UNIVERSITY OF LUXEMBOURG

THESIS FOR THE BACHELOR OF MATHEMATICS

High Dimensional Regression Models

BY JORIS LIMONIER

Supervisor: Mark PODOLSKIJ
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Abstract

Abstract goes here.

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Chapter 0

Notes

0.1 Notes for chapter 1

To be added

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- where the χ^2 distribution comes from in page 101

0.2 Notes for chapter 2

0.2.1 Section 6.2

$$\mathbf{Y} = \mathbf{X}\beta + \boldsymbol{\varepsilon} \tag{1}$$

We define $\hat{\beta}$ as follows

$$\hat{\beta} := \arg\min_{\beta} \left\{ \frac{\|\mathbf{Y} - \mathbf{X}\beta\|_2^2}{n} + \lambda\|\beta\|_1 \right\} \tag{2}$$

Lemma 0.1 (Basic Inequality)**.**

$$\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq 2\frac{\varepsilon^T\mathbf{X}(\hat{\beta} - \beta^0)}{n} + \lambda\|\beta^0\|_1$$

Proof. By definition of $\hat{\beta}$, we have that

$$\forall \beta \quad \frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta\|_2^2}{n} + \lambda\|\beta\|_1$$

In particular for $\beta = \beta^0$ we have

$$\frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta^0\|_2^2}{n} + \lambda\|\beta^0\|_1$$

We now replace $\mathbf{Y}$ using equation (1).

$$\frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta^0\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|(\mathbf{X}\beta^0 + \varepsilon) - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|(\mathbf{X}\beta^0 + \varepsilon) - \mathbf{X}\beta^0\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|\mathbf{X}(\beta^0 - \hat{\beta}) + \varepsilon\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{X}(\beta^0 - \beta^0) + \varepsilon\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\langle \mathbf{X}(\beta^0 - \hat{\beta}) + \varepsilon, \mathbf{X}(\beta^0 - \hat{\beta}) + \varepsilon \rangle}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\varepsilon\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|\mathbf{X}(\beta^0 - \hat{\beta})\|_2^2 + \|\varepsilon\|_2^2 + 2\langle \mathbf{X}(\beta^0 - \hat{\beta}), \varepsilon \rangle}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\varepsilon\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\langle \mathbf{X}(\hat{\beta} - \beta^0), \varepsilon \rangle}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\varepsilon^T \mathbf{X}(\hat{\beta} - \beta^0)}{n} + \lambda\|\beta^0\|_1$$

$$\square$$

Let

$$\mathscr{T} := \left\{ \max_{1 \leq j \leq p} 2\frac{\left|\varepsilon^T \mathbf{X}^{(j)}\right|}{n} \leq \lambda_0 \right\}$$

Lemma 0.2 (Lemma 6.2.). *For all $t > 0$ and*

$$\lambda_0 := 2\sigma\sqrt{\frac{t^2 + 2\log p}{n}}$$

we have

$$\mathbb{P}(\mathscr{T}) \geq 1 - 2\exp\left[-t^2/2\right]$$

Proof. We define

$$V_j := \frac{\varepsilon^T \mathbf{X}^{(j)}}{\sqrt{n\sigma^2}}$$

Then we have

$$\mathbb{P}(\mathscr{T}) = \mathbb{P}\left(\max_{1 \le j \le p} 2\frac{|\varepsilon^T \mathbf{X}^{(j)}|}{n} \le 2\sigma\sqrt{\frac{t^2 + 2\log p}{n}}\right)$$

$$= \mathbb{P}\left(\max_{1 \le j \le p}\left|\frac{\varepsilon^T \mathbf{X}^{(j)}}{\sqrt{n\sigma^2}}\right| \le \sqrt{t^2 + 2\log p}\right)$$

$$= \mathbb{P}\left(\max_{1 \le j \le p} |V_j| \le \sqrt{t^2 + 2\log p}\right)$$

$$= 1 - \mathbb{P}\left(\max_{1 \le j \le p} |V_j| > \sqrt{t^2 + 2\log p}\right)$$

$$= 1 - \mathbb{P}\left(\bigcup_{j=1}^{p} |V_j| > \sqrt{t^2 + 2\log p}\right)$$

$$\ge 1 - \sum_{j=1}^{p} \mathbb{P}\left(|V_j| > \sqrt{t^2 + 2\log p}\right)$$

$$\ge 1 - p\,\mathbb{P}\left(|V_j| > \sqrt{t^2 + 2\log p}\right)$$

$\square$

Corollary 0.3 (Consistency of the LASSO). *Assume $\sigma^2 = 1$ for all j. We define the regularization parameter as*

$$\lambda = 4\hat{\sigma}^2\sqrt{\frac{t^2 + 2\log p}{n}}$$

where $\hat{\sigma}$ is some estimator of σ.
Then with probability at least $1 - \alpha$, where $\alpha := 2\exp(-t^2/2) + \mathbb{P}(\hat{\sigma} \le \sigma)$ we have

$$2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} \le 3\lambda\|\beta^0\|_1$$

Lemma 0.4 (Lemma 6.3.). *We have on $\mathscr{T}$, with $\lambda \ge 2\lambda_0$,*

$$2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}_{S_0^c}\|_1 \le 3\lambda\|\hat{\beta}_{S_0} - \beta^0_{S_0}\|_1$$

Proof. We start with the Basic Inequality

$$\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \le 2\frac{\varepsilon^T \mathbf{X}(\hat{\beta} - \beta^0)}{n} + \lambda\|\beta^0\|_1$$

Now since we are on $\mathscr{T}$ and since $2\lambda_0 \leq \lambda$

$$\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \lambda_0\|\hat{\beta} - \beta^0\|_1 + \lambda\|\beta^0\|_1$$

$$2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + 2\lambda\|\hat{\beta}\|_1 \leq \lambda\|\hat{\beta} - \beta^0\|_1 + 2\lambda\|\beta^0\|_1$$

Let $\beta_{j,S} := \beta_j 1\{j \in S\}$. We use the triangle inequality on the left hand side

$$\begin{aligned} \|\hat{\beta}\|_1 &= \|\hat{\beta}_{S_0}\|_1 + \|\hat{\beta}_{S_0^c}\|_1 \\ &= \|\beta_{S_0}^0 - \beta_{S_0}^0 + \hat{\beta}_{S_0}\|_1 + \|\hat{\beta}_{S_0^c}\|_1 \\ &\geq \|\beta_{S_0}^0\|_1 - \|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + \|\hat{\beta}_{S_0^c}\|_1 \end{aligned}$$

whereas on the right hand side

$$\begin{aligned} \|\hat{\beta} - \beta^0\|_1 &= \|(\hat{\beta}_{S_0} + \hat{\beta}_{S_0^c}) - (\beta_{S_0}^0 + \underbrace{\beta_{S_0^c}^0}_{=0})\|_1 \\ &= \|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + \|\hat{\beta}_{S_0^c}\|_1 \end{aligned}$$

Injecting these two results, we get that

$$\begin{aligned} &2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + 2\lambda\|\hat{\beta}\|_1 \leq \lambda\|\hat{\beta} - \beta^0\|_1 + 2\lambda\|\beta^0\|_1 \\ \implies &2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + 2\lambda\left(\|\beta_{S_0}^0\|_1 - \|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + \|\hat{\beta}_{S_0^c}\|_1\right) \\ &\qquad \leq \lambda\left(\|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + \|\hat{\beta}_{S_0^c}\|_1\right) + 2\lambda\|\beta^0\|_1 \\ \implies &2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + 2\lambda\|\underbrace{\beta_{S_0}^0}_{=\beta^0}\|_1 + \lambda\|\hat{\beta}_{S_0^c}\|_1 \leq 3\lambda\|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + 2\lambda\|\beta^0\|_1 \\ \implies &2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}_{S_0^c}\|_1 \leq 3\lambda\|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 \end{aligned}$$

$\square$

Definition 0.5 (Compatibility condition)**.** *We say that the compatibility condition is met for the set S_0, if for some $\phi_0 > 0$, and for all β satisfying $\|\beta_{S_0^c}\|_1 \leq 3\|\beta_{S_0}\|_1$, it holds that*

$$\|\beta_{S_0}\|_1^2 \leq \left(\beta^T \hat{\Sigma} \beta\right) s_0/\phi_0^2 \tag{3}$$

Theorem 0.6 (Theorem 6.1.)**.** *Suppose the compatibility condition holds for S_0. Then on $\mathscr{T}$, we have for $\lambda \geq 2\lambda_0$,*

$$\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta} - \beta^0\|_1 \leq 4\lambda^2\frac{s_0}{\phi_0^2}$$

Proof. Using lemma 0.4 we have that

$$2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta} - \beta^0\|_1$$

$$= 2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}_{S_0} + \hat{\beta}_{S_0^c} - \beta_{S_0}^0 - \underbrace{\beta_{S_0^c}^0}_{=0}\|_1$$

$$= 2\frac{\|\mathbf{X}(\hat{\beta} - \beta^0)\|_2^2}{n} + \lambda\|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1 + \lambda\|\hat{\beta}_{S_0^c}\|_1 \quad \text{(by lemma 0.4)}$$

$$\leq 4\lambda\|\hat{\beta}_{S_0} - \beta_{S_0}^0\|_1$$

$$\leq 4\lambda\sqrt{\left(\hat{\beta}_{S_0} - \beta_{S_0}^0\right)^T \hat{\Sigma} \left(\hat{\beta}_{S_0} - \beta_{S_0}^0\right) s_0/\phi_0^2}$$

$$\leq \sqrt{\left(\hat{\beta}_{S_0} - \beta_{S_0}^0\right)^T \mathbf{X}^T\mathbf{X} \left(\hat{\beta}_{S_0} - \beta_{S_0}^0\right)}\frac{4\lambda\sqrt{s_0}}{\phi_0\sqrt{n}}$$

$$\leq \|\mathbf{X}(\hat{\beta}_{S_0} - \beta_{S_0}^0)\|_2\frac{4\lambda\sqrt{s_0}}{\phi_0\sqrt{n}}$$

$$\leq \|\mathbf{X}(\hat{\beta}_{S_0} - \beta_{S_0}^0)\|_2^2 + \frac{4\lambda^2 s_0}{\phi_0^2 n}$$

$\square$

0.2.2   Section 6.3

Now $\mathbf{Y} := \mathbf{f}^0 + \boldsymbol{\varepsilon}$ so $\mathbb{E}[\mathbf{Y}] := \mathbf{f}^0$

Lemma 0.7 (New version of the Basic Inequality)**.** *$\forall \beta^* \in \mathbb{R}^p$ we have*

$$\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\boldsymbol{\varepsilon}^T\mathbf{X}(\hat{\beta} - \beta^*)}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n} \quad (4)$$

$$\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\boldsymbol{\varepsilon}^T\mathbf{X}(\hat{\beta} - \beta^*)}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

Proof. By definition of $\hat{\beta}$, we have that

$$\forall \beta \quad \frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta\|_2^2}{n} + \lambda\|\beta\|_1$$

In particular for $\beta = \beta^*$ we have

$$\forall \beta^* \quad \frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta^*\|_2^2}{n} + \lambda\|\beta\|_1$$

We since $\mathbf{Y} = \mathbf{f}^0 + \varepsilon$

$$\frac{\|\mathbf{Y} - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|\mathbf{Y} - \mathbf{X}\beta^*\|_2^2}{n} + \lambda\|\beta^0\|_1$$

$$\implies \frac{\|(\mathbf{f}^0 + \varepsilon) - \mathbf{X}\hat{\beta}\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|(\mathbf{f}^0 + \varepsilon) - \mathbf{X}\beta^*\|_2^2}{n} + \lambda\|\beta^*\|_1$$

$$\implies \frac{\|(\mathbf{f}^0 - \mathbf{X}\hat{\beta}) + \varepsilon\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{\|(\mathbf{f}^0 - \mathbf{X}\beta^*) + \varepsilon\|_2^2}{n} + \lambda\|\beta^*\|_1$$

$$\implies \frac{\langle(\mathbf{f}^0 - \mathbf{X}\hat{\beta}) + \varepsilon, (\mathbf{f}^0 - \mathbf{X}\hat{\beta}) + \varepsilon\rangle}{n} + \lambda\|\hat{\beta}\|_1$$

$$\leq \frac{\langle(\mathbf{f}^0 - \mathbf{X}\beta^*) + \varepsilon, (\mathbf{f}^0 - \mathbf{X}\beta^*) + \varepsilon\rangle}{n} + \lambda\|\beta^*\|_1$$

$$\implies \frac{\|\mathbf{f}^0 - \mathbf{X}\hat{\beta}\|_2^2 + \|\varepsilon\|_2^2 + 2\langle\mathbf{f}^0 - \mathbf{X}\hat{\beta}, \varepsilon\rangle}{n} + \lambda\|\hat{\beta}\|_1$$

$$\leq \frac{\|\mathbf{f}^0 - \mathbf{X}\beta^*\|_2^2 + \|\varepsilon\|_2^2 + 2\langle\mathbf{f}^0 - \mathbf{X}\beta^*, \varepsilon\rangle}{n} + \lambda\|\beta^*\|_1$$

$$\implies \frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\langle\mathbf{X}(\hat{\beta} - \beta^*), \varepsilon\rangle}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies \frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\varepsilon^T\mathbf{X}(\hat{\beta} - \beta^*)}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$\square$

Lemma 0.8 (New version of the Lemma 6.3.). *We have on $\mathscr{T}$, with $\lambda \geq 4\lambda_0$,*

$$\frac{4\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 3\lambda\|\hat{\beta}_{S_*^c}\|_1 \leq 5\lambda\|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + \frac{4\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n} \tag{5}$$

Proof. We start with the Basic Inequality

$$\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\varepsilon^T\mathbf{X}(\hat{\beta} - \beta^*)}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

Now since we are on $\mathscr{T}$ and since $4\lambda_0 \leq \lambda$

$$\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \frac{2\boldsymbol{\varepsilon}^T\mathbf{X}(\hat{\beta} - \beta^*)}{n} + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies \frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + \lambda\|\hat{\beta}\|_1 \leq \lambda_0\|\hat{\beta} - \beta^*\|_1 + \lambda\|\beta^*\|_1 + \frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies 4\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 4\lambda\|\hat{\beta}\|_1 \leq \lambda\|\hat{\beta} - \beta^*\|_1 + 4\lambda\|\beta^*\|_1 + 4\frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

Let $S_* = \{j : \beta_j^* \neq 0\}$. We use the triangle inequality on the left hand side

$$\begin{aligned}
\|\hat{\beta}\|_1 &= \|\hat{\beta}_{S_*}\|_1 + \|\hat{\beta}_{S_*^c}\|_1 \\
&= \|\beta_{S_*}^* - \beta_{S_*}^* + \hat{\beta}_{S_*}\|_1 + \|\hat{\beta}_{S_*^c}\|_1 \\
&\geq \|\beta_{S_*}^*\|_1 - \|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + \|\hat{\beta}_{S_*^c}\|_1
\end{aligned}$$

whereas on the right hand side

$$\begin{aligned}
\|\hat{\beta} - \beta^*\|_1 &= \|(\hat{\beta}_{S_*} + \hat{\beta}_{S_*^c}) - (\beta_{S_*}^* + \underbrace{\beta_{S_*^c}^*}_{=0})\|_1 \\
&= \|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + \|\hat{\beta}_{S_*^c}\|_1
\end{aligned}$$

Injecting these two results, we get that

$$4\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 4\lambda\|\hat{\beta}\|_1 \leq \lambda\|\hat{\beta} - \beta^*\|_1 + 4\lambda\|\beta^*\|_1 + 4\frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies 4\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 4\lambda\left(\|\beta_{S_*}^*\|_1 - \|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + \|\hat{\beta}_{S_*^c}\|_1\right)$$

$$\leq \lambda\left(\|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + \|\hat{\beta}_{S_*^c}\|_1\right) + 4\lambda\|\beta^*\|_1 + 4\frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies 4\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 4\lambda\|\underbrace{\beta_{S_*}^*}_{=\beta^*}\|_1 + 3\lambda\|\hat{\beta}_{S_*^c}\|_1$$

$$\leq 5\lambda\|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + 4\lambda\|\beta^*\|_1 + 4\frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$$\implies 4\frac{\|\mathbf{X}\hat{\beta} - \mathbf{f}^0\|_2^2}{n} + 3\lambda\|\hat{\beta}_{S_*^c}\|_1 \leq 5\lambda\|\hat{\beta}_{S_*} - \beta_{S_*}^*\|_1 + 4\frac{\|\mathbf{X}\beta^* - \mathbf{f}^0\|_2^2}{n}$$

$\square$

Definition 0.9 (Compatibility condition for general sets)**.** *We say that the compatibility condition holds for the set S, if for some constant $\phi(S) > 0$, and for all β, with $\|\beta_{S^c}\|_1 \leq 3 \|\beta_S\|_1$, one has*

$$\|\beta_S\|_1^2 \leq \left(\beta^T \hat{\Sigma} \beta\right) |S|/\phi^2(S)$$

Chapter 1

Introduction

Chapter 2

Classical theory of Linear Regression

Chapter 3

Theory for LASSO in high dimensions