Lecture 21: Gaussian process regression

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Priors on function spaces

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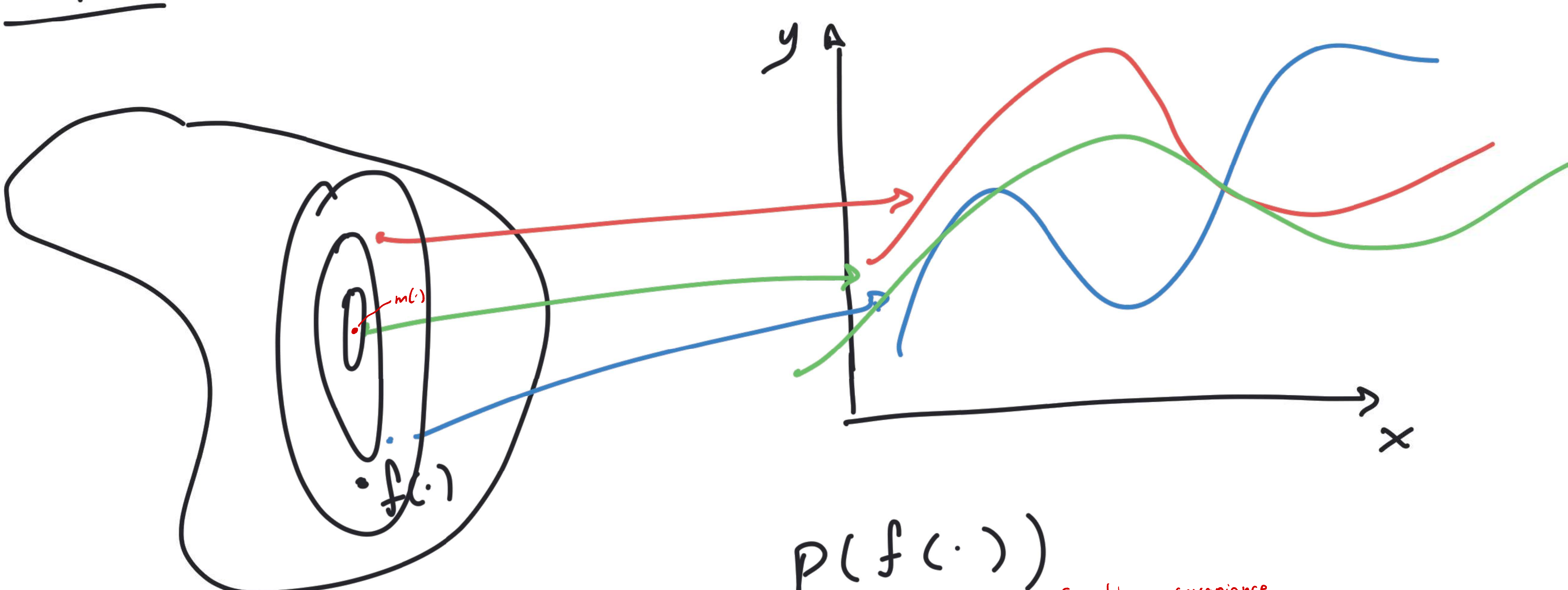
Probability measure on a function space

Inputs: $x \in \mathbb{R}$; Output: $y \in \mathbb{R}$



$p(f(\cdot))$

Space of function

mean function, covariance function (requires 2 inputs)

$f(\cdot) \sim GP(m(\cdot), c(\cdot,\cdot))$

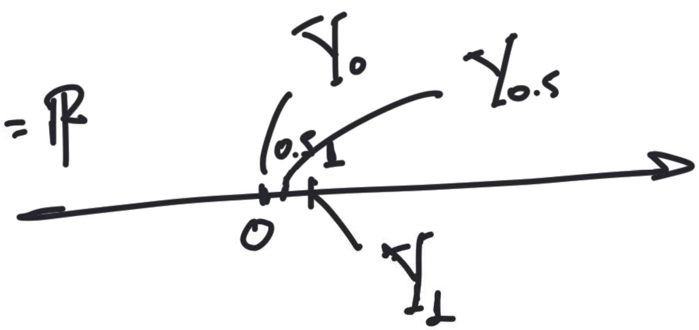
function indexed by a random key, say ω, from the sample space

What is a stochastic process? (or random process)

$\mathcal{X}$: set of inputs

Stochastic process on $\mathcal{X}$ is a collection of random variables Y_x, $x \in \mathcal{X}$

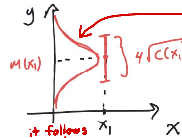
$\mathcal{X} = \mathbb{R}$



The Gaussian process prior

$f(\cdot) \sim GP(m(\cdot), c(\cdot,\cdot))$
(random function)

$\underline{\underline{n=1}}$ x_1, $f(\cdot)$ r.f. $\overset{\text{it follows that}}{\Rightarrow}$ $f(x_1)$ r.v. $\overset{\boxed{\text{By def. of GP}}}{\Rightarrow}$ $f(x_1) \sim N(m(x_1), c(x_1,x_1))$



$\underline{\underline{n=2}}$ x_1, x_2, $f(\cdot)$ r.f. $\overset{\text{it follows that}}{\Rightarrow}$ $f_{1:2} = (f(x_1), f(x_2))$ random vector

$\boxed{\text{By def. of GP}} \Rightarrow$ $f_{1:2} \sim N(m_{1:2}, C_2)$

$$m_{1:2} = \begin{pmatrix} m(x_1) \\ m(x_2) \end{pmatrix}, \quad C_2 = \begin{pmatrix} c(x_1,x_1) & c(x_1,x_2) \\ c(x_2,x_1) & c(x_2,x_2) \end{pmatrix}$$

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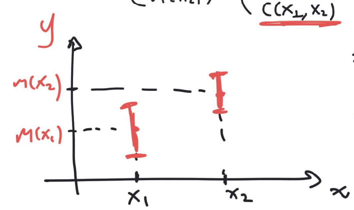

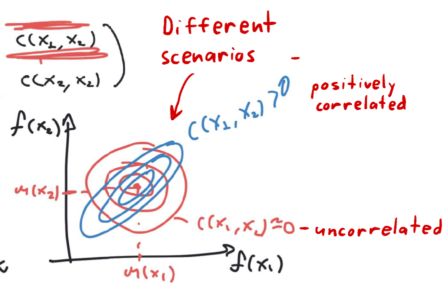

as $x_1 \to x_2$, the correlation increases

$\underline{n}$

$$x_{1:n} = (x_1, x_2, \dots, x_n)$$

$$f_{1:n} = (f(x_1), f(x_2), \dots, f(x_n)) \text{ random vector}$$

$$f_{1:n} \sim N(m_{1:n}, C_n)$$

$$m_{1:n} = \begin{pmatrix} m(x_1) \\ \vdots \\ m(x_n) \end{pmatrix}, \quad C_n = \begin{pmatrix} c(x_1,x_1) & \dots & c(x_1,x_n) \\ \vdots & \ddots & \vdots \\ c(x_n,x_1) & \dots & c(x_n,x_n) \end{pmatrix} = \left(c(x_i,x_j)\right)_{i,j=1}^{n}$$

- symmetric

implies

Stochastic Process > Kolmogorov Extension Theorem.

The mean function

$$f(\cdot) \sim GP(\boxed{m(\cdot)}, c(\cdot\,;\cdot))$$

$$f(x) \sim N(m(x), c(x,x))$$

$$\mathbb{E}[f(x)] = m(x)$$

what you expect $f(x)$ to be before you see any data.

↳ prior knowledge can be specified with $m(\cdot)$

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The covariance function

$$f(\cdot) \sim GP(m(\cdot), \boxed{c(\cdot,\cdot)})$$

$$f(x) \sim N(m(x), c(x,x))$$

$$\downarrow$$

$$V[f(x)] = c(x,x)$$

$$\begin{pmatrix} f(x_1), f(x_2) \end{pmatrix} \sim N\left(\begin{pmatrix} m(x_1) \\ m(x_2) \end{pmatrix}, \begin{pmatrix} c(x_1,x_1) & c(x_1,x_2) \\ c(x_1,x_2) & c(x_2,x_2) \end{pmatrix} \right)$$

$$C[f(x_1), f(x_2)] = c(x_1, x_2)$$

How correlated the function values at x_1 and x_2 are?

intuition

$c(x_1, x_2) \uparrow$ $f(x_1)$ and $f(x_2)$ are more correlated.

$c(x_1, x_2) \downarrow$ $f(x_1)$ and $f(x_2)$ are less correlated.

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