

## Exercise 1: Risk Minimization and Gradient Descent

This exercise builds upon the previous exercise sheet.

- (a) Write a function implementing a gradient descent routine for the optimization of the linear model defined in the previous exercise sheet. Start with:

```
#' @param step_size the step_size in each iteration
#' @param X the feature input matrix X
#' @param y the outcome vector y
#' @param beta a starting value for the coefficients
#' @param eps a small constant measuring the changes in each update step.
#' Stop the algorithm if the estimated model parameters do not change
#' more than \code{eps}.

#' @return a set of optimal coefficients beta
gradient_descent <- function(step_size, X, y, beta, eps = 1e-8){

  # >>> do something <<<

  return(beta)

}
```

- (b) Run a small simulation study by creating 20 data sets as indicated below and test different step sizes  $\alpha$  (fixed across iterations) against each other and against the state-of-the-art routine for linear models (in R, using the function `lm`, in Python, e.g., `sklearn.linear_model.LinearRegression`).

- Compare the difference in estimated coefficients  $\beta_j, j = 1, \dots, p$  using the mean squared error, i.e.

$$p^{-1} \sum_{j=1}^p (\beta_j^{\text{truth}} - \hat{\beta}_j)^2$$

and summarize the difference over all 20 simulation repetitions.

- Compare the run times of your implementation and the one given by the state-of-the-art method by wrapping the function calls into a timer (e.g., `system.time()` in R).

```
# settings
n <- 10000
p <- 100
nr_sims <- 20

# create data (only once)
X <- matrix(rnorm(n*p), ncol=p)
beta_truth <- runif(p, -2, 2)
f_truth <- X%%beta_truth

# create result object
result_list <- vector("list", nr_sims)

for(sim_nr in nr_sims)
```

```

{
  # create response
  y <- f_truth + rnorm(n, sd = 2)

  # >>> do something <<<

  # save results in list (performance, time)
  result_list[[sim_nr]] <- add_something_meaningful_here
}

```

- (c) Why is gradient descent maybe not the best option for optimization of a linear model with  $L2$  loss? What other options exist? Name at least one and describe how you would apply this for the above problem.
- (d) Can we say something about the algorithm's consistency w.r.t.  $\mathbb{P}_{xy}$ , if  $f^* \notin \mathcal{H}$ ?