Exercise Sheet 10

Machine Learning 2, SS16

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Exercise 1

The Lagrangian of the given primal problem is:

$$\mathcal{L}(R,c,\xi,\alpha,\lambda) = R^2 + \frac{1}{n\nu}\sum_i \xi_i - \sum_i \alpha_i(R^2 + \xi_i - \|\phi(x_i) - c\|) - \sum_i \lambda_i \xi_i$$
$$= R^2 + \frac{1}{n\nu}\sum_i \xi_i - \sum_i \alpha_i(R^2 + \xi_i - (\phi(x_i)^\top\phi(x_i) + c^\top c - 2c^\top\phi(x_i))) - \sum_i \lambda_i \xi_i$$
$$= R^2 + \frac{1}{n\nu}\sum_i \xi_i - \sum_i \alpha_i(R^2 + \xi_i - \phi(x_i)^\top\phi(x_i) - c^\top c + 2c^\top\phi(x_i)) - \sum_i \lambda_i \xi_i$$

We now differentiate w.r.t. primal variables R, c, ξ:

$$\frac{\partial}{\partial R}\mathcal{L}(R,c,\xi,\alpha,\lambda) = 2R - 2R\sum_i \alpha_i \stackrel{!}{=} 0 \qquad \Longrightarrow \qquad \sum_i \alpha_i = 1$$
$$\frac{\partial}{\partial c}\mathcal{L}(R,c,\xi,\alpha,\lambda) = 2c\sum_i \alpha_i - 2\sum_i \alpha_i\phi(x_i) \stackrel{!}{=} 0 \qquad \Longrightarrow \qquad c = \sum_i \alpha_i\phi(x_i)$$
$$\frac{\partial}{\partial \xi_i}\mathcal{L}(R,c,\xi,\alpha,\lambda) = \frac{1}{n\nu} - \alpha_i - \lambda_i \stackrel{!}{=} 0 \qquad \Longrightarrow \qquad \frac{1}{n\nu} = \alpha_i + \lambda_i$$

The Lagrangian of the dual problem then can be obtained by plugging in the derived results:

$$\mathcal{L}(\alpha,\lambda) = R^2 + \frac{1}{n\nu}\sum_i \xi_i - \sum_i \alpha_i(R^2 + \xi_i - \phi(x_i)^\top\phi(x_i) - c^\top c + 2c^\top\phi(x_i)) - \sum_i \lambda_i \xi_i$$
$$= \cancel{R^2} + \frac{1}{n\nu}\sum_i \xi_i - \cancel{R^2}\underbrace{\cancel{\sum_i \alpha_i}}_{1} - \sum_i \alpha_i\xi_i + \sum_i \alpha_i k(x_i,x_i) + c^\top c\underbrace{\sum_i \alpha_i}_{1} - 2c^\top\sum_i \alpha_i\phi(x_i) - \sum_i \lambda_i\xi_i$$
$$= \cancel{\frac{1}{n\nu}\sum_i \xi_i} - \cancel{\sum_i \underbrace{(\alpha_i + \lambda_i)}_{\frac{1}{n\nu}}\xi_i} + \sum_i \alpha_i k(x_i,x_i) + c^\top c - 2c^\top \underbrace{\sum_i \alpha_i\phi(x_i)}_{c}$$
$$= \sum_i \alpha_i k(x_i,x_i) - c^\top c$$

Lastly, by using the definition of c, we obtain the dual program:

$$\max_\alpha \sum_i \alpha_i k(x_i,x_i) - \sum_i\sum_j \alpha_i\alpha_j k(x_i,x_j)$$
$$\text{s.t.} \qquad \sum_i \alpha_i = 1 \quad \text{and} \quad \alpha_i \geq 0 \quad \text{and} \quad \lambda_i \geq 0 \quad \text{and} \quad \alpha_i + \lambda_i = \frac{1}{n\nu}$$
$$\Longrightarrow \max_\alpha \sum_i \alpha_i k(x_i,x_i) - \sum_i\sum_j \alpha_i\alpha_j k(x_i,x_j) \qquad \text{s.t.} \qquad \sum_i \alpha_i = 1 \quad \text{and} \quad \frac{1}{n\nu} \geq \alpha_i \geq 0$$

The primal variable c is determined by $c = \sum_i \alpha_i\phi(x_i)$. R, the support vectors, then can be found by using the constraint of the primal problem (by finding the points on the gutter, i.e. solving $\|\phi(x_i) - c\| = R$).

Exercise 2

Form of the QP problem:

$$\min_{\alpha} \alpha^\top P \alpha + q^\top \alpha \qquad \text{s.t.} \quad G\alpha \preceq h \quad \text{and} \quad A\alpha = b$$

The objective of the dual problem can be further derived like this:

$$\max_{\alpha} \mathcal{L}(\alpha) = \max_{\alpha} \sum_i \alpha_i k(x_i, x_i) - \sum_i \sum_j \alpha_i \alpha_j k(x_i, x_j) \qquad \text{s.t.} \qquad \sum_i \alpha_i = 1 \quad \text{and} \quad \frac{1}{n\nu} \geq \alpha_i \geq 0$$

$$\Longrightarrow \min_{\alpha} -\mathcal{L}(\alpha) = \min_{\alpha} \sum_i \sum_j \alpha_i \alpha_j k(x_i, x_j) - \sum_i \alpha_i k(x_i, x_i) \qquad \text{s.t.} \qquad \sum_i \alpha_i = 1 \quad \text{and} \quad \frac{1}{n\nu} \geq \alpha_i \geq 0$$

The variables can now be identified as follows:

$$P \hat{=} (K(x_i, x_j))_{i,j} \qquad q \hat{=} -(K(x_i, x_i))_i \qquad G \hat{=} \begin{bmatrix} \mathbf{I}_n \\ \textbf{-}\mathbf{I}_n \end{bmatrix}$$

$$h \hat{=} \frac{1}{n\nu} \begin{bmatrix} \vec{\mathbb{1}}_n \\ \vec{0}_n \end{bmatrix} \qquad A \hat{=} \begin{bmatrix} 1 & \dots & 1 \\ \phi(x_1) & \dots & \phi(x_n) \end{bmatrix} \qquad b \hat{=} \begin{bmatrix} 1 \\ \vec{c} \end{bmatrix}$$