Homework #1

John Karasev

STAT 672

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1 Orthogonal projection in a hilbert space

$$\pi_V(f) \in V;$$
$$\langle f - \pi_V(f), g \rangle = 0 \ \forall g \in V;$$

1.
$$\begin{aligned}\|f\|^2 &= \langle f, f \rangle \\ &= \langle \pi_v(f) + (f - \pi_v(f)), \pi_v(f) + (f - \pi_v(f)) \rangle \\ &= \langle \pi_v(f), \pi_v(f) \rangle + 2\langle \pi_v(f), f - \pi_v(f) \rangle + \langle f - \pi_v(f), f - \pi_v(f) \rangle \\ &= \|\pi_v(f)\|^2 + \|f - \pi_v(f)\|^2 \ \textit{center term cancels since orthogonal}\end{aligned}$$

2.
$$\begin{aligned}\langle f, \pi_v(g) \rangle &= \langle (f - \pi_v(f)) + \pi_v(f), \pi_v(g) \rangle \\ &= \langle f - \pi_v(f), \pi_v(g) \rangle + \langle \pi_v(f), \pi_v(g) \rangle \\ &= \langle \pi_v(f), \pi_v(g) \rangle \ \textit{by orthogonality}\end{aligned}$$

$$\begin{aligned}\langle g, \pi_v(f) \rangle &= \langle (g - \pi_v(g)) + \pi_v(g), \pi_v(f) \rangle \\ &= \langle g - \pi_v(g), \pi_v(f) \rangle + \langle \pi_v(g), \pi_v(f) \rangle \\ &= \langle \pi_v(g), \pi_v(f) \rangle \ \textit{by orthogonality}\end{aligned}$$

$$\langle g, \pi_v(f) \rangle = \langle f, \pi_v(g) \rangle$$

3.

2 A reproducing kernel is positive definite

1.
$$\begin{aligned}K(x,y) &= \langle K_x(y), K_y(x) \rangle \ \textit{by reproducing property} \\ K(y,x) &= \langle K_y(x), K_x(y) \rangle \ \textit{by reproducing property} \\ K(x,y) &= K(y,x)\end{aligned}$$

2.
$$\begin{aligned}K(x,y) &= \langle K_x(y), K_y(x) \rangle \\ &= \langle K_y(x), K_y(x) \rangle \geq 0 \ \textit{by symmetry}\end{aligned}$$

3.
$$\begin{aligned}|f(x)| &\leq \|f\|\sqrt{K(x,x)} \\ |\langle f, K_x \rangle| &\leq \|f\|\sqrt{\langle K_x, K_x \rangle} \\ |\langle f, K_x \rangle| &\leq \|f\|\|K_x\| \ \textit{true by Cauchy} - \textit{Schwartz inequality}\end{aligned}$$

3 RKHS over a finite set

1.
$$\langle \boldsymbol{f}, \boldsymbol{g} \rangle = \boldsymbol{f}^T \boldsymbol{K}^{-1} \boldsymbol{g} \quad \boldsymbol{f}, \boldsymbol{g} \in \mathbb{R}^{2m+1}$$

$$\boldsymbol{\mathcal{N}}(\boldsymbol{x}; \boldsymbol{\mu}, \boldsymbol{\Sigma}) = \frac{1}{(2\pi)^{\frac{n}{2}} |\boldsymbol{\Sigma}|^{\frac{1}{2}}} exp\left\{ \frac{-(\boldsymbol{x} - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\boldsymbol{x} - \boldsymbol{\mu})}{2} \right\} \quad \boldsymbol{x} \in \mathbb{R}^n$$

$$\begin{aligned} p(\boldsymbol{f}) &= Ce^{-\frac{\|\boldsymbol{f}\|_H^2}{2}} \\ &= Cexp\left\{ -\frac{\boldsymbol{f}^T \boldsymbol{K}^{-1} \boldsymbol{f}}{2} \right\} \\ &= \frac{1}{(2\pi)^{\frac{2m+1}{2}} |\boldsymbol{K}|^{\frac{1}{2}}} exp\left\{ -\frac{\boldsymbol{f}^T \boldsymbol{K}^{-1} \boldsymbol{f}}{2} \right\} \\ p(\boldsymbol{f}) &= \boldsymbol{\mathcal{N}}(\boldsymbol{f}; \boldsymbol{0}, \boldsymbol{K}) \end{aligned}$$

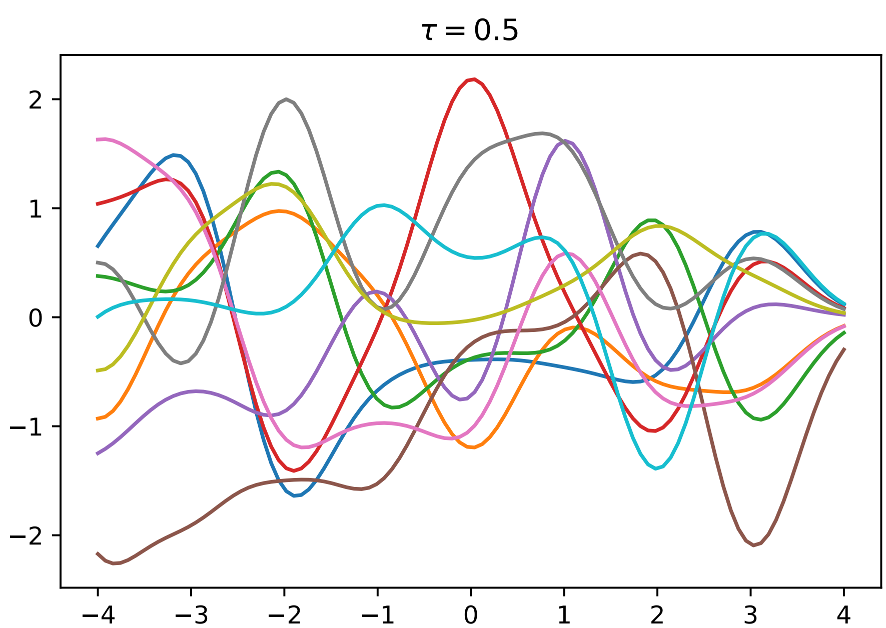
$$\begin{aligned} \therefore \ \boldsymbol{\mu} &= \boldsymbol{0} \\ \boldsymbol{\Sigma} &= \boldsymbol{K} \end{aligned}$$

2. C is a normalizing constant so the probability distribution sums to 1

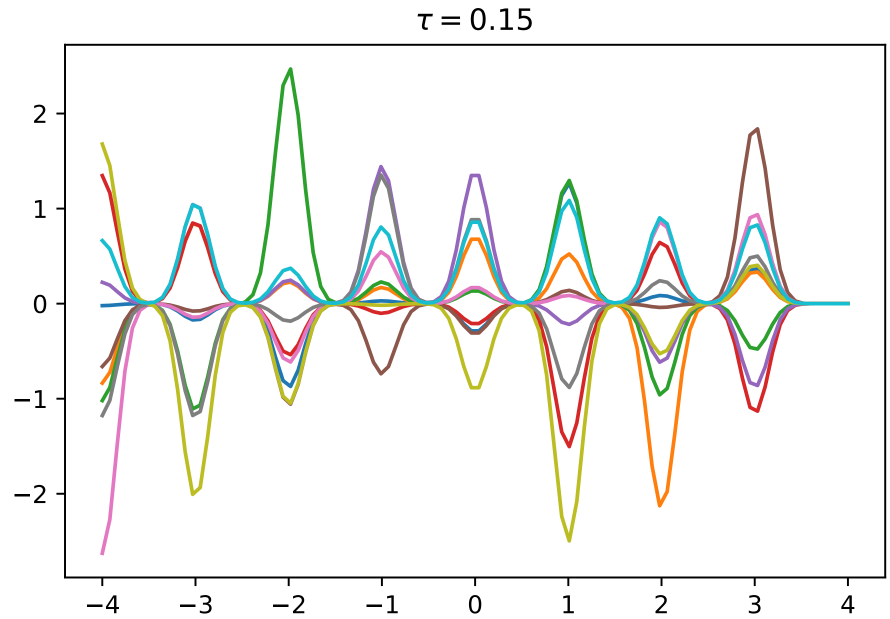
$$C = \frac{1}{(2\pi)^{\frac{2m+1}{2}} |\boldsymbol{K}|^{\frac{1}{2}}}$$

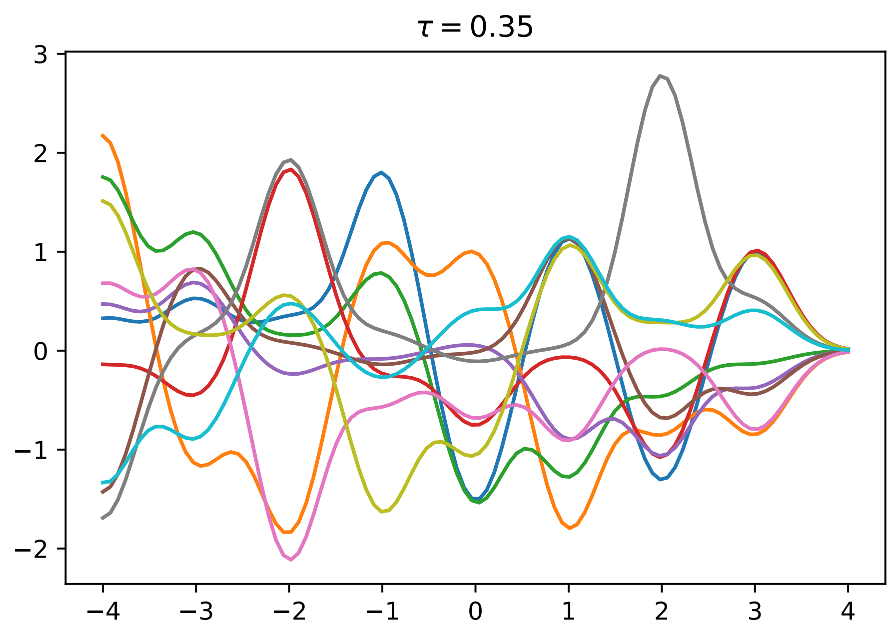
which is taken from the $\boldsymbol{\mathcal{N}}(\boldsymbol{f}; \boldsymbol{0}, \boldsymbol{K})$ normalization constant

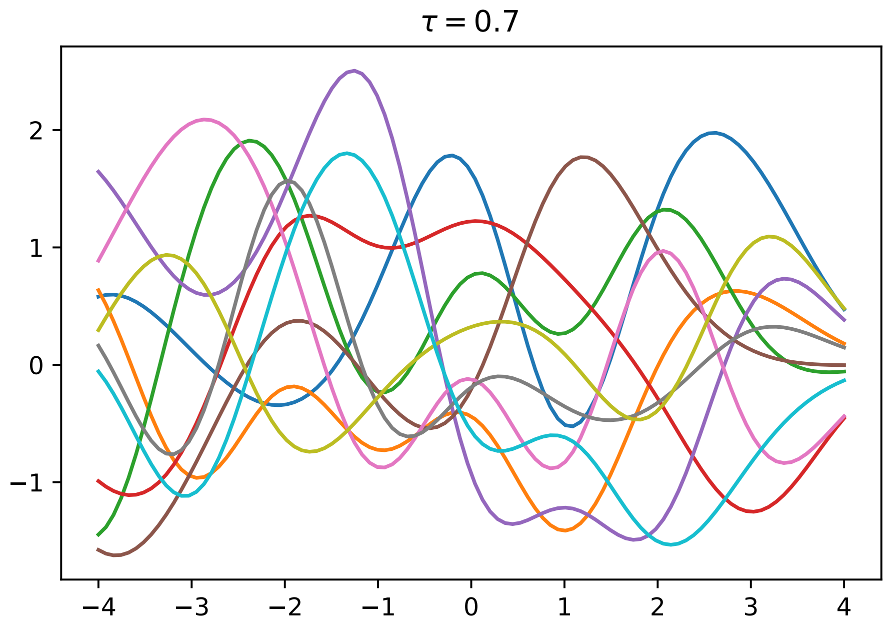
3. (a) kernel matrix: $\boldsymbol{K} = [k_{ij}] = Ce^{-\frac{(i-j)^2}{2\tau^2}}$



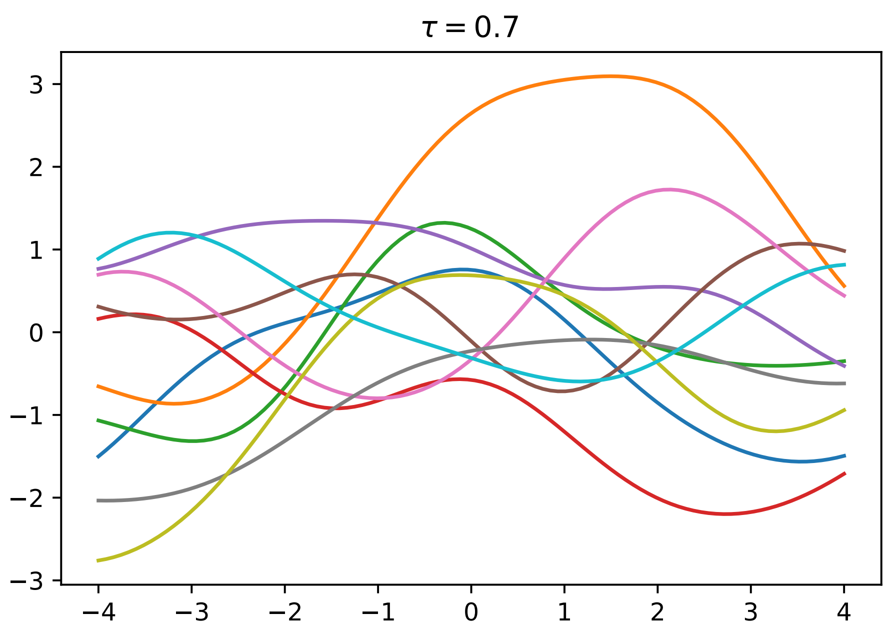
(b) functions become smoother as τ increases



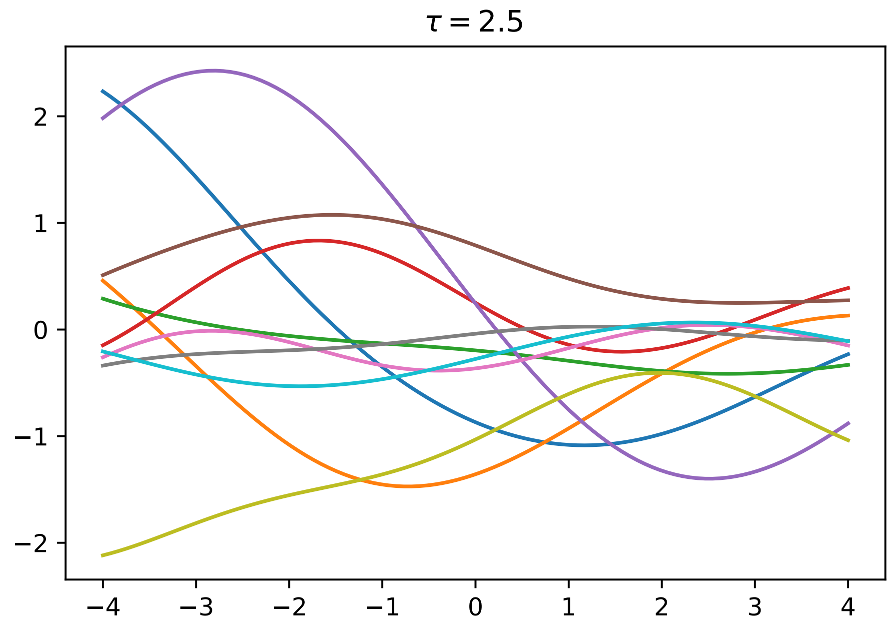


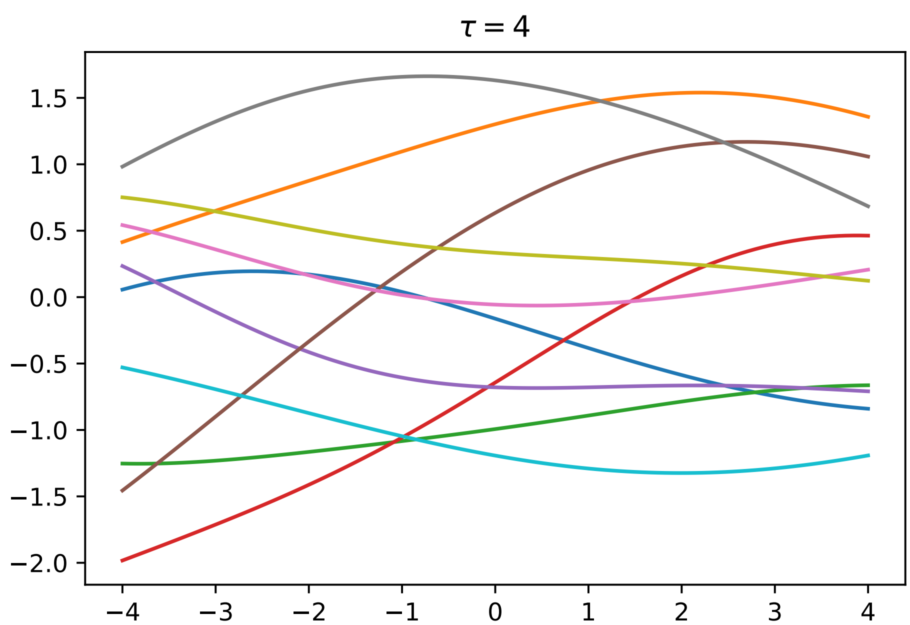


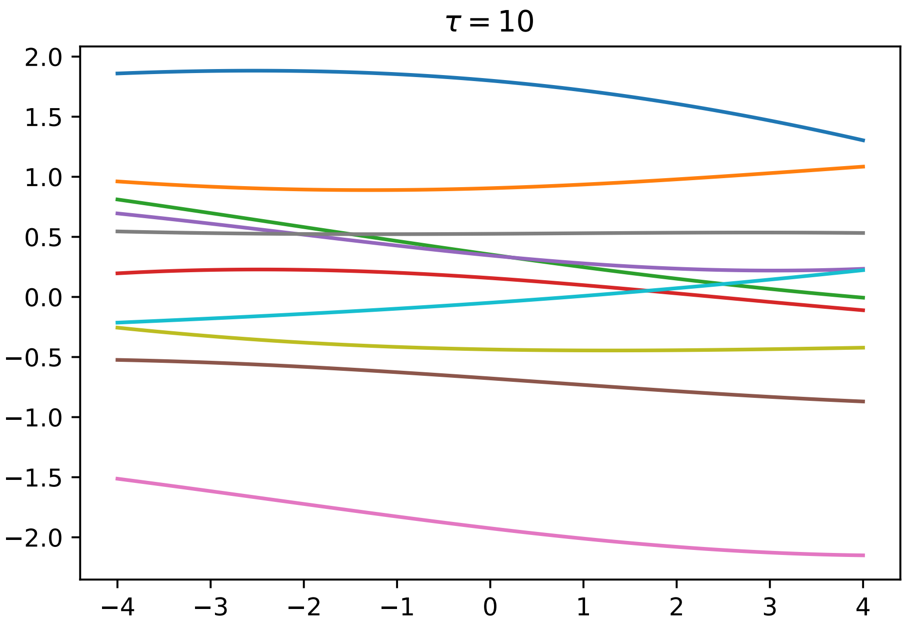
$\tau = 0.7$



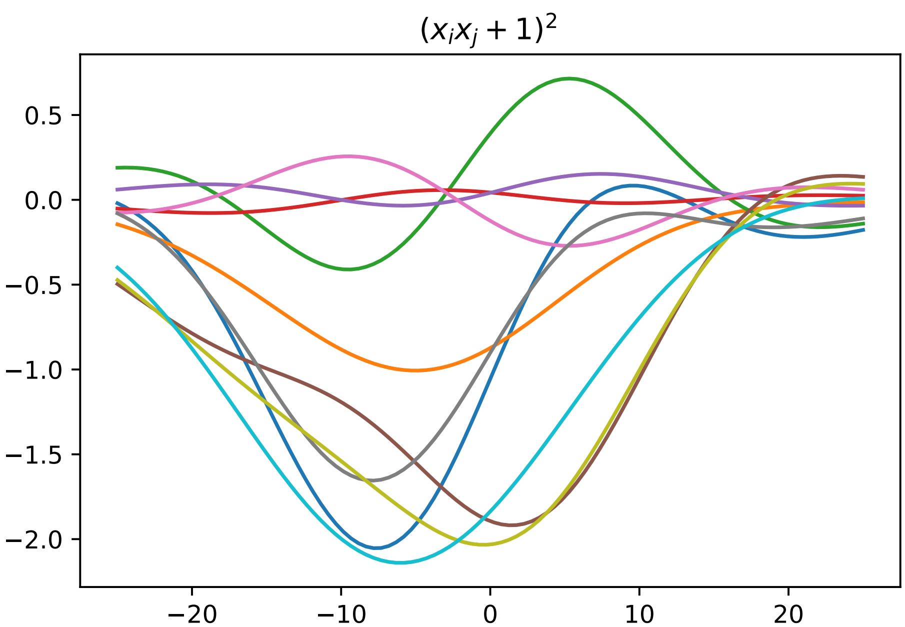
$\tau = 0.7$

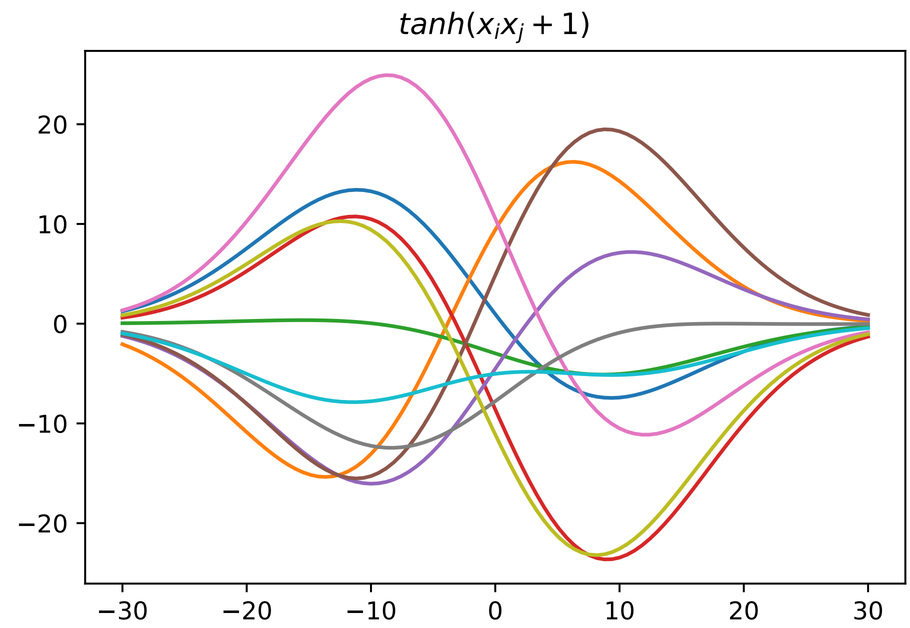

$\tau = 2.5$
2
1
0
−1
−2
−4
−3
−2
−1
0
1
2
3
4

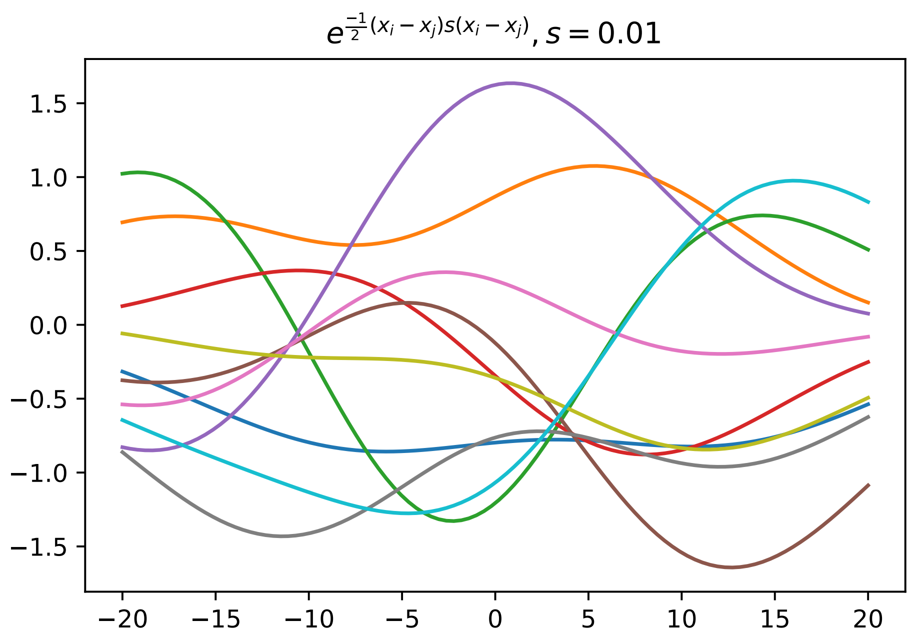

$\tau = 4$
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−4
−3
−2
−1
0
1
2
3
4

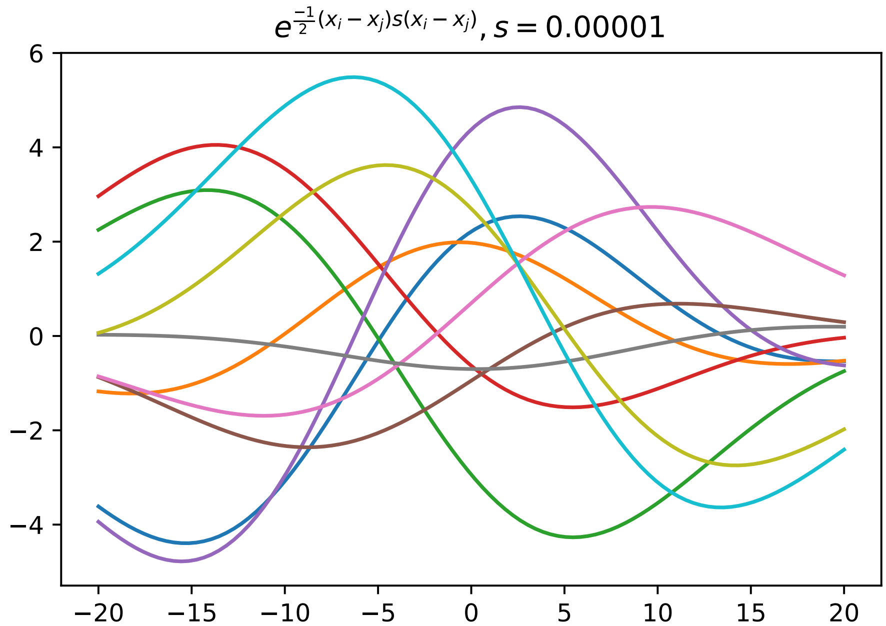

$\tau = 10$
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−4
−3
−2
−1
0
1
2
3
4

(c)


$(x_i x_j + 1)^2$
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−20
−10
0
10
20


$tanh(x_i x_j + 1)$
20
10
0
−10
−20
−30
−20
−10
0
10
20
30


$e^{\frac{-1}{2}(x_i - x_j)s(x_i - x_j)}, s = 0.01$
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−20
−15
−10
−5
0
5
10
15
20


$e^{\frac{-1}{2}(x_i - x_j)s(x_i - x_j)}, s = 0.00001$
6
4
2
0
−2
−4
−20
−15
−10
−5
0
5
10
15
20