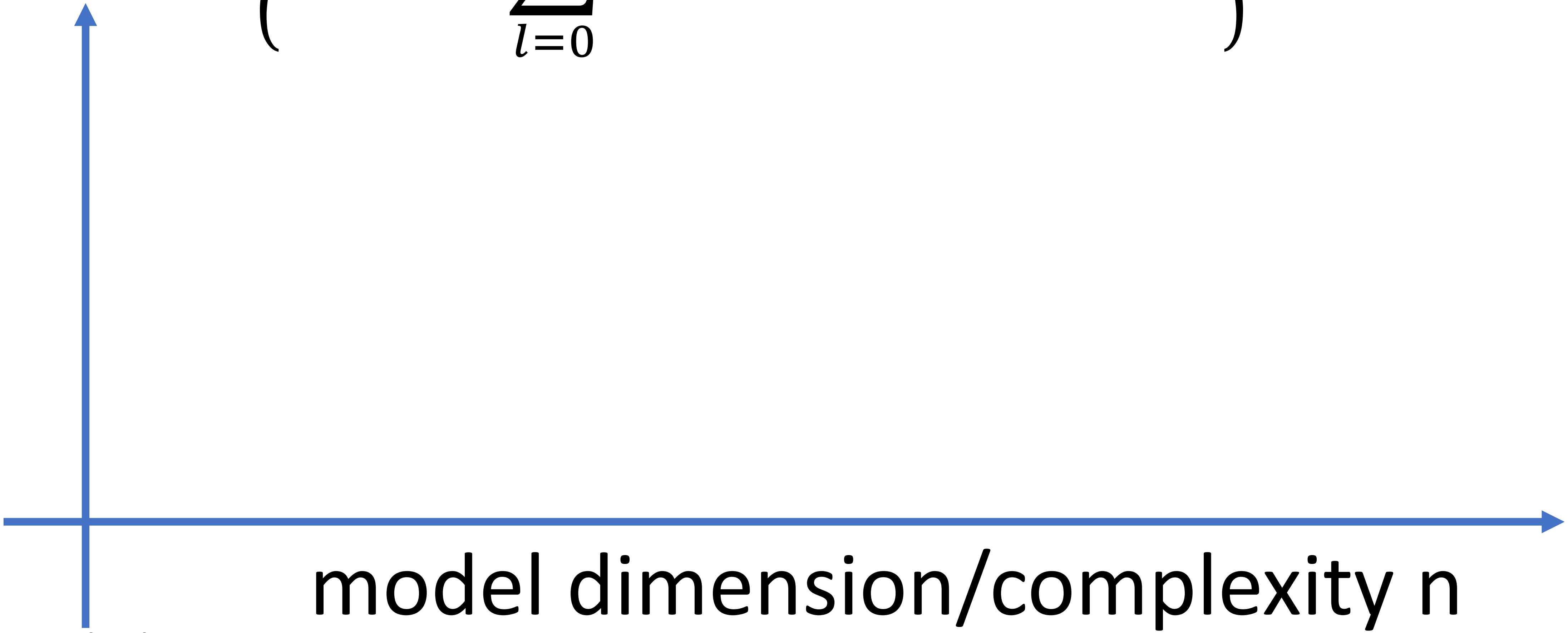
Basic Idea of Model Selection

choose model via validation error

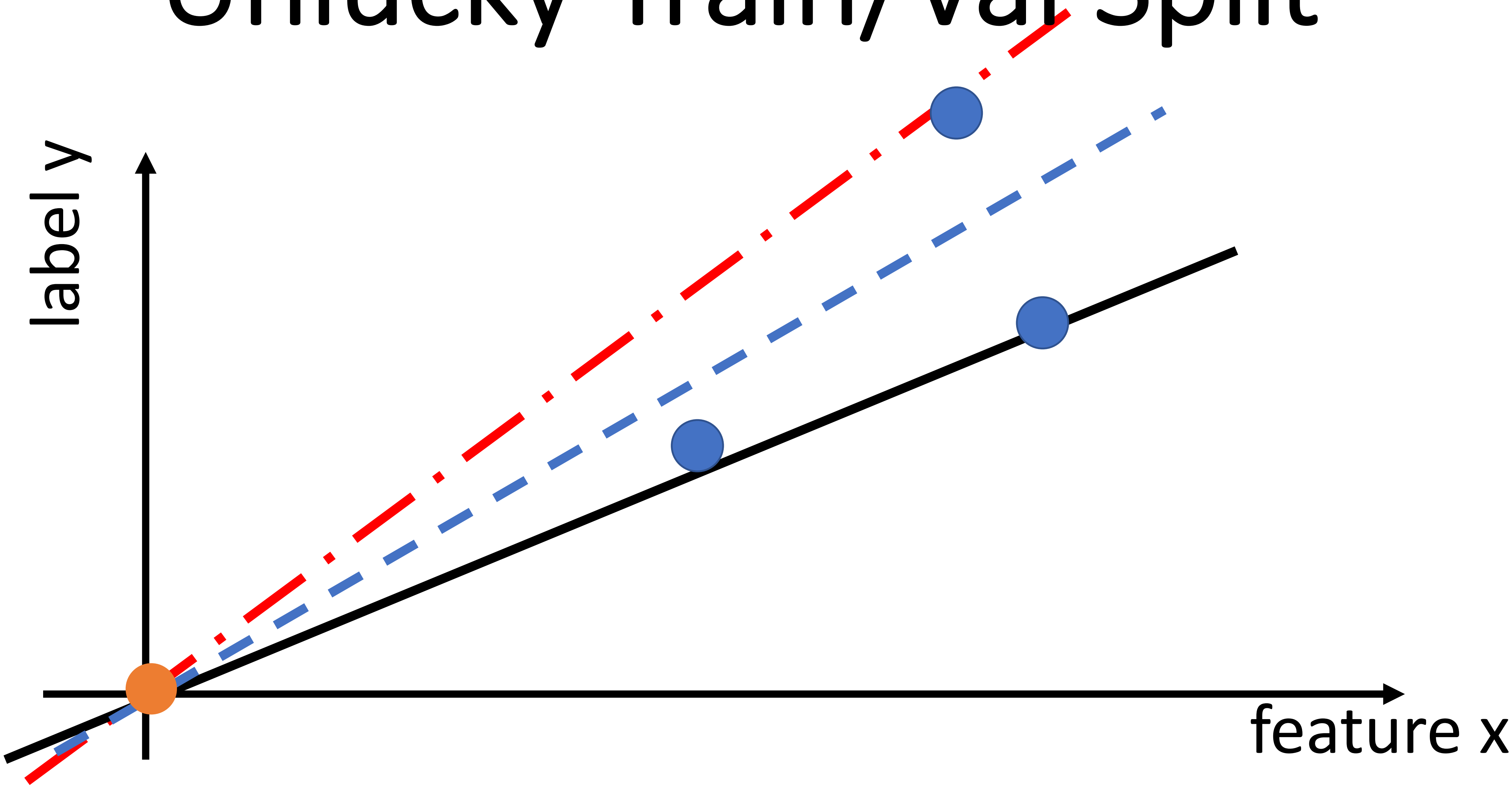


Train/Val Error vs Model Complexity

$$\mathcal{H}^{(n)} = \left\{ h(x) = \sum_{l=0}^{n-1} w_l x^l \text{ with weights } w_l \right\}$$



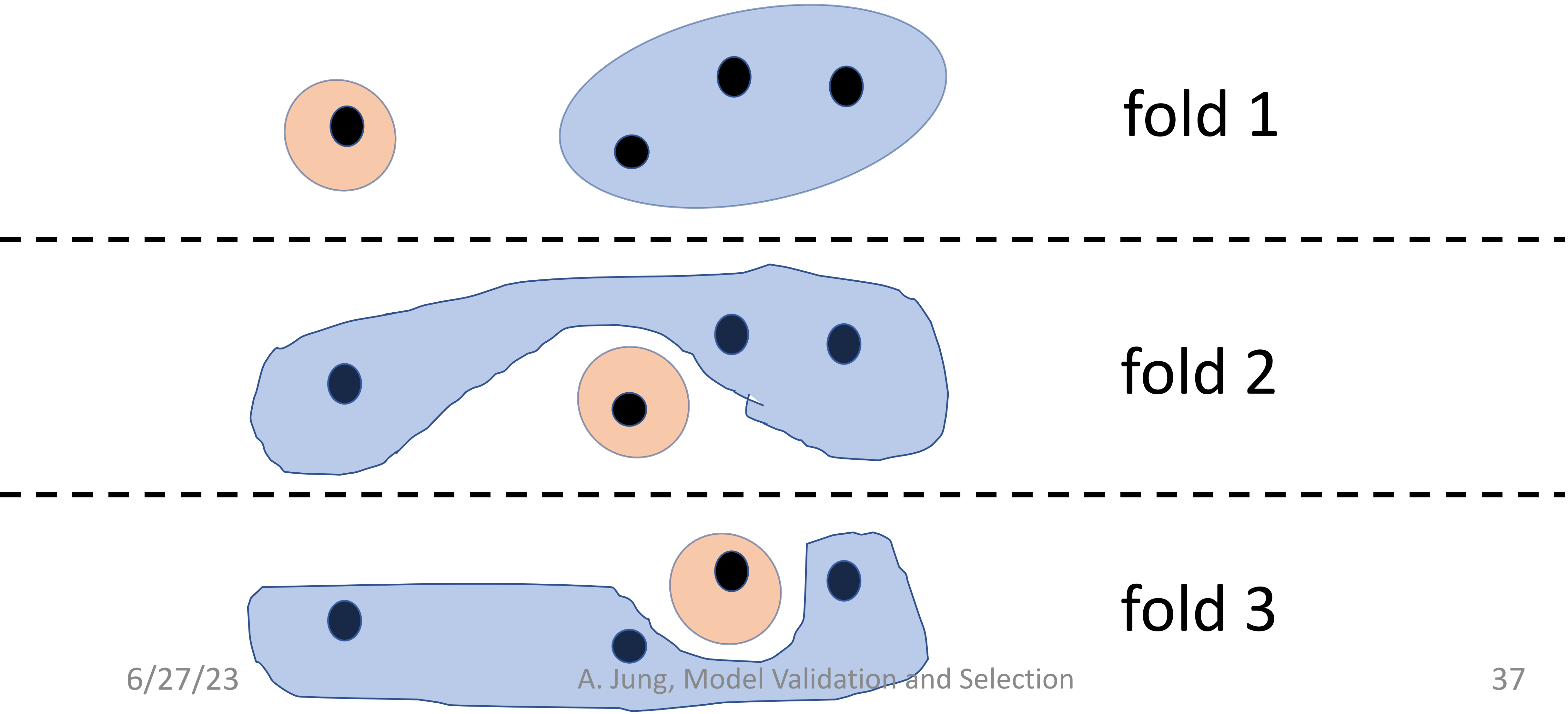
Unlucky Train/Val Split



k-Fold Cross Validation

- might be unlucky with train/val split
- problematic for small datasets
- IDEA: randomly split several times
- "average out" unlucky splits

K-Fold Cross Validation



k-Fold Cross Validation

how to choose nr of folds (the “k” in k-fold CV) ?

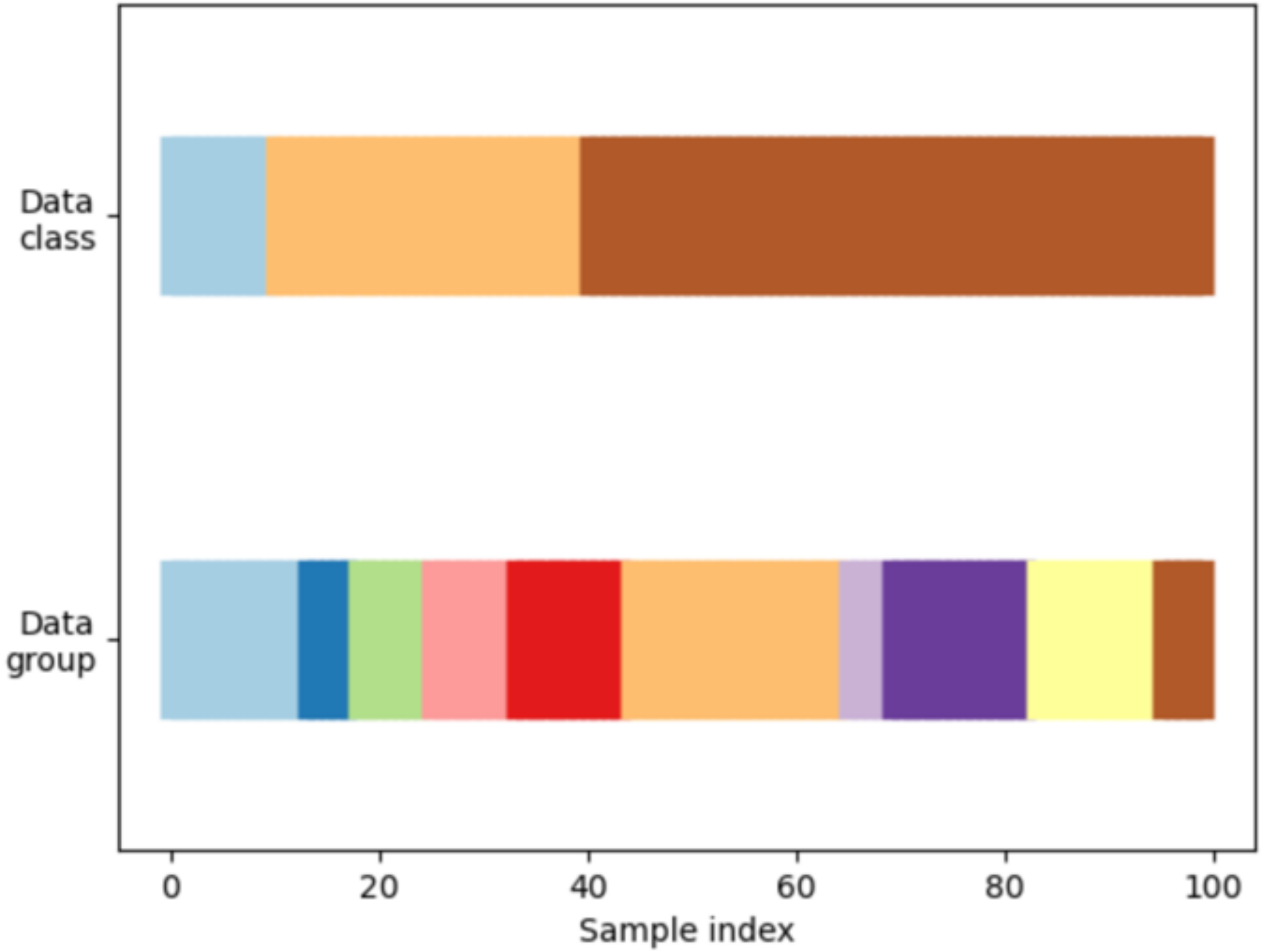
- train fold should be sufficiently large (avoid overfitting)

- val folds should sufficiently large (to get reliable estimate of generalization)

CAUTION!

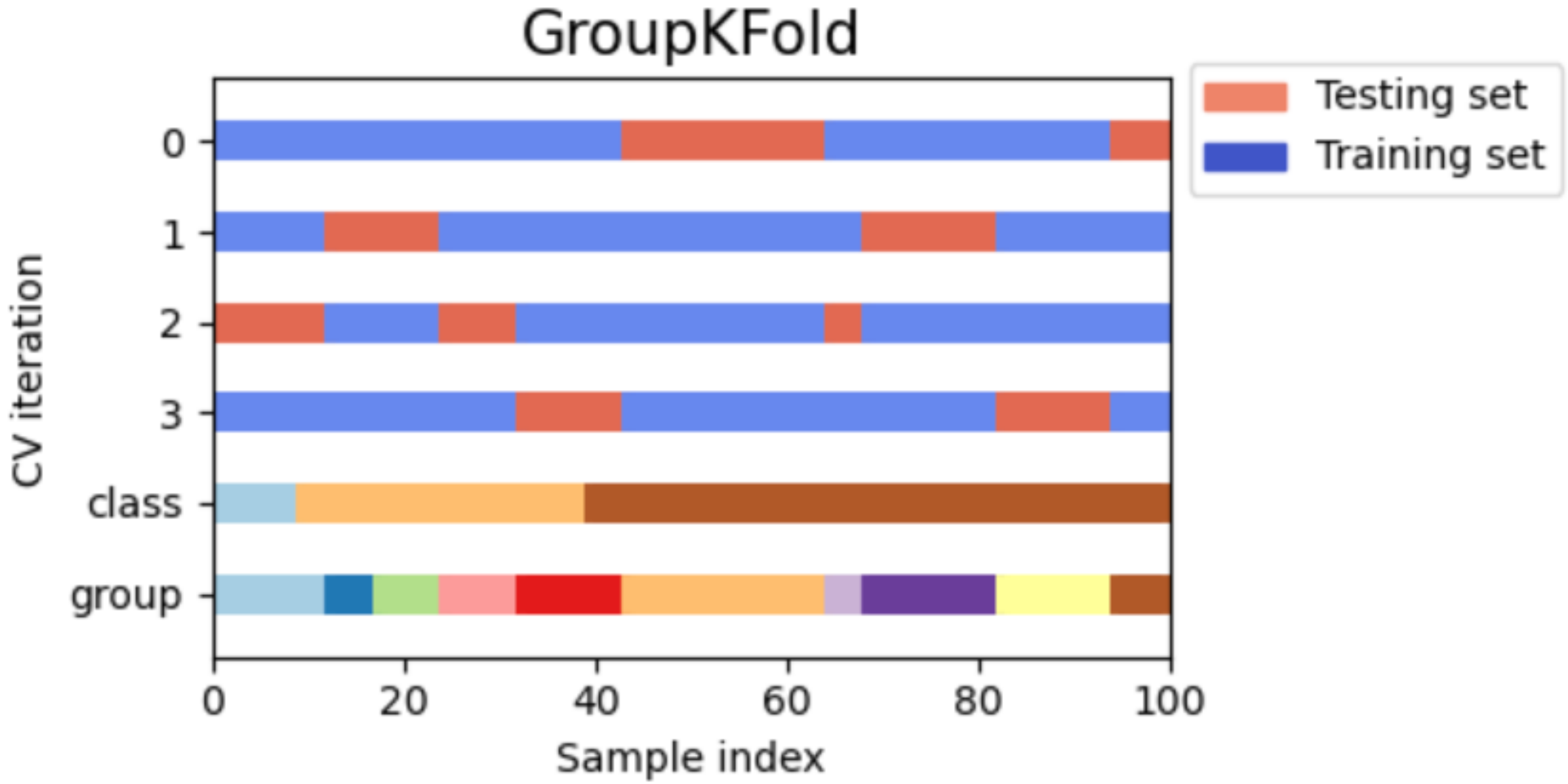
- k-fold CV requires a method to split into folds
- most basic method: evenly divide into k folds
- works if data is i.i.d. (“order of data points is arbitrary”)
- fails if data points are grouped or ordered

Imbalanced Classes and Group Structure



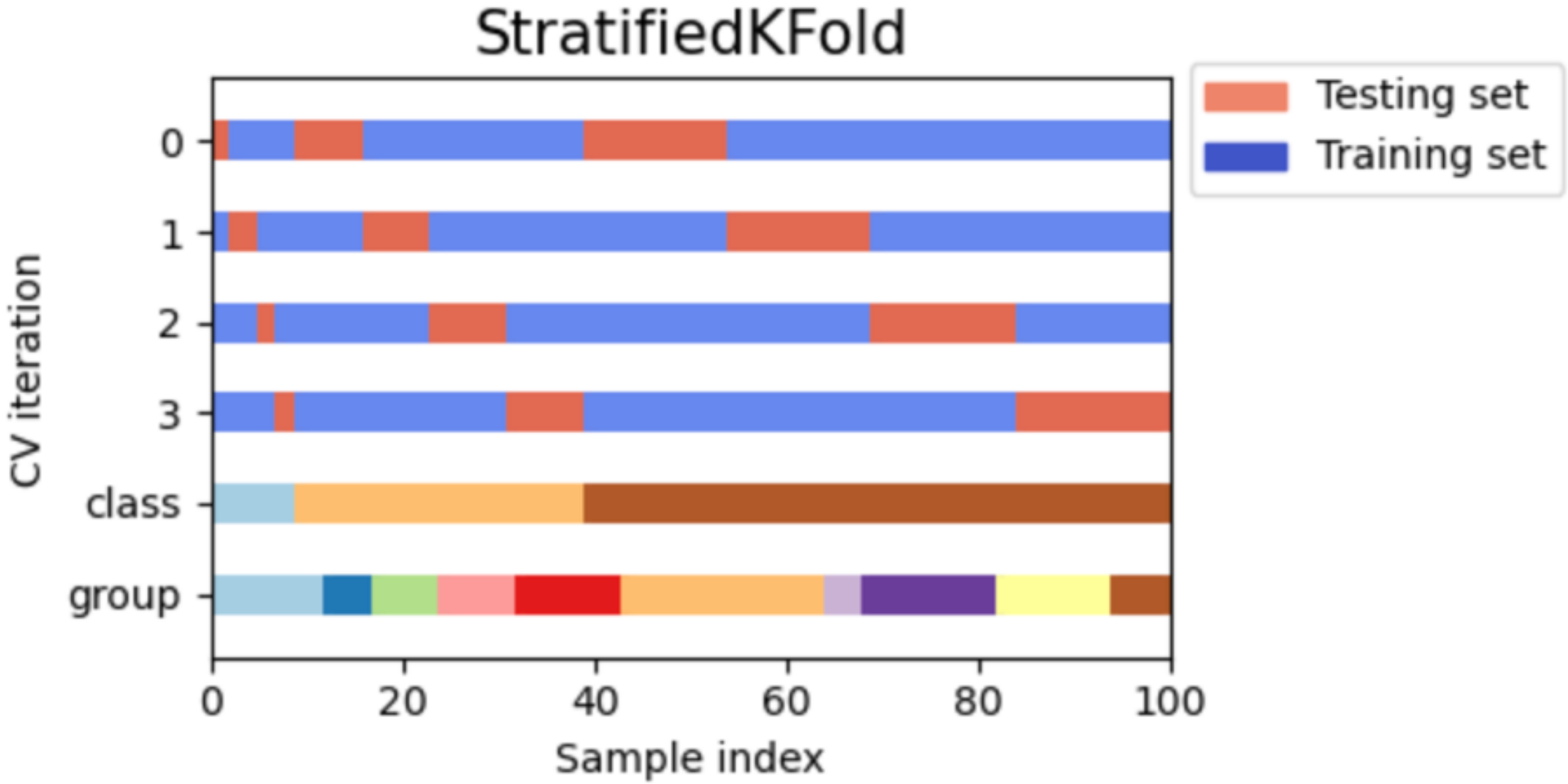
- e.g. data points with same label are contiguous blocks
- or data points are obtained at consecutive time instants (→ correlations)

Group-Preserving Splitting

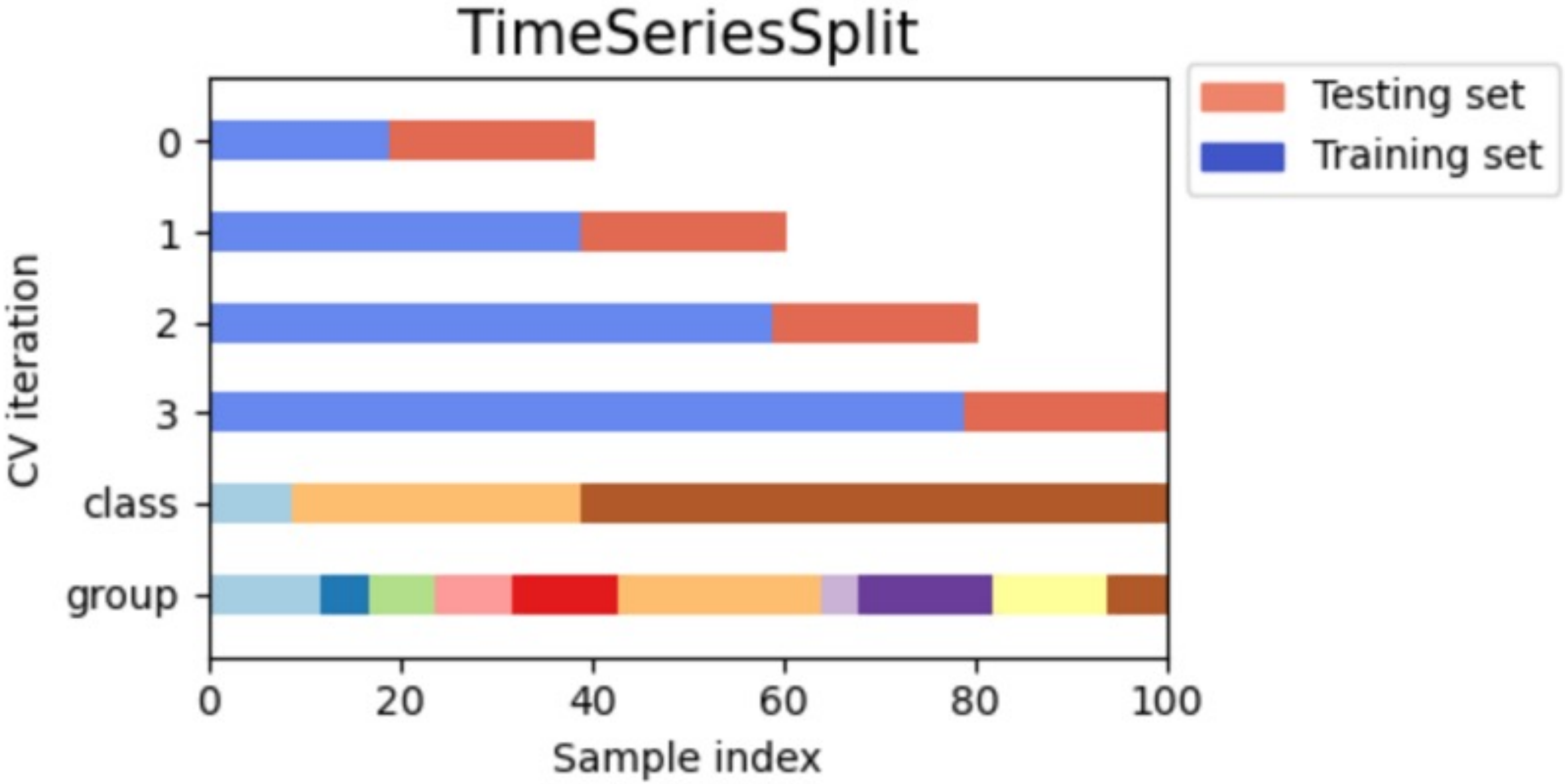


https://scikit-learn.org/stable/modules/generated/sklearn.model_selection.GroupKFold.html

Class-Ratio Preserving Splitting



Temporal Successive Splitting



source: https://scikit-learn.org/stable/

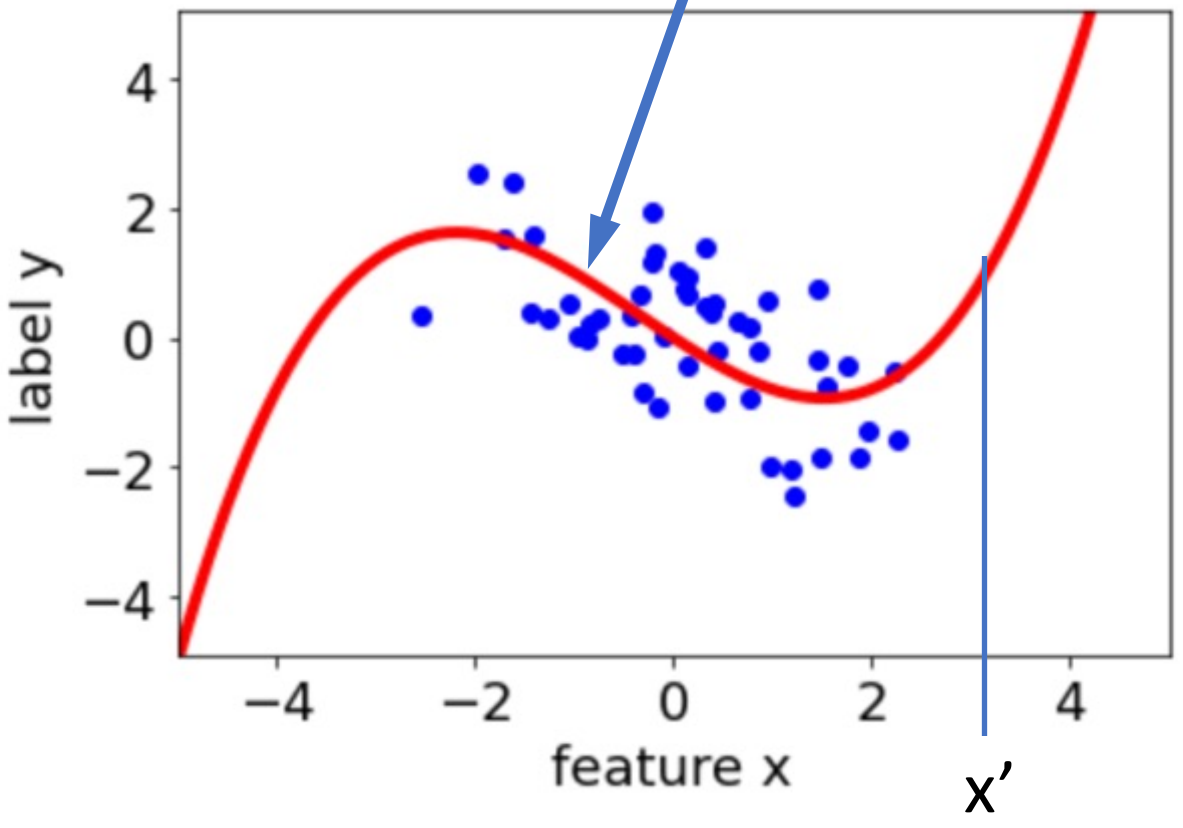
Bias and Variance Decomposition

“Bias” error component due to model being too small

“Variance” reflects error due to dataset being too small

Toy Data

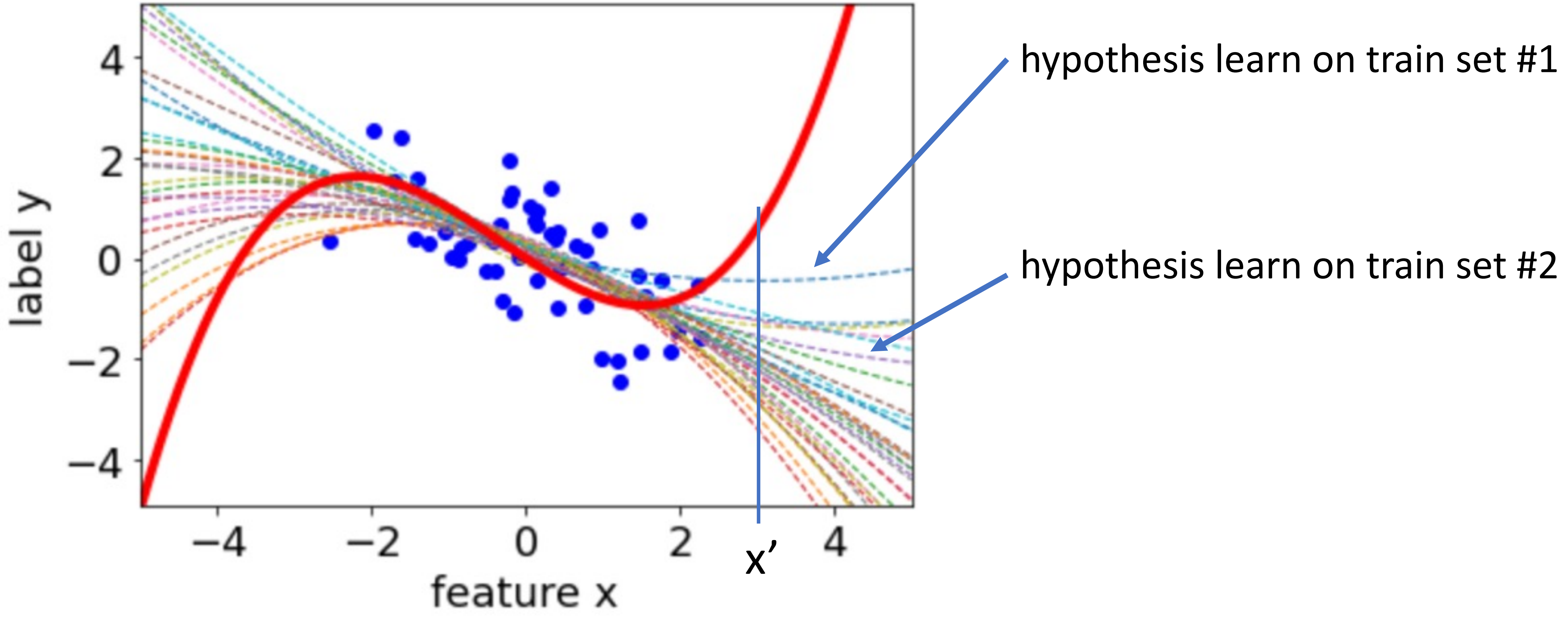
y = g(x) + "noise"



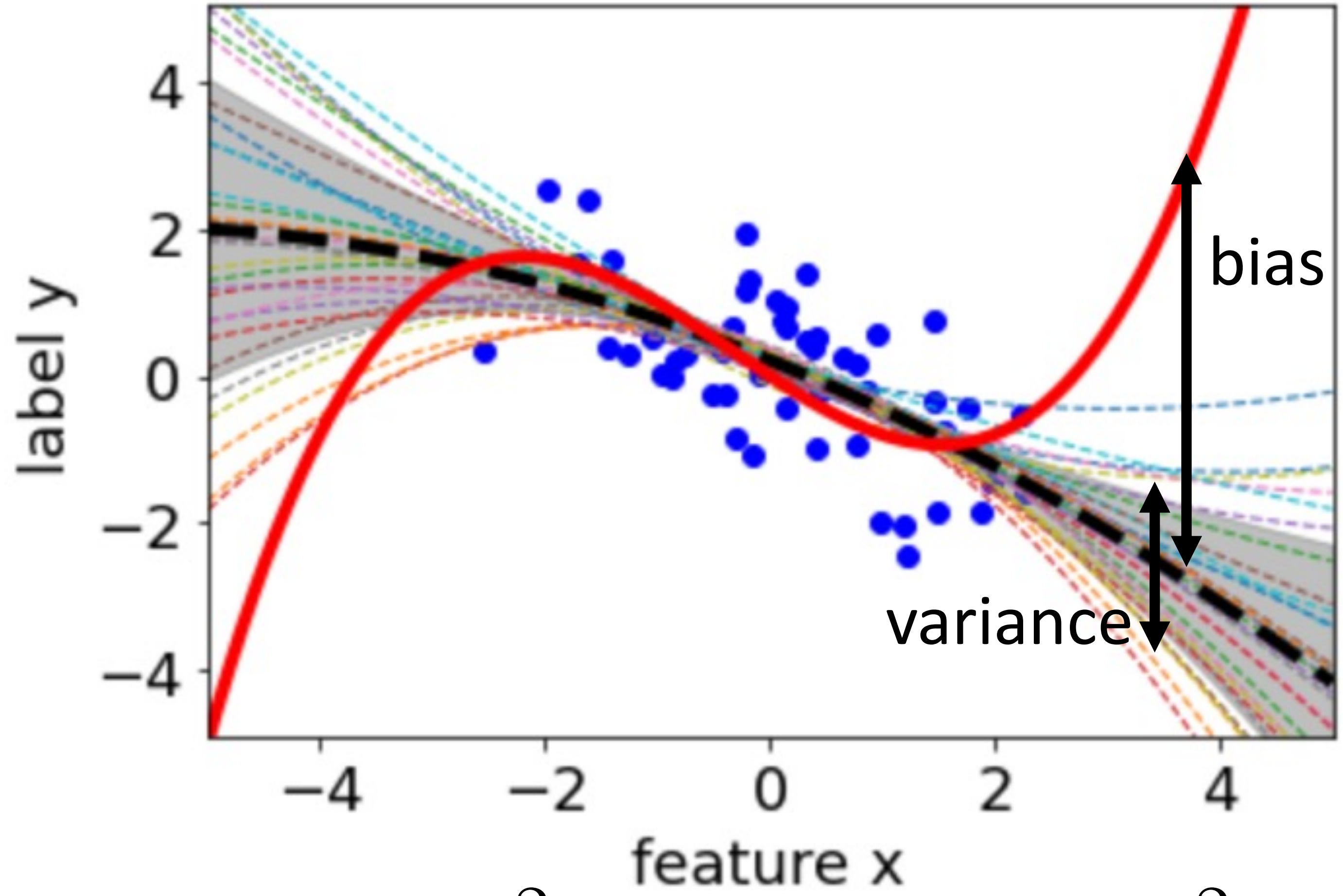
learn hypothesis h(.) using a randomly selected training set

compute prediction h(x') for a fixed feature value x'

Ensemble of Learnt Hypotheses



Bias and Variance

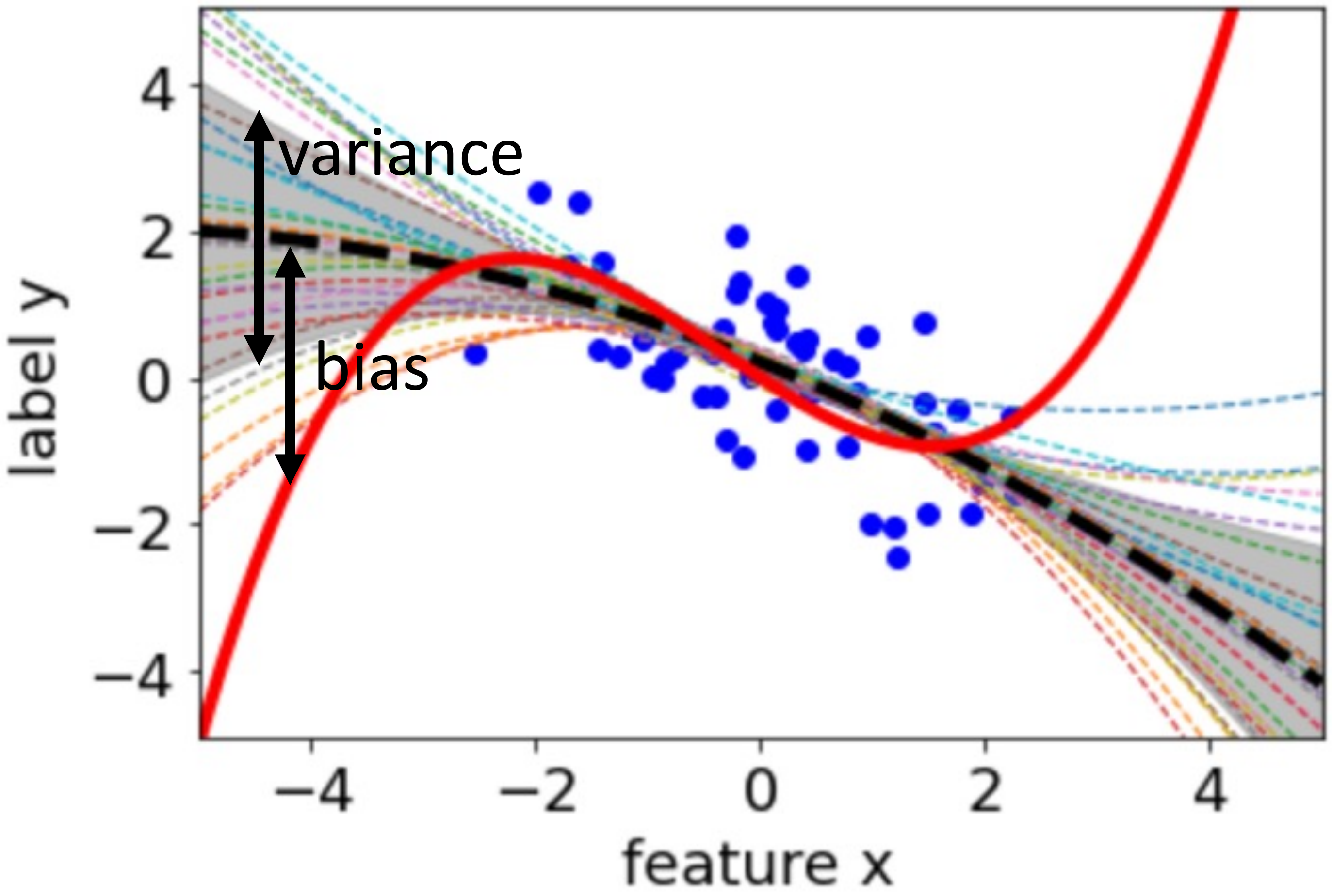


$$\hat{y} = h(x')$$

RV since obtained from a randomly selected training set

$$\mathrm{E}\{(\hat{y}-y)^2\} = (\mathrm{E}\{\hat{y}\}-y)^2 + \mathrm{E}\{(\hat{y}-\mathrm{E}\{\hat{y}\})^2\}$$

Bias and Variance Tradeoff

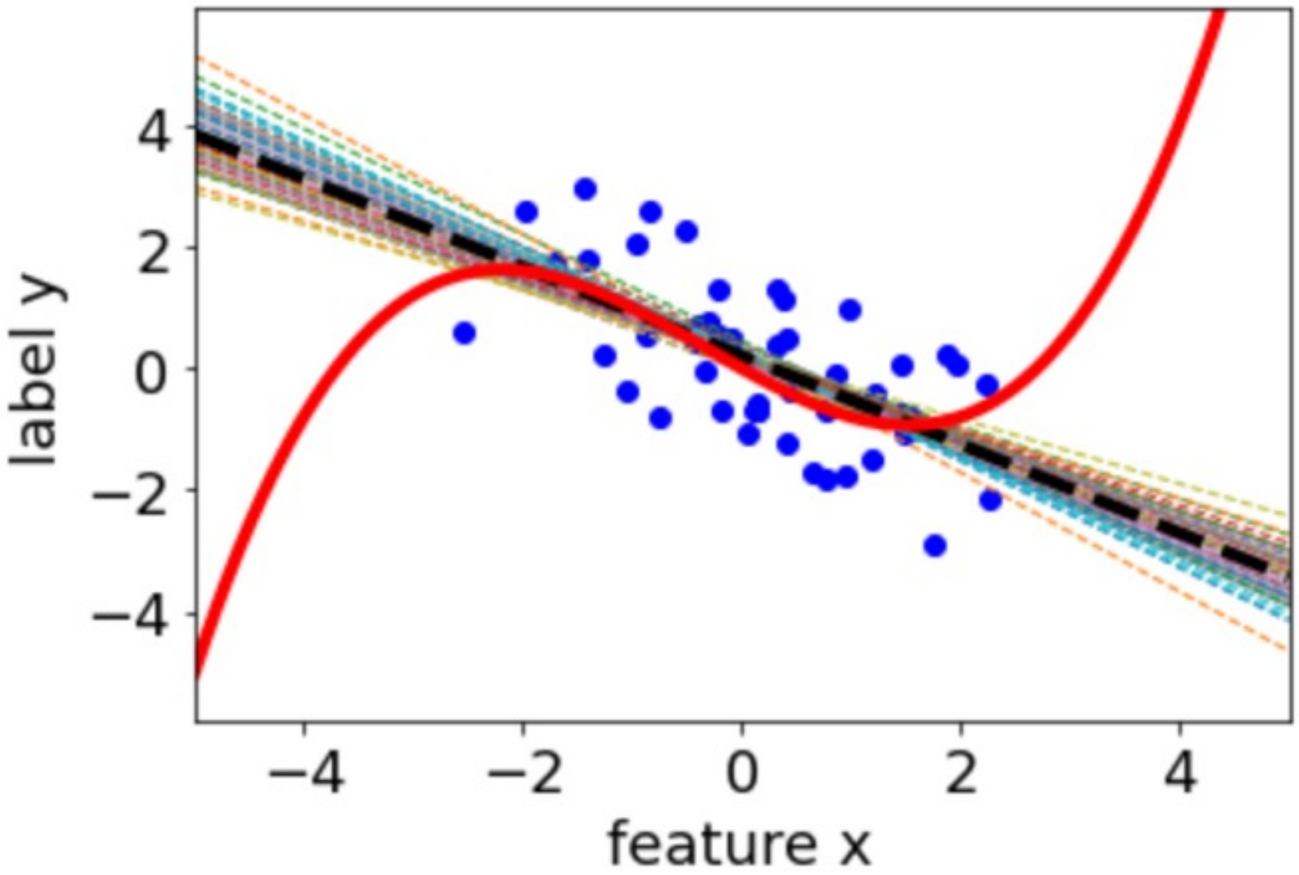


"Prediction Error = Bias + Variance"

bias reduction typically incurs variance increase and vice versa

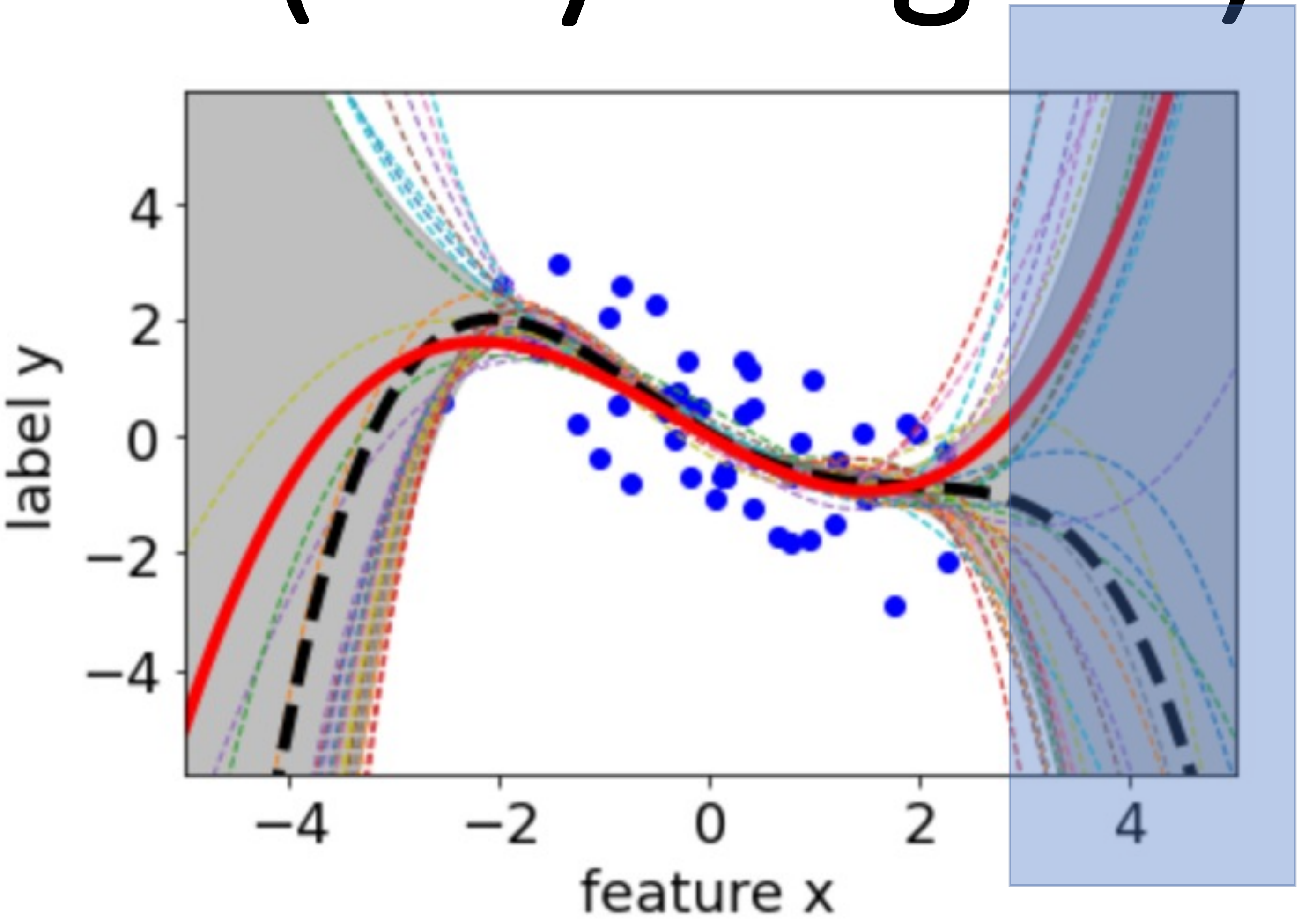
Smaller Model (Poly.Degree)

- small variance
- large bias

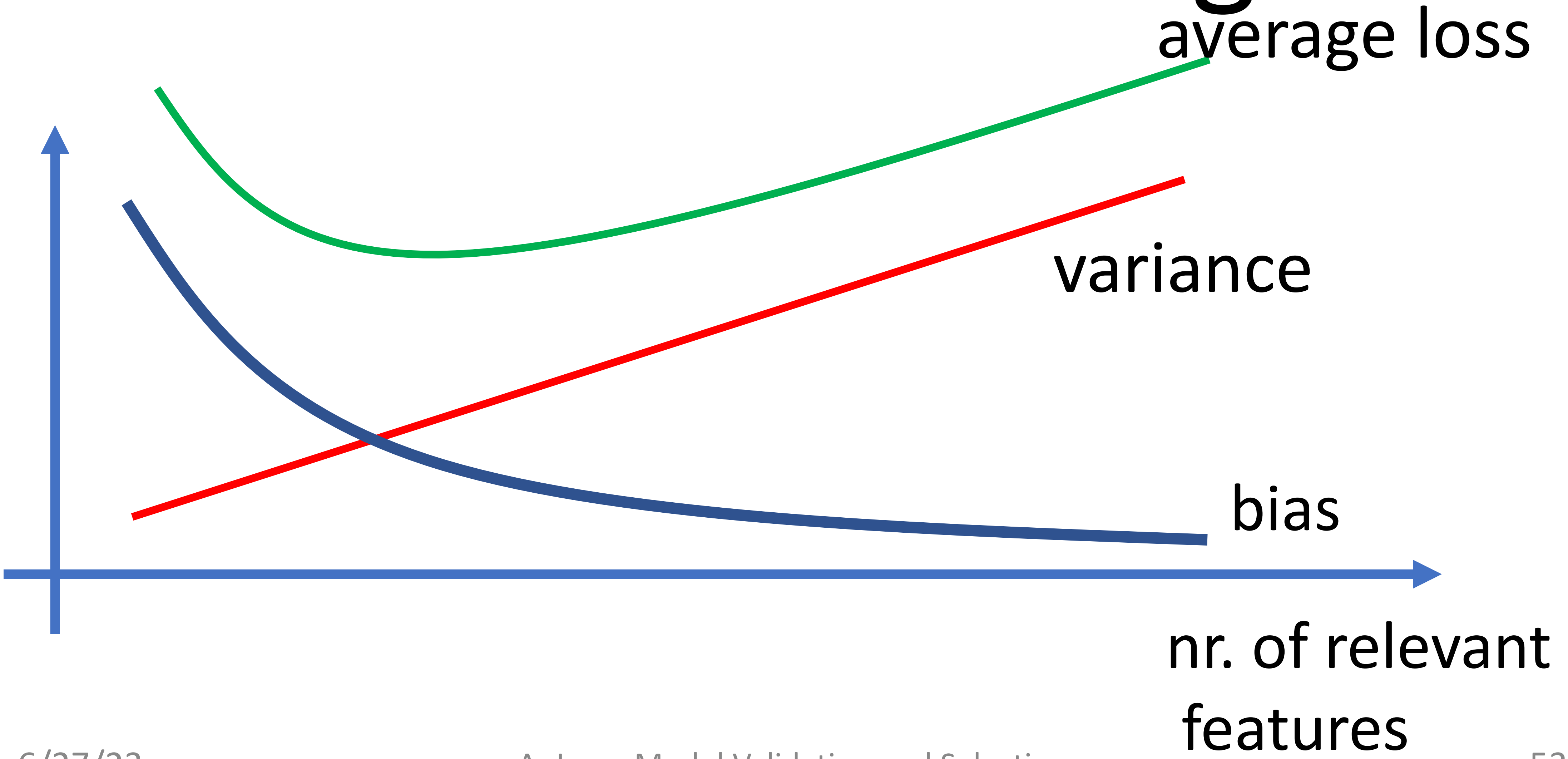


Larger Model (Poly. Degree)

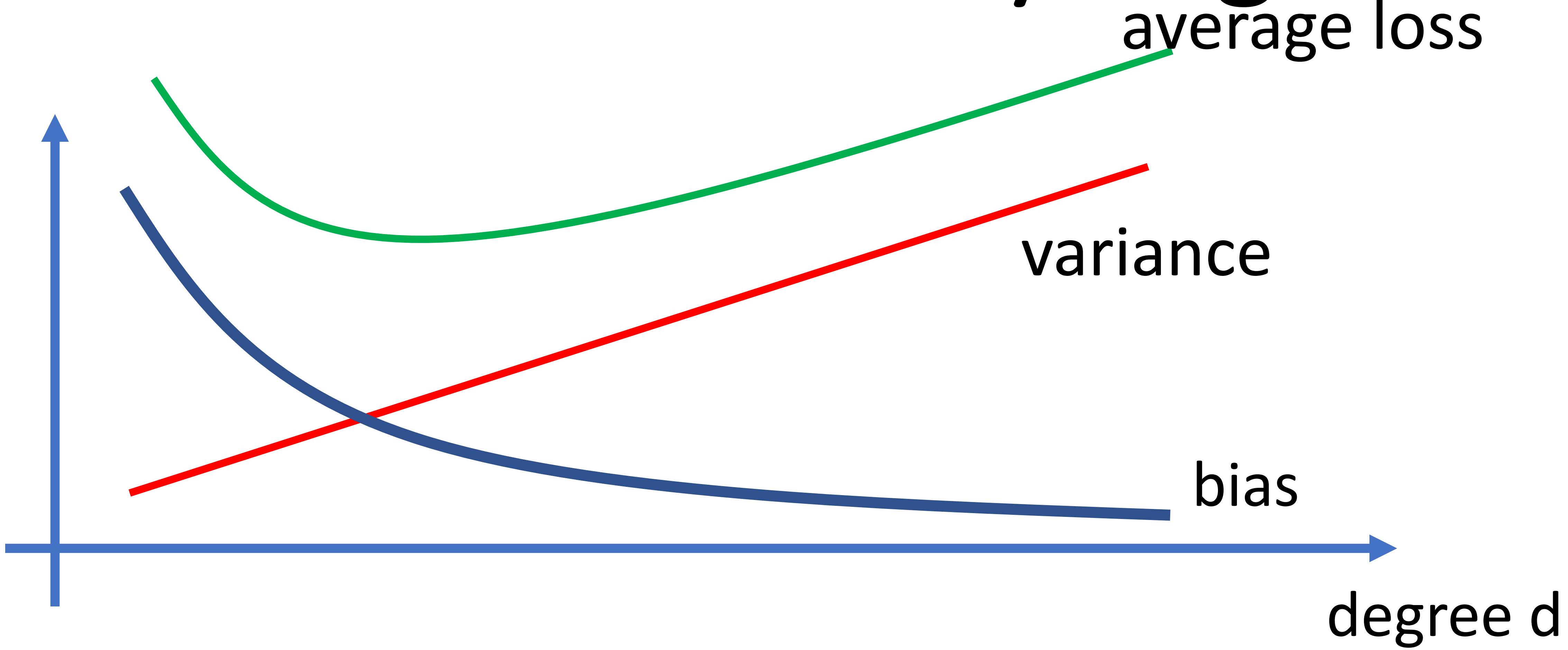
- large variance
- small bias



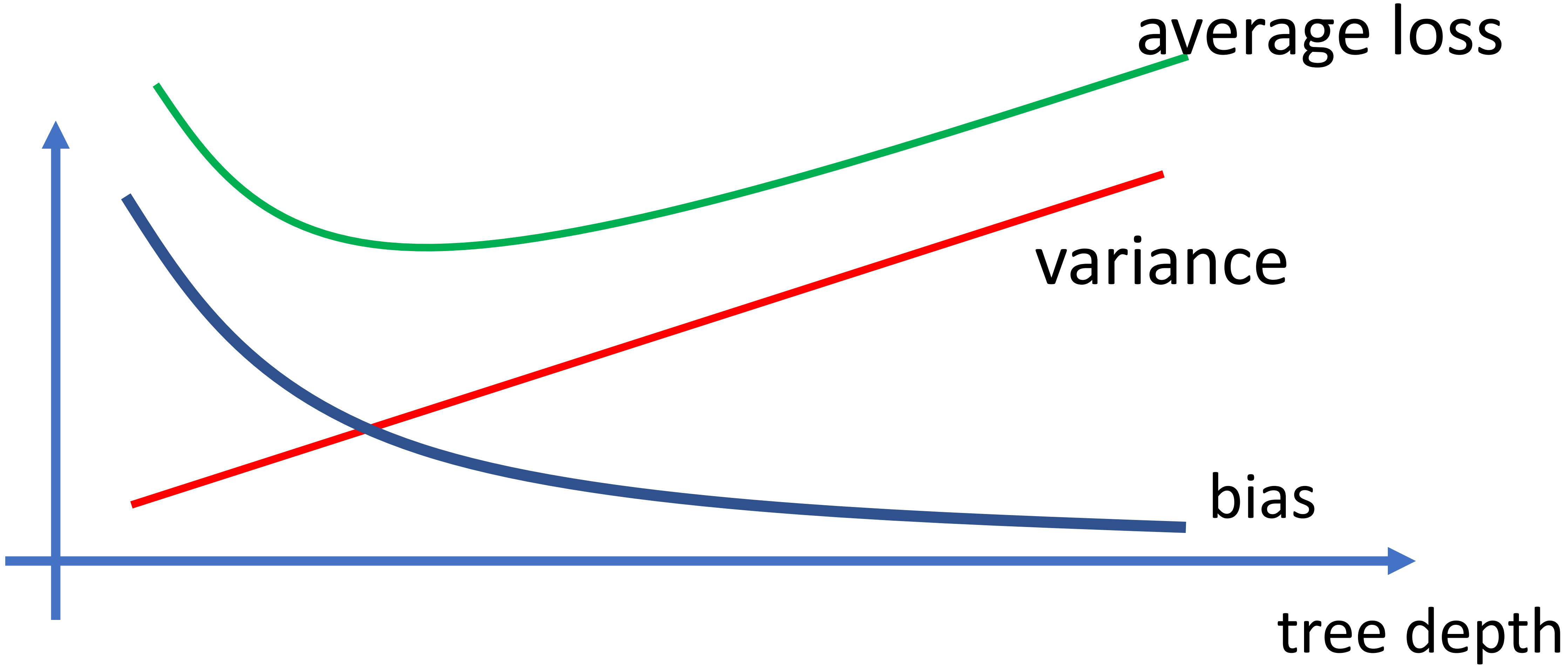
Bias vs. Variance Lin.Reg.



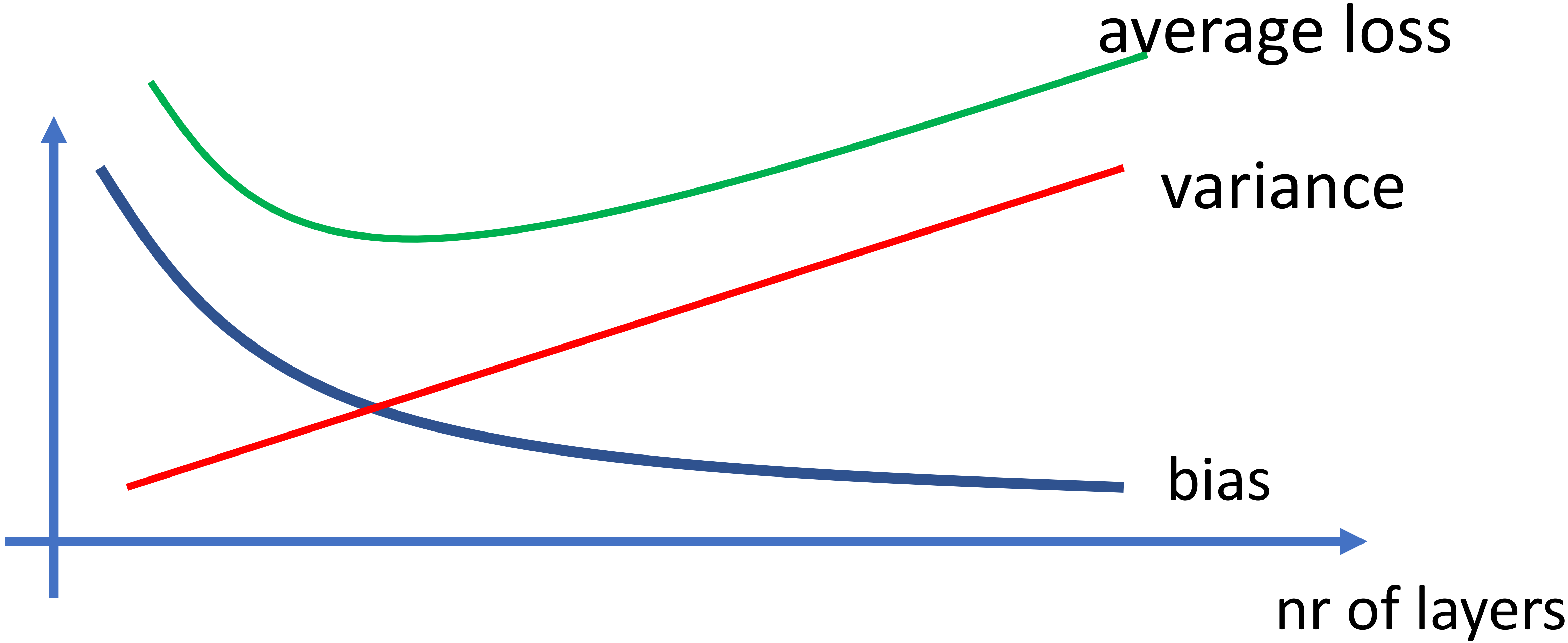
Bias vs. Variance Poly.Reg.



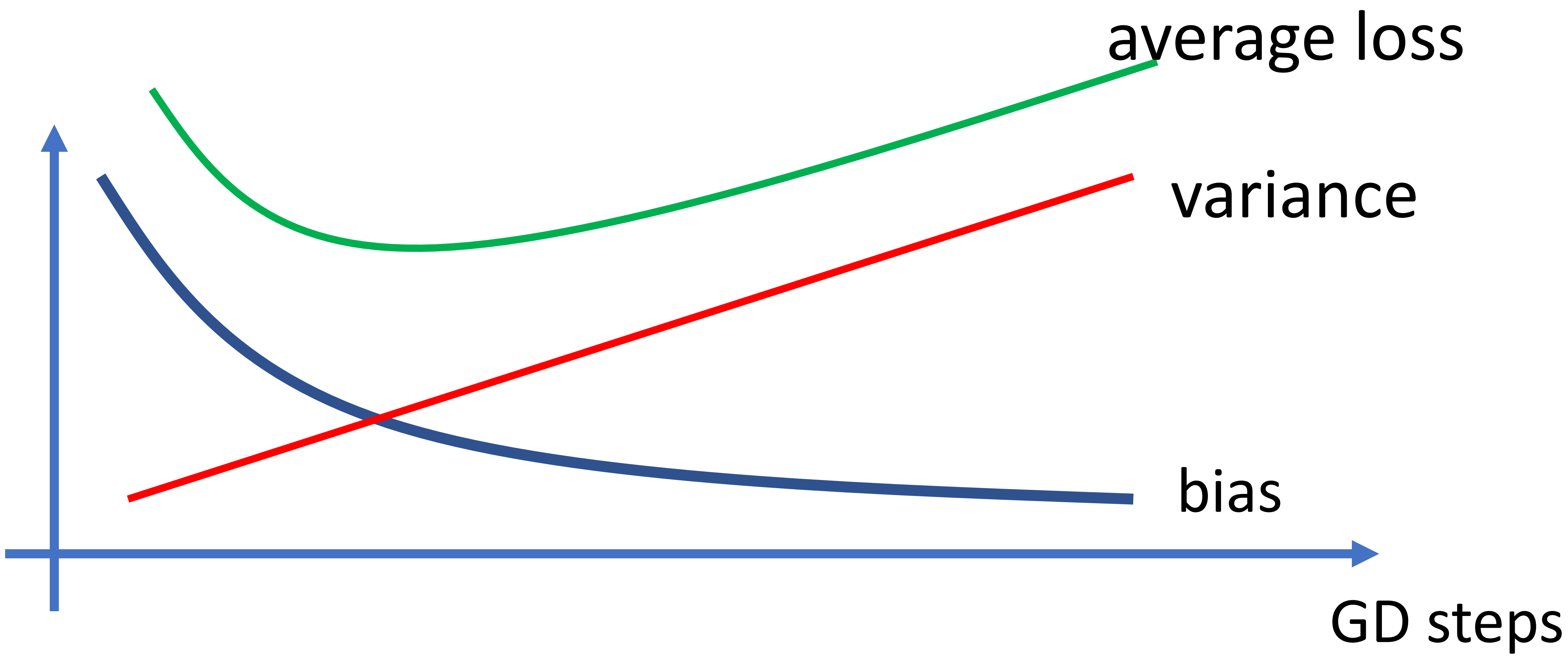
Bias vs. Variance Dec. Tree.



Bias vs. Variance Deep Learning

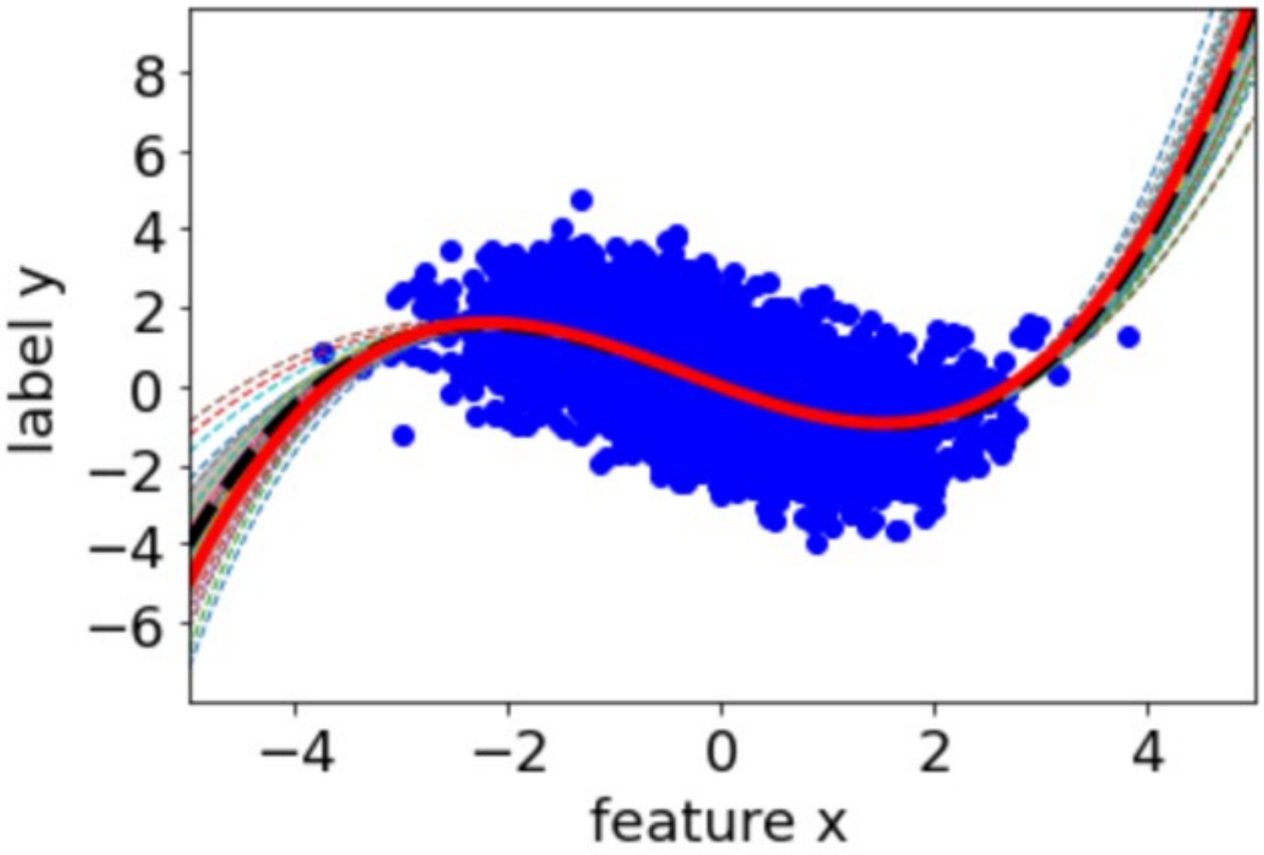


Bias vs. Variance Grad. Desc.



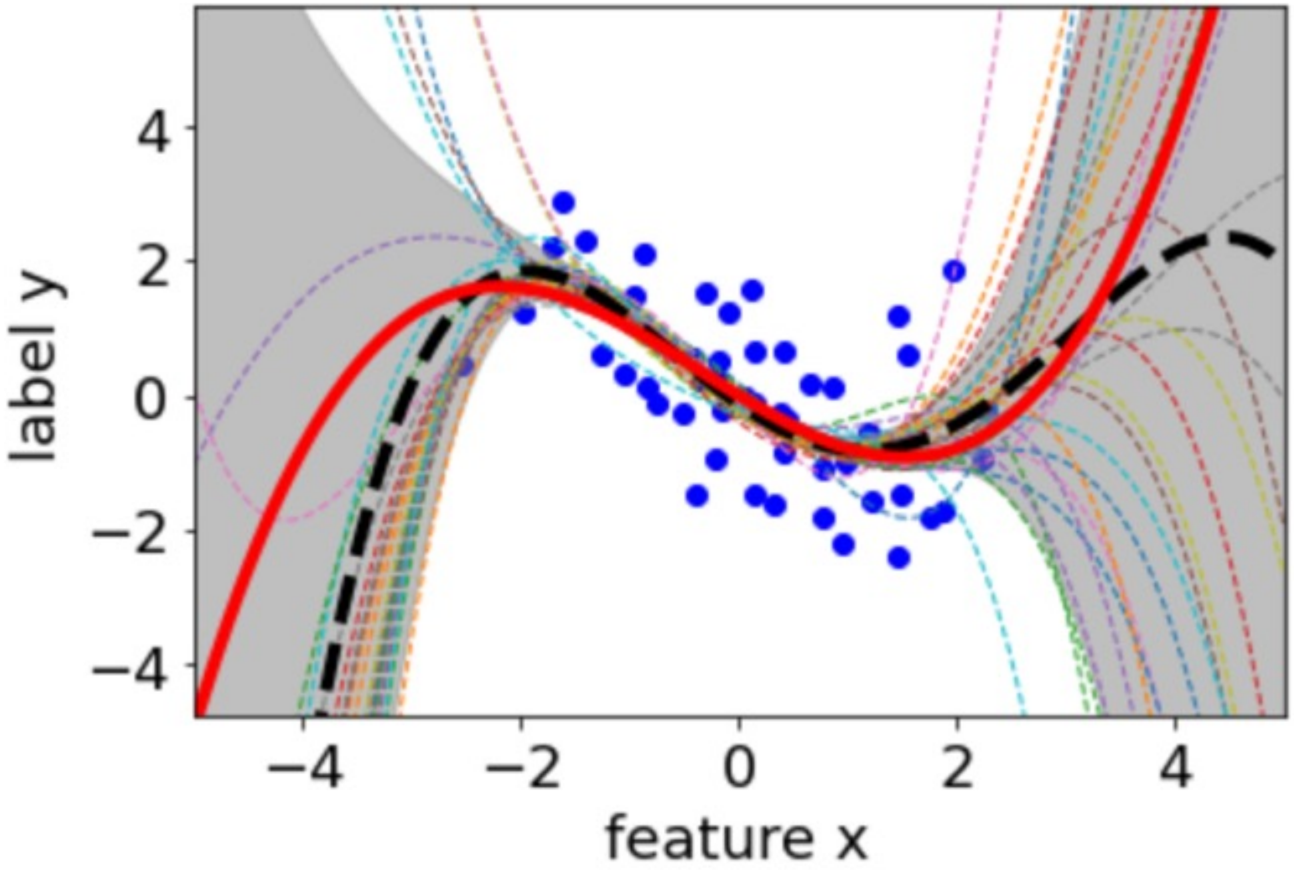
More Data

-> smaller variance

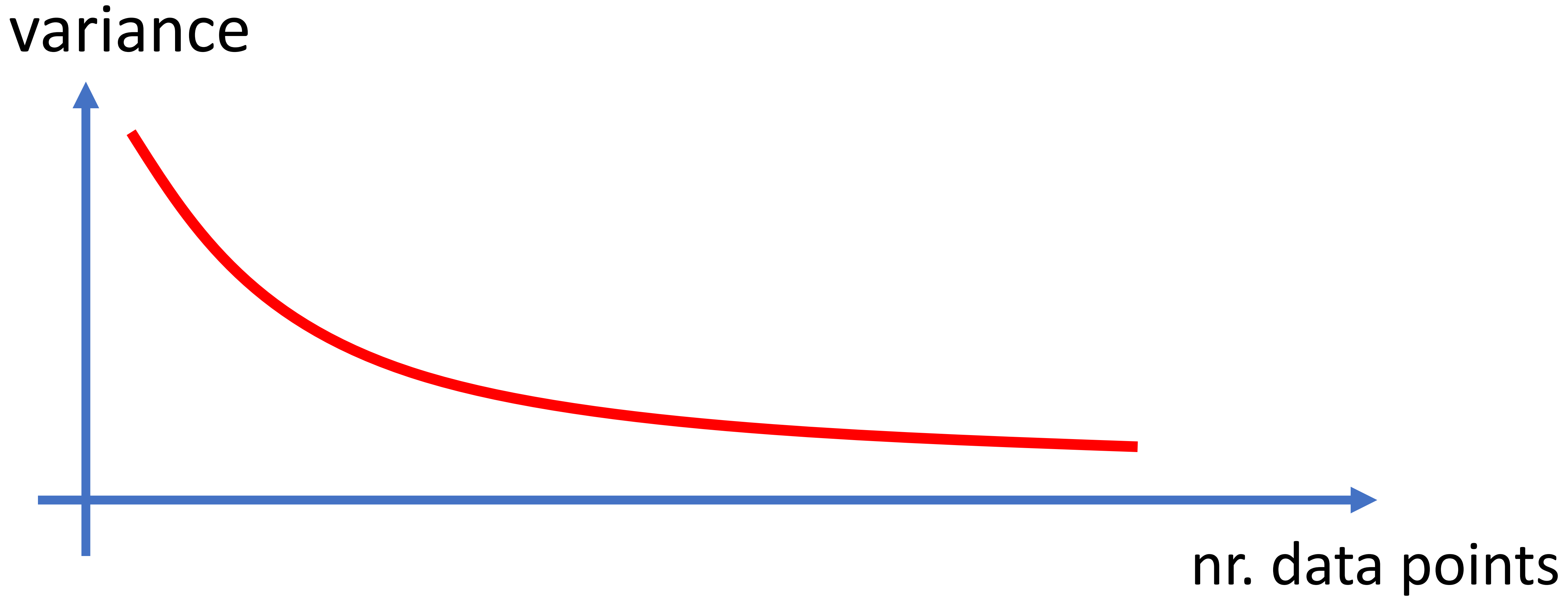


Less Data

-> larger variance



Learning Curve



Alex’ Rule of Thumb

effective number of training data points

>

10 * nr. tunable effective model parameters

stretch the term “effective” as much as possible !

ML Diagnosis

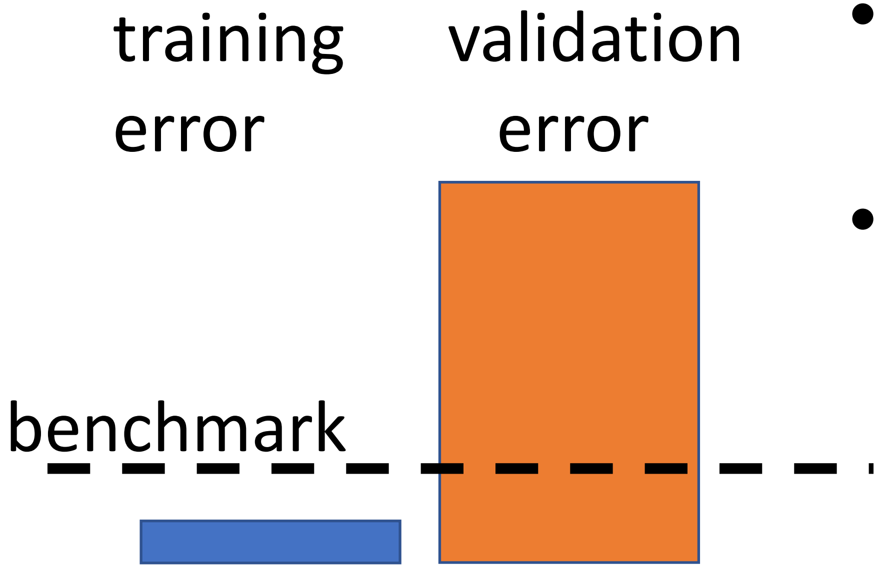
Simple Recipe

- consider ML method with some hypothesis space
- learn hypothesis by min. average loss on train.set
- training error = average loss of learnt hypothesis
- compute validation error
- compare val err, train err with a baseline

Benchmark/Baseline

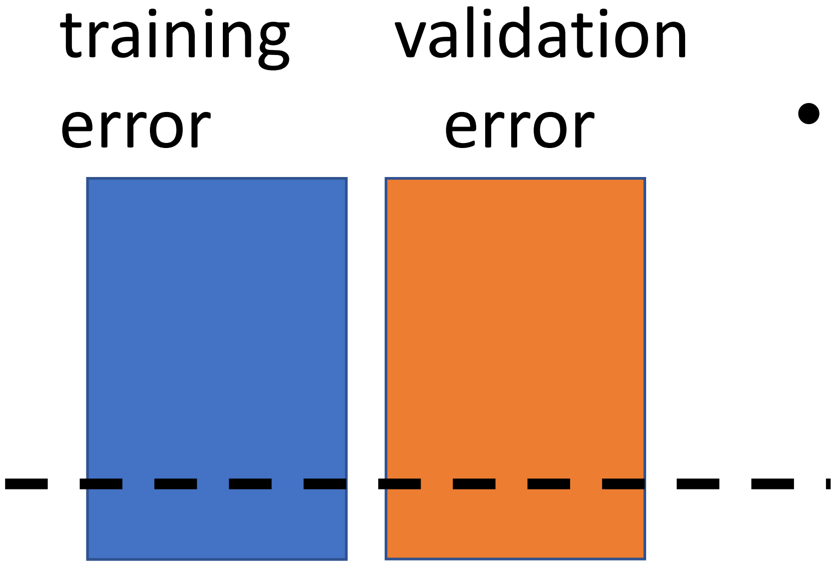
could be obtained from

- probabilistic models
- domain expertise
- existing ML methods
- human performance
- …

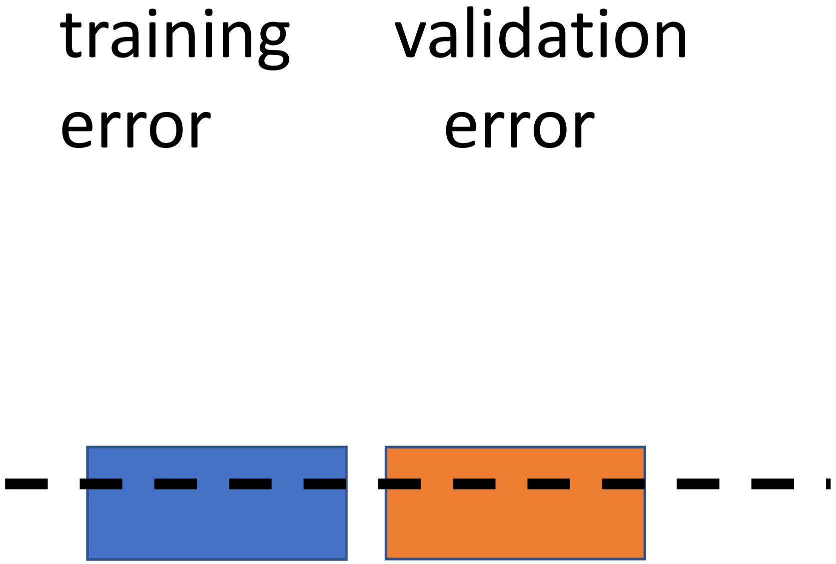


- small train error -> hypothesis space is large
- large val err -> overfitting

- Workaround ?



- large train error -> no good hypothesis found
- Workaround ?



- Case Solved !

Take Home Messages

- large models (e.g. deep nets) often overfit
- small training error does not mean much!
- diagnosis by comparing train/val err
- bias/variance analysis can guide model improvement

Thank You !