Situation: We have n data points $(x_i, y_i),\ i = 1, ..., n$ with $x_i \in \mathbb{R}^d$ and $y \in \{-1, 1\}$.

Probit Model: y_i is a realization of the random variable Y_i. $Y_1, ..., Y_n$ are independent. The distribution of Y_i is as follows:

$$P(Y_i = 1|x_i; \beta) = \Phi(x_i^T \beta)$$
$$P(Y_i = -1|x_i; \beta) = 1 - \Phi(x_i^T \beta)$$

where $\beta \in \mathbb{R}^d$. It follows that

$$P(Y_i = y_i|x_i; \beta) = \Phi(y_i x_i^T \beta)$$

Likelihood: The likelihood of a parameter vector β is given as follows:

$$L(\beta) = \prod_{i=1}^{n} P(Y_i = y_i|x_i; \beta) = \prod_{i=1}^{n} \Phi(y_i x_i^T \beta)$$

The negative log-likelihood that we wish to minimize is:

$$\mathcal{L}(\beta) = -\sum_{i=1}^{n} \log \Phi(y_i x_i^T \beta)$$

The weighted case: We introduce sample weights $w_i \in \mathbb{R}_{>0}$ comprising a weight vector $w \in \mathbb{R}^n_{>0}$. The weights sum to 1, i.e. $\sum_{i=1}^n w_i = 1$. Further, let $g(z) = -\log \Phi(-z)$. The objective function now becomes:

$$f_w(\beta) = \sum_{i=1}^{n} w_i g(-y_i x_i^T \beta)$$

To make the notation easier, we define $z_i = -y_i x_i^T$ and introduce the matrix $Z \in \mathbb{R}^{n \times d}$ with row vectors $Z_i = z_i$. This gives us:

$$f_w(\beta) = \sum_{i=1}^{n} w_i g(z_i \beta)$$

Lemma 1. *Let $g(z) = -\log \Phi(-z)$. Then it holds for all $z \geq 0$ that:*

$$\frac{1}{2} z^2 \leq g(z)$$

For all $z \geq 2$ it holds that:

$$g(z) \leq 2z^2$$

Proof. TODO. □

Definition 1. *Let $Z \in \mathbb{R}^{n\times d}$. Then we define*

$$\mu_w(Z) = \sup_{\beta\in\mathbb{R}^d\setminus\{0\}} \frac{\|(D_w Z\beta)^+\|_2^2}{\|(D_w Z\beta)^-\|_2^2} = \sup_{\beta\in\mathbb{R}^d\setminus\{0\}} \frac{\|(D_w Z\beta)^-\|_2^2}{\|(D_w Z\beta)^+\|_2^2}$$

Z weighted by w is called μ-complex if $\mu_w(Z) \leq \mu$.

Lemma 2. *Let $Z \in \mathbb{R}^{n\times d}$ weighted by $w \in \mathbb{R}^n_{>0}$ be μ-complex. Let U be an orthonormal basis for the columnspace of $D_w Z$. If for index i, the supreme β in (TODO) satisfies $2 \leq z_i\beta$, then $w_i g(z_i\beta) \leq$ something.*

Proof. Let $D_w Z = UR$, where U is an orthonormal basis for the columnspace of $D_w Z$. It follows from $2 \leq z_i\beta$ and from the monotonicity of g that

$$\begin{aligned}
w_i g(z_i\beta) &= w_i g\left(\frac{w_i z_i \beta}{w_i}\right) = w_i g\left(\frac{U_i R\beta}{w_i}\right) \leq w_i g\left(\frac{\|U_i\|_2\|R\beta\|_2}{w_i}\right)\\
&= w_i g\left(\frac{\|U_i\|_2\|UR\beta\|_2}{w_i}\right) = w_i g\left(\frac{\|U_i\|_2\|D_w Z\beta\|_2}{w_i}\right)\\
&\leq \frac{2}{w_i}\|U_i\|_2^2\|D_w Z\beta\|_2^2 \leq \frac{2}{w_i}\|U_i\|_2^2(1+\mu)\|(D_w Z\beta)^+\|_2^2\\
&= \frac{2}{w_i}\|U_i\|_2^2(1+\mu)\sum_{j:\ w_j z_j\beta\geq 0} w_j^2(z_j\beta)^2\\
&\leq \frac{4}{w_i}\|U_i\|_2^2(1+\mu)\sum_{j:\ w_j z_j\beta\geq 0} w_j^2 g(z_j\beta)\\
&\leq \frac{4}{w_i}\|U_i\|_2^2(1+\mu)\sum_{j:\ w_j z_j\beta\geq 0} w_j g(z_j\beta)\\
&\leq \frac{4}{w_i}\|U_i\|_2^2(1+\mu)\sum_{j=1}^{n} w_j g(z_j\beta)\\
&= \frac{4}{w_i}\|U_i\|_2^2(1+\mu) f_w(\beta)
\end{aligned}$$

□

References