

Ex 1]

$\Psi: \mathbb{R} \rightarrow \mathbb{R}$ ,  $k$ -Lipschitz

$$F_0 = \left\{ x \mapsto w^T x + \|w\|_1 \leq B \right\}, \quad o \in F_0$$

$$F_n = \left\{ x \mapsto \Psi \left( v + \sum_{i=1}^m w_i f_i(x) \right) \mid |v| \leq V, \|w\|_1 \leq B, f_i \in F_0 \right\}$$

$$F_P = \left\{ x \mapsto \Psi \left( v + \sum_{i=1}^m w_i^* f_i(x) \right) \mid |v| \leq V, \|w\|_1 \leq B, f_i \in F_P \right\}$$

$$\text{2) } \widehat{\mathcal{B}\mathcal{R}}_n(F_n) = \mathbb{E} \left[ \sup_{\substack{|v| \leq V \\ \|w\|_1 \leq B \\ f_i \in F_0}} \frac{1}{n} \sum_{i=1}^n \varepsilon_i (v + \sum_{j=1}^m w_j^* f_j(x)) \right]$$

$$= k \left( \mathcal{B}\widehat{\mathcal{R}}_n(\text{absconv}(F_0)) + \mathbb{E} \left[ \sup_{|v| \leq V} \frac{1}{n} \sum |\varepsilon_i| v \right] \right)$$
$$\leq k (\mathcal{B}\widehat{\mathcal{R}}_n(\text{conv}(F_0 \cup (-F_0))) + \frac{V}{n} \mathbb{E} \left[ |\sum \varepsilon_i| \right])$$

$$= k \left( \mathcal{B}\widehat{\mathcal{R}}_n(F_0 \cup (-F_0)) + \frac{V}{n} \mathbb{E} \left[ \left( \sum \varepsilon_i \right)^2 \right]^{1/2} \right)$$
$$\leq k \left( \mathcal{B}\widehat{\mathcal{R}}_n(F_0 + (-F_0)) + \frac{V}{n} \mathbb{E} \left[ \left( \sum \varepsilon_i \right)^2 \right]^{1/2} \right)$$
$$= k \left( 2\mathcal{B}\widehat{\mathcal{R}}_n(F_0) + \frac{V}{n} \sqrt{n} \right)$$

$$\mathbb{E} \left[ \left( \sum \varepsilon_i \right)^2 \right] = k \left( 2\mathcal{B}\widehat{\mathcal{R}}_n(F_0) + \frac{V}{n} \right) \quad (\text{if } F_0 = -F_0 \Rightarrow k \widehat{\mathcal{R}}_n(F_0))$$
$$(F_0 \cup (-F_0) \subset F_0 + (-F_0))$$

$$= V(\sum \varepsilon_i) + \mathbb{E} \left[ \sum \varepsilon_i \right]$$

$$= \sum_{i=1}^n 1 \cdot \mathbb{E} [\varepsilon_i]$$

$$= n$$

$$2) \text{ Assume } \mathcal{X} = \{x \in \mathbb{R}^d \mid \|x\|_\infty \leq 1\}$$

$$\begin{aligned} \widehat{\mathcal{R}}_n(F_0) &= \mathbb{E} \left[ \sup_w \sum_{i=1}^n \epsilon_i w^\top x_i \right] \\ &= \mathbb{E} \left[ \sup_w w^\top \sum_{i=1}^n \epsilon_i x_i \right] \\ &\leq \mathbb{E} \left[ \sup_w \|w\|_1 \left\| \sum_{i=1}^n \epsilon_i x_i \right\|_\infty \right] \quad (\text{Holder}) \\ &\leq B \mathbb{E} \left[ \max_{1 \leq i \leq d} \left| \sum_{i=1}^n \epsilon_i x_i^{(i)} \right| \right] \\ &= B \mathbb{E} \left[ \max_{a \in A} \left| \sum_{i=1}^n \epsilon_i a_i \right| \right] \end{aligned}$$

$$\text{ou } A = \left\{ \{x_1^{(1)}, \dots, x_n^{(1)}\}, \dots, \{x_1^{(d)}, \dots, x_n^{(d)}\} \right\}$$

$$= B \mathbb{E} \left[ \max_{a \in A \cup \{0\}} \sum_{i=1}^n \epsilon_i a_i \right]$$

$$\leq B r \sqrt{2 \ln 2d}$$

$$\text{avec } r = \max_{a \in A \cup \{0\}} \|a\|_1 = \max_{a \in A} \left( \sum_{i=1}^n |a_i|^r \right)^{\frac{1}{r}} \leq \left( \sum_{i=1}^n 1^r \right)^{\frac{1}{r}} = \sqrt{n}$$

$$\Rightarrow \widehat{\mathcal{R}}_n(F_0) \leq \frac{B \sqrt{2 \ln 2d}}{\sqrt{n}}$$

3) Recurrence : ( $\Psi(-u) = -\Psi(u)$ )

Test  $F_0$ :

$$\widehat{R}_n(F_0) \leq \frac{1}{\sqrt{n}} \cdot \mathcal{D} \sqrt{2 \ln(2d)} = \frac{\mathcal{D} \sqrt{2 \ln 2d}}{\sqrt{n}} (\tilde{q}^2)$$

Supposons  $p$ . Montrons  $p+1$ :

$$\begin{aligned}
 \widehat{R}_n(F_{p+1}) &= \frac{1}{n} \mathbb{E} \left[ \sup_{\|w\|_n \leq V} \sum_{i=1}^n \varepsilon_i \Psi(v + w^\top f(x_i)) \right] \\
 &\quad \|w\|_n \leq B \\
 &\quad f_i \in F_p \\
 &= \frac{1}{n} \mathbb{E} \left[ \sup_{\|w\|_n \leq V} \sum_{i=1}^n \varepsilon_i (v + w^\top f(x_i)) \right] \text{ (Lipschitz)} \\
 &\quad \|w\|_n \leq B \\
 &\quad f_i \in F_p \\
 &\leq \frac{1}{n} \mathbb{E} \left[ \sup_{\|w\|_n \leq B} \sum_{i=1}^n \varepsilon_i w^\top f(x_i) \right] + \frac{V}{\sqrt{n}} \\
 &\quad f_i \in F_p \\
 &= \mathcal{D} \widehat{R}_n(\text{absconv}(F_p)) + \frac{V}{\sqrt{n}} \\
 &= \mathcal{D} \widehat{R}_n(F_p \cup (-F_p)) + \frac{V}{\sqrt{n}}
 \end{aligned}$$

Or, comme  $F_0 = -F_0$  et que  $\Psi$  est impaire, on peut facilement montrer par récurrence que,  $\forall p \geq 0$ ,  $F_p = -F_{p-1}$ . On obtient donc:

$$\begin{aligned}
\widehat{Q}_n(F_{P,n}) &\leq \mathfrak{B} Q_n(F_P) + \frac{V}{\sqrt{n}} \\
&\leq \frac{\mathfrak{B}}{\sqrt{n}} \left( \mathfrak{B}^{p+1} \sqrt{2 \ln 2d} + V \sum_{l=0}^{p-1} \mathfrak{B}^l \right) + \frac{V}{\sqrt{n}} \\
&= \frac{1}{\sqrt{n}} \left( \mathfrak{B}^{p+2} \sqrt{2 \ln 2d} + \mathfrak{B} V \sum_{l=0}^{p-1} \mathfrak{B}^l + V \right) \\
&= \frac{1}{\sqrt{n}} \left( \mathfrak{B}^{p+2} \sqrt{2 \ln 2d} + V \left( \sum_{l=1}^p \mathfrak{B}^l + 1 \right) \right) \\
&= \frac{1}{\sqrt{n}} \left[ \mathfrak{B}^{p+2} \sqrt{2 \ln 2d} + V \sum_{l=0}^p \mathfrak{B}^l \right]
\end{aligned}$$

□

$E \times 2$

$$F_\lambda = \left\{ f = \sum_{j=1}^N w_j q_j : N \in \mathbb{N}, q_j \in \mathcal{G}_j, w_j \in \mathbb{R}, \sum_{j=1}^N |w_j| \leq \lambda \right\}$$

$$\begin{aligned} 1) R_n(F_\lambda) &= \mathbb{E} \left[ \sup_{\substack{N \in \mathbb{N} \\ q_j \in \mathcal{G}_j \\ \|w_j\|_1 \leq 1}} \left\{ \frac{1}{n} \sum_{i=1}^n E \left[ \sum_{j=1}^N w_j q_j(x) \right] \right\} | D_n \right] \\ &= \lambda \mathbb{E} \left[ \sup_{\substack{N \in \mathbb{N} \\ q_j \in \mathcal{G}_j \\ \|w_j\|_1 \leq 1}} \left\{ \frac{1}{n} \sum_{i=1}^n E \left[ \sum_{j=1}^N w_j q_j(x) \right] \right\} | D_n \right] \\ &= \lambda R_n(\text{conv}(\mathcal{G})) \\ &= \lambda R_n(\mathcal{G} \cup (-\mathcal{G})) \end{aligned}$$

On suppose que  $\exists g \in \mathcal{G}, \forall x \quad g(x) = 0$ .

$$\text{Ainsi, } \mathcal{G} \cup (-\mathcal{G}) \subseteq \mathcal{G} + (-\mathcal{G}).$$

$$\begin{aligned} \text{On en déduit } \lambda R_n(\mathcal{G} \cup (-\mathcal{G})) &\leq \lambda (R_n(\mathcal{G}) + R_n(-\mathcal{G})) \\ &= \lambda 2 R_n(\mathcal{G}) \end{aligned}$$

$$\leq 2\lambda \left( \frac{2 \log \delta(q_{1,n})}{n} \right)^{1/2} \quad (\text{Corollary 2.1b})$$

$$\leq 2\lambda \left( \frac{2 \log \left( \frac{en}{\sqrt{r}} \right)}{n} \right)^{1/2} \quad (\text{Sauer's Lemma})$$

$$\begin{aligned}
 2) \quad & \Psi(n) = \log_2 \left( 1 + e^n \right) \\
 A(f) &= \mathbb{E} \left[ \Psi(-Y f(x)) \right] \quad \left\{ \begin{array}{l} f^*(x) = \ln \left( \frac{f(x)}{1-f(x)} \right) \mid \text{ex 7.6 TD1} \\ \end{array} \right. \\
 A(f^*) &= \mathbb{E} \left[ q(x) \underbrace{\log_2 \left( 1 + \frac{1-q(x)}{q(x)} \right)}_{q=1} + (1-q(x)) \underbrace{\log_2 \left( 1 + \frac{1}{1-q(x)} \right)}_{q=-1} \right] \\
 &= \mathbb{E} \left[ q(x) \log_2 \left( \frac{1}{q(x)} \right) + (1-q(x)) \log_2 \left( \frac{1}{1-q(x)} \right) \right] \\
 &= \mathbb{E} \left[ -q(x) \log_2(q(x)) - (1-q(x)) \log_2(1-q(x)) \right] \\
 &= \mathbb{E} \left[ -q(x) \log_2(q(x)) - \log(1-q(x)) + q(x) \log(1-q(x)) \right] \\
 &= \mathbb{E} \left[ q(x) \log_2 \left( \frac{1-q(x)}{q(x)} \right) - \log(1-q(x)) \right] \\
 \Rightarrow H(t) &= t \log_2 \left( \frac{1-t}{t} \right) - \log_2(1-t)
 \end{aligned}$$

$$3) H(t) = H\left(\frac{1}{2}\right) + H'\left(\frac{1}{2}\right)\left(t - \frac{1}{2}\right) + \frac{H''(v)}{2} \left(t - \frac{1}{2}\right)^2$$

On a :

$$H\left(\frac{1}{2}\right) = 1, \quad H'(t) = \log_2\left(\frac{2t}{t}\right) - \frac{1}{1-t} + \frac{1}{t-1}$$

$$= \log_2\left(\frac{1-t}{t}\right)$$

$$H'\left(\frac{1}{2}\right) = 0$$

$$H''(t) = \frac{1}{\ln 2} \left( \ln\left(\frac{1-t}{t}\right) \right)'$$

$$= \frac{1}{\ln 2} \left( \frac{t}{1-t} \times -\frac{1}{t^2} \right)$$

$$= \frac{-1}{\ln 2 t (1-t)}.$$

Or,  $\forall t \in [0,1]$ ,  $t(1-t) \leq \frac{1}{4}$ . Ainsi,

$$H''(t) \leq -\frac{4}{\ln 2}$$

On en déduit

$$H(t) \leq 1 - \frac{2}{\ln 2} \left(t - \frac{1}{2}\right)^2$$

$$= 1 - \frac{2}{\ln 2} \left(\frac{1-t}{2}\right)^2 = 1 - \left(\sqrt{\frac{2}{\ln 2}} \frac{1-t}{2}\right)^2$$

$$\Rightarrow H(t) \leq 1 - \left( \frac{1-t}{2c} \right)^L, \quad c \triangleq \sqrt{\frac{\ln 2}{2}}.$$

h)  $\varphi$  est une fonction de coût et :

$$\begin{aligned} & \inf_{x \in \mathbb{R}} (2^{\varphi(f(x))} + (1-2)^{\varphi(x)}) \\ &= 2^{\varphi(-f^*)} + (1-2)^{\varphi(f^*)} \end{aligned}$$

On a donc

$$H(t) = \inf_{x \in \mathbb{R}} 2^{\varphi(f(x))} + (1-2)^{\varphi(x)}$$

$$\text{De plus, } H(t) \leq 1 - \left( \frac{1-t}{2c} \right)^L$$

$$\Rightarrow H(t) \leq 1 - c^{-2} \left( \frac{1}{2} - t \right)^L$$

$$\Rightarrow \left( \frac{1}{2} - t \right)^L \leq c^2 (1 - H(t))$$

$$\Rightarrow \left( \frac{1}{2} - t \right)^2 \leq \frac{\ln 2}{2} (1 - H(t))$$

L'inégalité de Zhang permet de conclure :

$$\forall f, \quad L(\text{sgn}(f)) - L^* \leq 2c (A(f) - A^*)^{1/2}$$

$$\Rightarrow \frac{L(f) - L^*}{(A(f) - A^*)^{1/2}} \leq \ln 2.$$

5) On pose  $F = \Psi_0 \tilde{F}$ ,  $\tilde{F} = \{(x, y) \mapsto -y \text{ for } f \in F_x\}$

On peut appliquer le théorème 2.10 : avec probabilité  $1-\delta$ :

$$\sup_{h \in F} \left( E[h(z)] - \frac{1}{n} \sum h(z_i) \right) \leq 2R_n(F) + c \sqrt{\frac{\log(1/\delta)}{2n}}$$

On cherche  $c$ . Il suffit de borner toute fonction de  $F$ :

$$\forall h \in F, |h(z)| = |\Psi(f_y f(x))| = \log_2 \left( 1 + e^{-y \sum w_i g_i(x)} \right)$$

$$\leq \log_2 (1 + e^k) \triangleq c$$

$$(g_i \in \{-1, 1\})$$

De plus,  $\Psi'(x) = \frac{c}{1+e^x} \frac{1}{\ln 2} \leq \frac{1}{\ln 2} \Rightarrow \Psi(x)$  est  $\frac{1}{\ln 2}$ -Lipschitz

$$\underbrace{\frac{c}{1+e^x}}_{< 1}$$

On a :

$$\sup_{f \in F_x} |\hat{A}_n(f) - A(f)| \leq \frac{1}{\ln 2} R_n(F_x) + \log_2(1 + e^k) \sqrt{\frac{\log(1/\delta)}{2n}}$$

$$\Rightarrow \sup_{f \in F_\lambda} |\widehat{A}_n(f) - A(f)| \leq \underbrace{\left( \frac{h\lambda \sqrt{2}}{\ln 2} \right)}_{C_1(\lambda)} \sqrt{\underbrace{\frac{\ln \left( \frac{e_n}{\nu} \right)}{n}}_{\frac{1}{n} \ln \frac{1}{\delta}} + \underbrace{\log_2(1+e^\lambda)}_{C_2(\lambda)}} \quad (1)$$

$$6) L(\widehat{f}_{n,\lambda}) - L^* \leq \ln 2 (A(\widehat{f}_{n,\lambda}) - A^*)^{\frac{1}{2}}$$

$$\leq \ln 2 \left[ \left( A(\widehat{f}_{n,\lambda}) - \inf_{f \in F_\lambda} A(f) \right)^{\frac{1}{2}} + \left( \inf_{f \in F_\lambda} A(f) - A^* \right)^{\frac{1}{2}} \right]$$

$$\text{Or, } A(\widehat{f}_{n,\lambda}) - A(\bar{f})$$

$$= A(\widehat{f}_{n,\lambda}) - A(\bar{f}) - \widehat{A}_n(\widehat{f}_{\lambda,n}) + \widehat{A}_n(\widehat{f}_{\lambda,n}) \quad \widehat{A}_n(\bar{f}_\lambda) - \widehat{A}_n(\bar{f}) \leq 0$$

$$= A(\widehat{f}_{n,\lambda}) - \widehat{A}_n(\widehat{f}_{\lambda,n}) + \widehat{A}_n(\bar{f}) - A(\bar{f}) + \underbrace{A_n(\widehat{f}_{\lambda,n}) - \widehat{A}_n(\bar{f})}_{\leq 0}$$

$$\leq \left( 2 \sup_{f \in F_\lambda} |A(f) - \widehat{A}_n(f)| \right) \quad (\bar{f}, \widehat{f}_{\lambda,n} \in F_\lambda)$$

Cela nous donne la borne suivante:

$$L(\widehat{f}_{n,\lambda}) - L^* \leq \ln 2 \left[ \left( 2 \sup_{f \in F_\lambda} |A(f) - \widehat{A}_n(f)| \right)^{\frac{1}{2}} + (A(\bar{f}) - A^*)^{\frac{1}{2}} \right]$$

Utiliser (1) permet de conclure.

TD1:

-1, 2, 3

TD3:

-1, 3, 5

TD4:

-1