



Minimax risk over large classes of signals

Statistical theory for high- and infinite-dimensional models

Jolien Oomens

May 10th, 2017



Some L^2 theory



Some L^2 theory

Recall we write

$$e_n = e^{2\pi i n x} \in L^2[0, 1]$$



Some L^2 theory

Recall we write

$$e_n = e^{2\pi i n x} \in L^2[0, 1]$$

and that

$$\{e_n : n \in \mathbb{Z}\}$$

is an orthonormal basis of $L^2[0, 1]$.



Some L^2 theory

Recall we write

$$e_n = e^{2\pi i n x} \in L^2[0, 1]$$

and that

$$\{e_n : n \in \mathbb{Z}\}$$

is an orthonormal basis of $L^2[0, 1]$.

The distance between e_n and e_m ($m \neq n$) is $\sqrt{2}$:



Some L^2 theory

Recall we write

$$e_n = e^{2\pi i n x} \in L^2[0, 1]$$

and that

$$\{e_n : n \in \mathbb{Z}\}$$

is an orthonormal basis of $L^2[0, 1]$.

The distance between e_n and e_m ($m \neq n$) is $\sqrt{2}$:

$$\|e_n - e_m\|_{L^2}^2 = \langle e_n - e_m, e_n - e_m \rangle$$



Some L^2 theory

Recall we write

$$e_n = e^{2\pi i n x} \in L^2[0, 1]$$

and that

$$\{e_n : n \in \mathbb{Z}\}$$

is an orthonormal basis of $L^2[0, 1]$.

The distance between e_n and e_m ($m \neq n$) is $\sqrt{2}$:

$$\|e_n - e_m\|_{L^2}^2 = \langle e_n - e_m, e_n - e_m \rangle = 1 + 1 = 2.$$

Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$.



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{n}e_j : j \in \{1, 2, \dots, e^{n^2}\}\}.$$



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne}j : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated,



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne_j} : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^{n^2}$



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne_j} : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^{n^2}$ and $\text{diam}(\mathcal{G}_n)^2 = 2n$.



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne}j : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^{n^2}$ and $\text{diam}(\mathcal{G}_n)^2 = 2n$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^{n^2} = |\mathcal{G}_n|,$$



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne}j : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^{n^2}$ and $\text{diam}(\mathcal{G}_n)^2 = 2n$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^{n^2} = |\mathcal{G}_n|,$$

so the proposition gives

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq cr_n^p.$$



Exercise 5.1(i)

Prove that for every $p > 0$ we have

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \rightarrow \infty \text{ as } n \rightarrow \infty.$$

We would like to use Proposition 5.2.2.

Define $r_n = \frac{1}{2}\sqrt{2n}$. Define

$$\mathcal{G}_n := \{\sqrt{ne}j : j \in \{1, 2, \dots, e^{n^2}\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^{n^2}$ and $\text{diam}(\mathcal{G}_n)^2 = 2n$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^{n^2} = |\mathcal{G}_n|,$$

so the proposition gives

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq cr_n^p.$$

Letting $n \rightarrow \infty$ now proves the desired equality.



Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L_1^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$



Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L_1^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$

Define $r_n = \frac{1}{2}\sqrt{2}$ and

$$\mathcal{G}_n := \{e_j : j \in \{1, 2, \dots, e^n\}\}.$$



Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L_1^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$

Define $r_n = \frac{1}{2}\sqrt{2}$ and

$$\mathcal{G}_n := \{e_j : j \in \{1, 2, \dots, e^n\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^n$ and $\text{diam}(\mathcal{G}_n)^2 = 2$.



Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L_1^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$

Define $r_n = \frac{1}{2}\sqrt{2}$ and

$$\mathcal{G}_n := \{e_j : j \in \{1, 2, \dots, e^n\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^n$ and $\text{diam}(\mathcal{G}_n)^2 = 2$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^n = |\mathcal{G}_n|,$$

Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L^2_1[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$

Define $r_n = \frac{1}{2}\sqrt{2}$ and

$$\mathcal{G}_n := \{e_j : j \in \{1, 2, \dots, e^n\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^n$ and $\text{diam}(\mathcal{G}_n)^2 = 2$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^n = |\mathcal{G}_n|,$$

so the proposition gives

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq cr_n^p.$$



Exercise 5.1(ii)

Prove that for $p > 0$ there exists $c > 0$ such that

$$\inf_{\hat{f}} \sup_{f \in L^2_1[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq c.$$

Define $r_n = \frac{1}{2}\sqrt{2}$ and

$$\mathcal{G}_n := \{e_j : j \in \{1, 2, \dots, e^n\}\}.$$

Then the elements in \mathcal{G}_n are $2r_n$ -separated, $|\mathcal{G}_n| = e^n$ and $\text{diam}(\mathcal{G}_n)^2 = 2$. Hence indeed

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^n = |\mathcal{G}_n|,$$

so the proposition gives

$$\inf_{\hat{f}} \sup_{f \in L^2[0,1]} E_f \|\hat{f} - f\|_{L^2}^p \geq cr_n^p.$$

Letting $n \rightarrow \infty$ we obtain desired equality.



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$.



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ .



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball.

Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls.

Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls.



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \|\hat{f} - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls. Then $|\mathcal{G}_n| = e^{n^2}$

Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \| \hat{f} - f \|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls. Then $|\mathcal{G}_n| = e^{n^2}$, the elements of \mathcal{G}_n are ϵ -separated



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} E_f \| \hat{f} - f \|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls. Then $|\mathcal{G}_n| = e^{n^2}$, the elements of \mathcal{G}_n are ϵ -separated and $\text{diam}(\mathcal{G}_n)^2 \leq 4M^2$.



Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} \|E_f\|_{L^2}^p - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls. Then $|\mathcal{G}_n| = e^{n^2}$, the elements of \mathcal{G}_n are ϵ -separated and $\text{diam}(\mathcal{G}_n)^2 \leq 4M^2$. For large n

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^{2nM^2} \leq |\mathcal{G}_n| = e^{n^2},$$

Exercise 5.1(iii)

Let $\mathcal{F} \subset L^2[0, 1]$ be bounded but not totally bounded. Show that for $p > 0$ there is a $c > 0$ such that $\inf_{\hat{f}} \sup_{f \in \mathcal{F}} \|E_f\|_{L^2}^p - f\|_{L^2}^p \geq c$.

Let $n \in \mathbb{N}$ and take M such that $\mathcal{F} \subset B(0, M)$. Since \mathcal{F} is not totally bounded there exists $\epsilon > 0$ such that \mathcal{F} cannot be covered by finitely many balls of radius ϵ .

- Pick a first ball $B_1 \subset \mathcal{F}$ of radius ϵ . (This is possible, otherwise we could cover \mathcal{F} with one ball.)
- If we've chosen $m - 1$ balls we can pick B_m such that the centre is not inside some previously picked ball. (If not, then we covered \mathcal{F} with $m - 1$ balls.)

We continue this process until we have e^{n^2} of these balls. Now let \mathcal{G}_n be the set of all centres of these balls. Then $|\mathcal{G}_n| = e^{n^2}$, the elements of \mathcal{G}_n are ϵ -separated and $\text{diam}(\mathcal{G}_n)^2 \leq 4M^2$. For large n

$$e^{\frac{1}{2}n \text{diam}(\mathcal{G}_n)^2} = e^{2nM^2} \leq |\mathcal{G}_n| = e^{n^2},$$

so the proposition gives the result.

