

Graphic Lasso: Possible Accuracy

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1 Optimization with $1/2$ norm

Let $Q(\Omega) = \text{tr}(S\Omega) - \log |\Omega|$. Consider the primal minimization problem

$$\begin{aligned} \min_{\Omega = \llbracket \omega_{j,j'} \rrbracket} Q(\Omega), \\ \text{s.t.} \quad \sum_{j \neq j'} |\omega_{j,j'}|^{1/2} \leq C. \end{aligned}$$

For simplicity, let $|\Omega|^{1/2} = \sum_{j \neq j'} |\omega_{j,j'}|^{1/2}$, T denote the set of indices of non-zero off-diagonal elements, and $q = |T|$. We assume following assumptions.

1. There exist two constants τ_1, τ_2 such that $0 < \tau_1 < \phi_{\min}(\Omega_0) \leq \phi_{\max}(\Omega_0) < \tau_2 < \infty$, for all $p \geq 1, k = 1, \dots, K$, where $\phi_{\min}(\cdot), \phi_{\max}(\cdot)$ denote the minimal and maximal eigenvalues, respectively.
2. There exists a constant $\tau_3 > 0$ such that $\min_{(j,j') \in T} |\omega_{0,j,j'}| \geq \tau_3$.

Theorem 1.1 (Consistency (Preliminary)). *Suppose two assumptions hold and C is a positive constant. Let Ω denote the true precision matrix. There exists a local minimizer $\hat{\Omega}$ such that $Q(\hat{\Omega}) \leq Q(\Omega)$ and $|\hat{\Omega}|^{1/2} \leq C$, and the following accuracy bound holds with probability tending to 1.*

$$\|\hat{\Omega} - \Omega\|_F = O_p \left[\left\{ \frac{(p+q) \log p}{n} \right\}^{1/4} \right].$$

Proof follows tensor paper

Proof. Consider the following decomposition

$$G(\Delta) = \text{tr}(S(\Omega + \Delta)) - \text{tr}(\Omega) - \log |\Omega + \Delta| + \log |\Omega| = I_1 + I_2,$$

where

$$I_1 = \text{tr}((S - \Sigma)\Delta), \quad I_2 = (\tilde{\Delta})^T \int_0^1 (1-v)(\Omega + v\Delta)^{-1} \otimes (\Omega + v\Delta)^{-1} dv \tilde{\Delta}.$$

Suppose $\hat{\Omega} = \Omega + \Delta$ has larger or equal likelihood value than the true precision matrix Ω . Then, we have $G(\Delta) \leq 0$, i.e.,

$$I_2 \leq -I_1 \leq |I_1|. \tag{1}$$

Note that

$$|I_1| \leq C_1 \left(\frac{\log p}{n} \right)^{1/2} (|\Delta_T^-|_1 + |\Delta_{T^c}^-|_1) + C_2 \left(\frac{p \log p}{n} \right)^{1/2} \|\Delta^+\|_F, \quad I_2 \geq \frac{1}{4\tau_2^2} \|\Delta\|_F^2,$$

$|\Delta_T^-|_1 \leq q^{1/2} \|\Delta\|_F$, and $|\Delta_{T^c}^-|_1 \leq C$. To satisfy the inequality (1), we have

$$\frac{1}{4\tau_2^2} \|\Delta\|_F^2 \leq (C_1 + C_2) \left(\frac{(p+q) \log p}{n} \right)^{1/2} \|\Delta\|_F + C_1 \left(\frac{(p+q) \log p}{n} \right)^{1/2} C. \quad (2)$$

Consider the equation

$$0 = -\frac{1}{4\tau_2^2} x^2 + (C_1 + C_2) \left(\frac{(p+q) \log p}{n} \right)^{1/2} x + C_1 \left(\frac{(p+q) \log p}{n} \right)^{1/2} C. \quad (3)$$

The solutions to the equation (3) are

$$\begin{aligned} x^* &= 2\tau_2^2 \left\{ (C_1 + C_2) \left(\frac{(p+q) \log p}{n} \right)^{1/2} \pm \sqrt{(C_1 + C_2)^2 \left(\frac{(p+q) \log p}{n} \right)^{1/2} + C_1 C \left(\frac{(p+q) \log p}{n} \right)^{1/2} / \tau_2^2} \right\} \\ &= \mathcal{O} \left[\left(\frac{(p+q) \log p}{n} \right)^{1/4} \right], \end{aligned} \quad (4)$$

where the second equality follows by the fact that the term $\sqrt{C_1 C \left(\frac{(p+q) \log p}{n} \right)^{1/2} / \tau_2^2}$ dominates the solution. Therefore, to satisfy the inequality (2), we have

$$\|\hat{\Omega} - \Omega\|_F = \|\Delta\|_F = \mathcal{O} \left[\left(\frac{(p+q) \log p}{n} \right)^{1/4} \right].$$

□

Proof follows Guo's paper

Proof. Let $\mathcal{A} = \left\{ \|\Delta\|_F \leq M \left(\frac{(p+q) \log p}{n} \right)^{1/4}, |\Omega + \Delta|^{1/2} \leq C \right\}$. Define $G(\Delta)$, I_1 , and I_2 same as above proof. We know that

$$\begin{aligned} G(\Delta) &\geq I_2 - |I_1| \\ &\geq \frac{1}{4\tau_2^2} \|\Delta\|_F^2 - \left(\frac{(p+q) \log p}{n} \right)^{1/2} \|\Delta\|_F - C_1 \left(\frac{(p+q) \log p}{n} \right)^{1/2} C. \end{aligned}$$

By the solution (4), we have $G(\Delta) > 0$ for all $\Delta \in \partial\mathcal{A}$ with M large enough. Therefore, there exists a local minimizer inside \mathcal{A} and thus $\|\hat{\Omega} - \Omega\|_F = \mathcal{O} \left[\left(\frac{(p+q) \log p}{n} \right)^{1/4} \right]$ □

2 Different constrains

1. We change the constrain as

$$\frac{|\Omega + \Delta|_1}{\|\Omega + \Delta\|_F} < C.$$

Then we have

$$|\Delta_{T^c}^-|_1 < C \|\Omega + \Delta\|_F.$$

However, the relationship between $\|\Omega + \Delta\|_F$ and $\|\Delta\|_F$ is uncertain. We only have

$$\|\Omega + \Delta\|_F \leq \|\Delta\|_F + \|\Omega\|_F = \|\Delta\|_F + C'.$$

The solutions x^* are still dominated by the $\left(\frac{(p+q)\log p}{n}\right)^{1/4}$ term.

2. We change the constrain as

$$|\Omega + \Delta|_0 < s.$$

Note that $|\Omega + \Delta|_0 = |\Omega_T + \Delta_T|_0 + |\Delta_{T^c}|_0 < s$. We have

$$|\Delta_{T^c}^-|_1 < |\Delta_{T^c}^-|_0 \|\Delta\|_{\max} \leq s \|\Delta\|_F. \quad (5)$$

Plugging (5) into the inequality (1), we have inequality 1: $G(\Delta) < 0$.

$$\frac{1}{4\tau_2^2} \|\Delta\|_F^2 \leq (C_1 + C_2) \left(\frac{(p+q)\log p}{n}\right)^{1/2} \|\Delta\|_F + C_1 \left(\frac{\log p}{n}\right)^{1/2} s \|\Delta\|_F,$$

and thus we have

$$\|\hat{\Omega} - \Omega\|_F = \|\Delta\|_F = \mathcal{O} \left[\left(\frac{(p+q)\log p}{n}\right)^{1/2} \right]. \quad (6)$$

Remark. The above accuracy (6) holds when q is fixed. Since the true Ω should satisfy the constrain, we need $|\Omega|_0 = q < s$. Therefore, when q is not a fixed number, let $s = Mq$ for some constant M . The accuracy is of order $\mathcal{O} \left\{ q \left(\frac{\log p}{n}\right)^{1/2} \right\}$.

3 Optimization without constrain

Consider the problem

$$\min_{\Omega = \llbracket \omega_{j,j'} \rrbracket} Q(\Omega).$$

Theorem 3.1. Suppose two assumptions hold. For estimation $\hat{\Omega}$ such that $Q(\hat{\Omega}) \leq Q(\Omega)$, we have following accuracy bound with probability tending to 1.

$$\|\hat{\Omega} - \Omega\|_F = O_p \left[p \left\{ \frac{\log p}{n} \right\}^{1/2} \right].$$

Proof. Define $G(\Delta)$, I_1 , and I_2 same as above proofs. Unlike above proofs, we have

$$\begin{aligned} |I_1| &\leq C_1 \left(\frac{\log p}{n} \right)^{1/2} |\Delta|_1 + C_2 \left(\frac{p \log p}{n} \right)^{1/2} \|\Delta^+\|_F \\ &\leq \left\{ C_1 p \left(\frac{\log p}{n} \right)^{1/2} + C_2 \left(\frac{p \log p}{n} \right)^{1/2} \right\} \|\Delta\|_F, \end{aligned}$$

where the second inequality follows by the fact that $|\Delta|_1 \leq p \|\Delta\|_F$. Then, to let $G(\Delta) \neq 0$, we need $I_2 \leq |I_1|$, i.e.,

$$\frac{1}{4\tau_2^2} \|\Delta\|_F^2 \leq C' p \left(\frac{\log p}{n} \right)^{1/2} \|\Delta\|_F,$$

which implies that

$$\left\| \hat{\Omega} - \Omega \right\|_F = \|\Delta\|_F = O_p \left[p \left\{ \frac{\log p}{n} \right\}^{1/2} \right].$$

□

This result makes sense. The degree of freedom for the dense model is p^2 while for sparse model is $p + q$. Compared with the accuracy with constrain, the optimization without constrain corresponds to the dense model, and the $p + q$ part in the accuracy is replaced by p^2 .