Functional Data Analysis

Lecture – 4 & 5
Mathematical foundation & Exploratory Data Analysis

May 8, 2018

Outline

Usual linear regression model

$$y = X\alpha + \epsilon$$

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In fda, the data is usually some realisation of a stochastic process, as against a random variable. Therefore, we're mostly interested in:

$$y(t) = f(t) + \epsilon(t),$$

where we wish to *estimate* $f(t)$, given the observation $y(t)$.

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Let us recall how to characterise standard normal distribution on $\mathbb{R}^n$:

- density is given by $(2\pi)^{-n/2} \exp\left(-\frac{x^2}{2}\right)$
- or, all linear combinations are Normal with appropriate mean and variance.

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One can define Gaussian distribution on ℓ^2 with mean m, and covariance $\mathcal{C}$ as long as

$$m \in \ell^2,$$

and $\mathcal{C}$ is a **linear operator**[1] on ℓ^2 such that

$$\sum_{i \geq 1} \langle \mathcal{C} e_i, e_i \rangle < \infty,$$

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What about $\|X\|^2$ in general? $\|X\|^2 = \infty$ almost surely. One can actually show that $\|X\|^2 < \infty$, whenever $\mathcal{C}$ is trace class.

Covariance between various linear combinations

In finite dimensions:

On $\mathbb{R}^n$, let $Y \sim \mathcal{N}(\mu, \Sigma)$, then $\langle a, Y \rangle$ and $\langle b, Y \rangle$ are both normally distributed, with covariance $\langle \Sigma a, b \rangle$.

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After some analysis, one can conclude that

$$\mathcal{C} = \sum_{i \geq 1} \lambda_i \; \phi_i \otimes \phi_i \qquad \text{(Mercer's Theorem)}$$

for some ONB $\{\phi_i\}$. (compare with matrices, and discuss L^2 representation).

In fact, there exist a sequence $\{\xi_n\}$ of zero-mean, uncorrelated random variables such that $\mathbb{E}(\xi_i^2) = \lambda_i$, and

$$Y = \sum_{i \geq 1} \xi_i \, \phi_i \qquad \text{(Karhunen–Loéve expansion)}$$

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Special case

In case the functional data is realisation of certain stochastic process, then the mean m is a **mean function** $m(t) = \mathbb{E}(X(t))$, and the covariance operator becomes a **covariance kernel**, $\mathcal{C}(s, t) = \mathrm{cov}(X(s)X(t))$.

Outline

- sample mean;
- sample covariance
- functional PCA (with Karhunen–Loéve –using probe functions)