Exercise 7

1. **a) Quadratic Discriminant Analysis (QDA)**
   Assume the normal model $X|Y = j \sim \mathcal{N}_p(\mu_j, \Sigma_j)$, $\mathbb{P}[Y = j] = p_j$, $\sum_{j=0}^{J-1} p_j = 1$.
   Show that (6.2) and (6.4) lead to

$$\hat{\delta}_j^{QDA}(x) = -\log(\det(\hat{\Sigma}_j))/2 - (x - \hat{\mu}_j)^\intercal \hat{\Sigma}_j^{-1}(x - \hat{\mu}_j)/2 + \log(\hat{p}_j).$$

   b) Linear Discriminant Analysis (LDA)
   Use the result from a) and replace $\hat{\Sigma}_j$ by $\hat{\Sigma}$ to get

$$\begin{aligned} \hat{\delta}_j^{LDA}(x) &= x^\intercal \hat{\Sigma}^{-1} \hat{\mu}_j - \hat{\mu}_j{}^\intercal \hat{\Sigma}^{-1} \hat{\mu}_j/2 + \log(\hat{p}_j) \\ &= (x - \hat{\mu}_j/2)^\intercal \hat{\Sigma}^{-1} \hat{\mu}_j + \log(\hat{p}_j). \end{aligned} \tag{1}$$

   c) The LDA decision function can be written as (see (1) above)

$$\hat{\delta}_j(x) = x^\intercal b_j + c_j,$$

   where $b_j \in \mathbb{R}^p$ and $c_j \in \mathbb{R}$. Assume that we only have two classes ($j = 0, 1$). Use the equation above to characterize the decision boundary.

   d) Small Simulation
   Use the R-code below to get an idea about how LDA works. Change the covariance matrix and mean vectors if you like.
   Manually calculate (see c)) the boundary between group 1 and 2. Add your solution to the plot with `abline()`.
   Hint:
   If `A <- fit$scaling` it holds (in the case of $p+1$ groups in $\mathbb{R}^p$) that $\hat{\Sigma}^{-1} = AA^\intercal$. The means and prior probabilites can also be found in the `lda`-object.
   R-Code:

```
library(mvtnorm) ## Needed for rmvnorm
library(MASS) ## Needed for lda/qda
source("http://stat.ethz.ch/teaching/lectures/aktuell/CompStat/predplot.R")
  ## Needed for predplot
## Covariance Matrix
sigma <- cbind(c(0.5, 0.3), c(0.3, 0.5))
## Mean vectors
mu1 <- c(3, 1.5)
mu2 <- c(4, 4)
mu3 <- c(8.5, 2)
m <- matrix(0, nrow = 300, ncol = 3)
## Grouping vector
m[,3] <- rep(1:3, each = 100)
## Simulate data
m[1:100,1:2] <- rmvnorm(n = 100, mean = mu1, sigma = sigma)
m[101:200,1:2] <- rmvnorm(n = 100, mean = mu2, sigma = sigma)
m[201:300,1:2] <- rmvnorm(n = 100, mean = mu3, sigma = sigma)
```

```
m <- data.frame(m)
## Perform LDA
fit <- lda(x = m[,1:2], grouping = m[,3])
## Plot the decision boundaries
predplot(fit, m)
```

Preliminary discussion: Friday, May 27, 2005. **Deadline:** Friday, June 3, 2005.

Advice: Thursdays from 12.00-13.00, LEO C12.1, Leonhardstr. 27. Or contact either Maik Berchtold, `berchtld@stat.math.ethz.ch`, or Lukas Meier, `meier@stat.math.ethz.ch`.