

Introduction to Machine Learning

ML-Basics: Models & Parameters

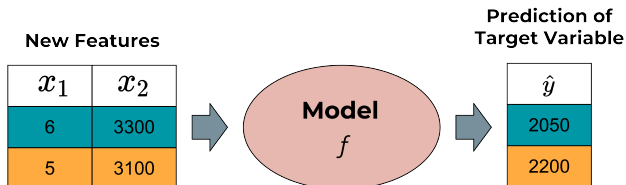
WHAT IS A MODEL?

- A **model** (or **hypothesis**)

$$f : \mathcal{X} \rightarrow \mathbb{R}^g$$

is a function that maps feature vectors to predicted target values.

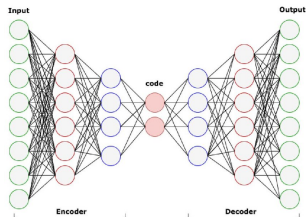
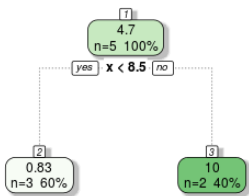
- Loosely speaking: if f is fed a set of features, it will output the target corresponding to these feature values under our hypothesis.



In conventional regression we will have $g = 1$; for classification g equals the number of classes, and output vectors are scores or class probabilities (details later).

WHAT IS A MODEL?

- f is meant to capture intrinsic patterns of the data, the underlying assumption being that these hold true for *all* data drawn from \mathbb{P}_{xy} .
- It is easily conceivable how models can range from super simple (e.g., tree stumps) to reasonably complex (e.g., variational autoencoders), and how there is an infinite number of them.



- In fact, machine learning requires **constraining** f to a certain type of functions.

HYPOTHESIS SPACES

- Without restrictions on the functional family, the task of finding a “good” model among all the available ones is impossible to solve.
- This means: we have to determine the class of our model *a priori*, thereby narrowing down our options considerably.
- The set of functions defining a specific model class is called a **hypothesis space** \mathcal{H} :

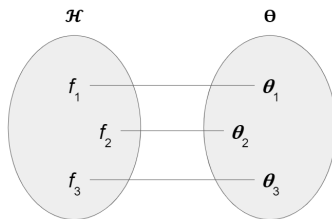
$$\mathcal{H} = \{f : f \text{ belongs to a certain functional family}\}$$

PARAMETERS OF A MODEL

- All models within one hypothesis space share a common functional structure.
- In fact, the only aspect in which they differ is the values of **parameters**.
- We usually subsume all these parameters in a **parameter vector** $\theta = (\theta_1, \theta_2, \dots)$ from a **parameter space** Θ .
- They are our means of configuration: once set, our model is fully determined.

PARAMETERS OF A MODEL

- This means: finding the optimal model is perfectly equivalent to finding the optimal set of parameter values.
- The bijective relation between optimization over $f \in \mathcal{H}$ and optimization over $\theta \in \Theta$ allows us to operationalize our search for the best model via the search for the optimal value on a p -dimensional parameter surface.

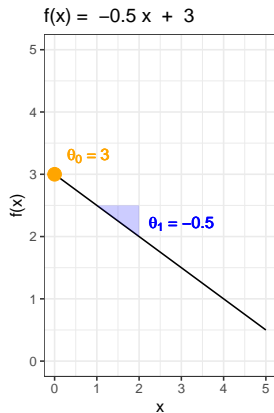
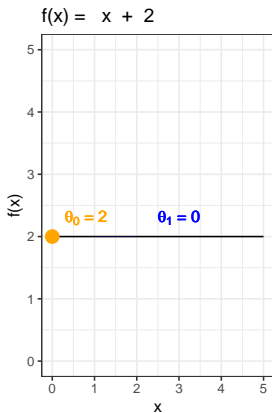
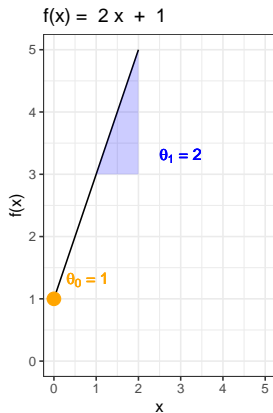


- θ might be scalar or comprise thousands of parameters, depending on the complexity of our model.

EXAMPLES FOR HYPOTHESIS SPACES

Example 1: Hypothesis space of univariate linear functions

$$\mathcal{H} = \{f : f(\mathbf{x}) = \boldsymbol{\theta}^T \mathbf{x} = \theta_0 + \theta_1 x, \boldsymbol{\theta} \in \mathbb{R}^2\}$$



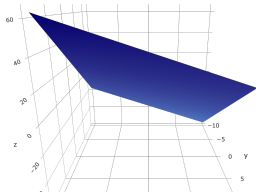
EXAMPLES FOR HYPOTHESIS SPACES

Example 2: Hypothesis space of bivariate quadratic functions

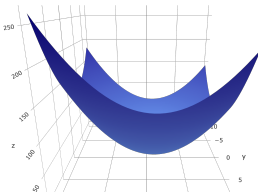
$$\mathcal{H} = \{f : f(\mathbf{x}) = \theta_0 + \mathbf{P}\mathbf{x}^T + \mathbf{xQx}^T = \\ = \theta_0 + \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_1^2 + \theta_4 x_2^2 + 2\theta_5 x_1 x_2, \theta \in \mathbb{R}^6\},$$

where $P = (\theta_1 \ \theta_2)$ and $Q = \begin{pmatrix} \theta_3 & \theta_5 \\ \theta_5 & \theta_4 \end{pmatrix}$.

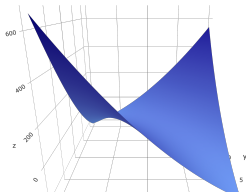
$$f(x) = 3 + 2x_1 + 4x_2$$



$$f(x) = 3 + 2x_1 + 4x_2 + \\ + 1x_1^2 + 1x_2^2$$



$$f(x) = 3 + 2x_1 + 4x_2 + \\ + 1x_1^2 + 1x_2^2 + 4x_1 x_2$$



EXAMPLES FOR HYPOTHESIS SPACES

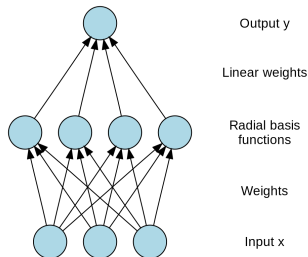
Example 3: Hypothesis space of radial basis function networks with Gaussian basis functions

$$\mathcal{H} = \left\{ f : f(\mathbf{x}) = \sum_{i=1}^n a_i \rho(\|\mathbf{x} - \mathbf{c}_i\|) \right\},$$

where

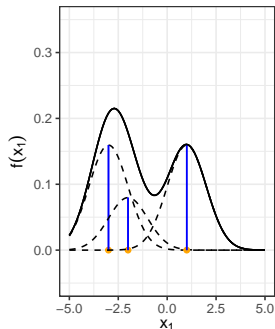
- a_i is the weight of the i -th neuron,
- \mathbf{c}_i its center vector, and
- $\rho(\|\mathbf{x} - \mathbf{c}_i\|) = \exp(-\beta\|\mathbf{x} - \mathbf{c}_i\|^2)$ is the i -th radial basis function with bandwidth $\beta \in \mathbb{R}$.

Usually, the number of centers, n , and the bandwidth β need to be set in advance (so-called *hyperparameters*).



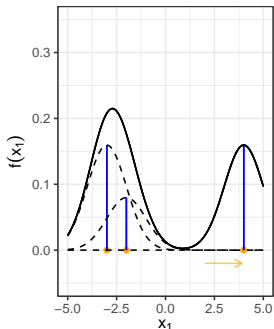
EXAMPLES FOR HYPOTHESIS SPACES

Exemplary setting



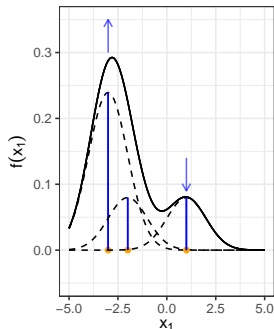
- $a_1 = 0.4$
 $a_2 = 0.2$
 $a_3 = 0.4$
- $c_1 = -3$
 $c_2 = -2$
 $c_3 = 1$

Centers altered



- $a_1 = 0.4$
 $a_2 = 0.2$
 $a_3 = 0.4$
- $c_1 = -3$
 $c_2 = -2$
 $c_3 = 4$

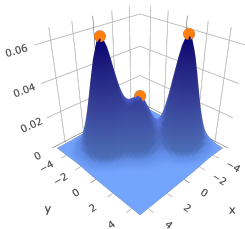
Weights altered



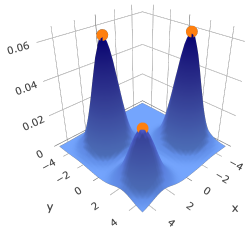
- $a_1 = 0.6$
 $a_2 = 0.2$
 $a_3 = 0.2$
- $c_1 = -3$
 $c_2 = -2$
 $c_3 = 1$

EXAMPLES FOR HYPOTHESIS SPACES

Exemplary setting



Centers altered



Weights altered

