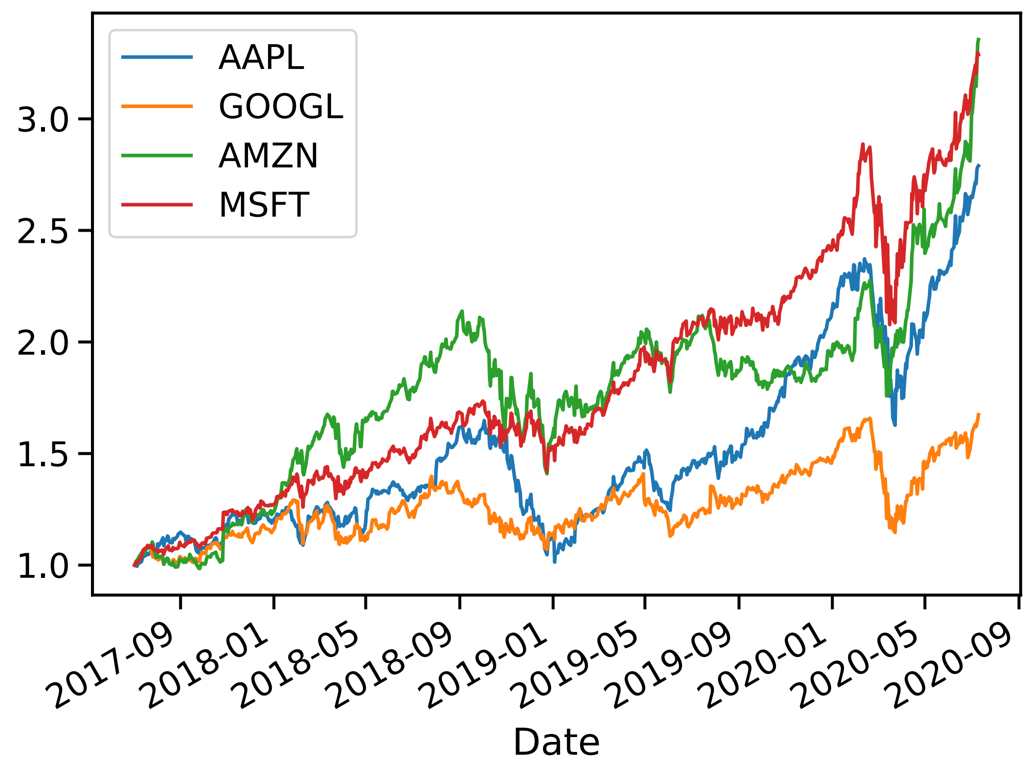
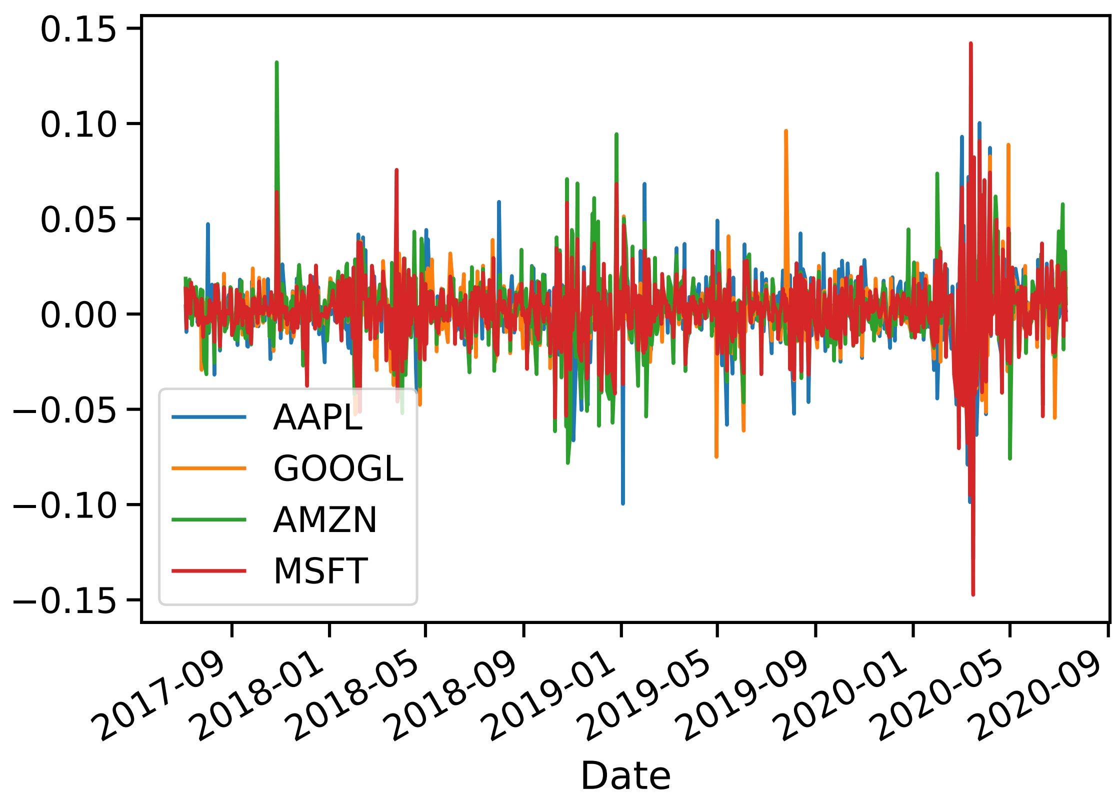
Gaussian Process Latent Variable Models in Finance

Rajbir-Singh Nirwan


AAPL
GOOGL
AMZN
MSFT
3.0
2.5
2.0
1.5
1.0
2017-09
2018-01
2018-05
2018-09
2019-01
2019-05
2019-09
2020-01
2020-05
2020-09
Date


0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
AAPL
GOOGL
AMZN
MSFT
2017-09
2018-01
2018-05
2018-09
2019-01
2019-05
2019-09
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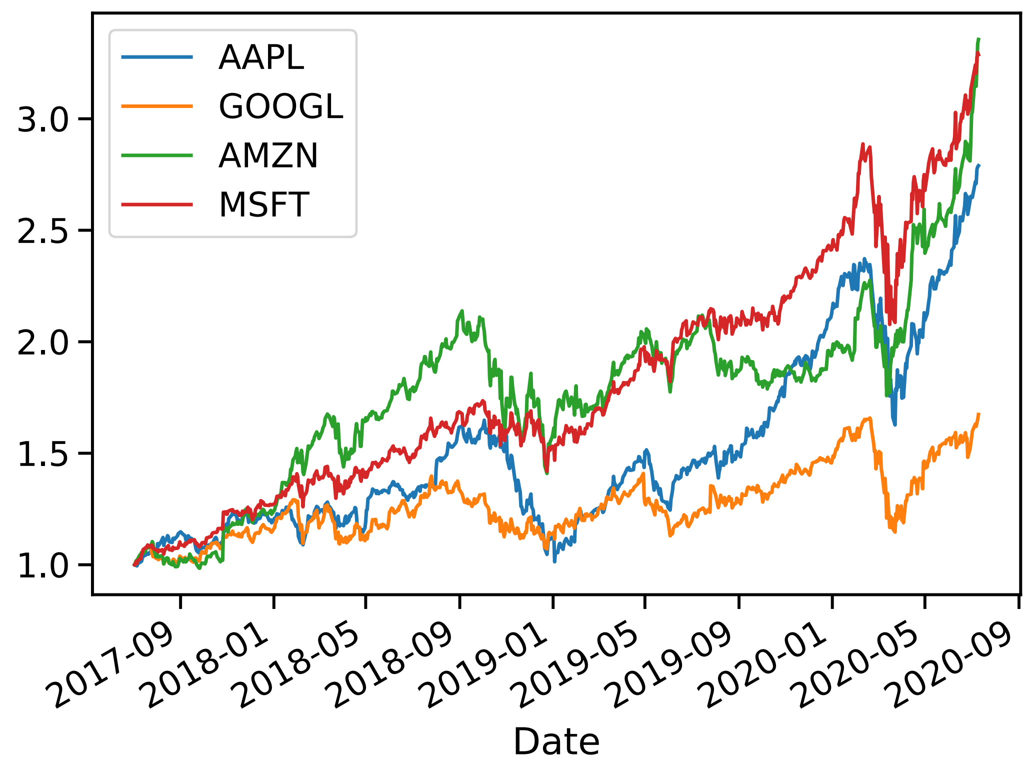
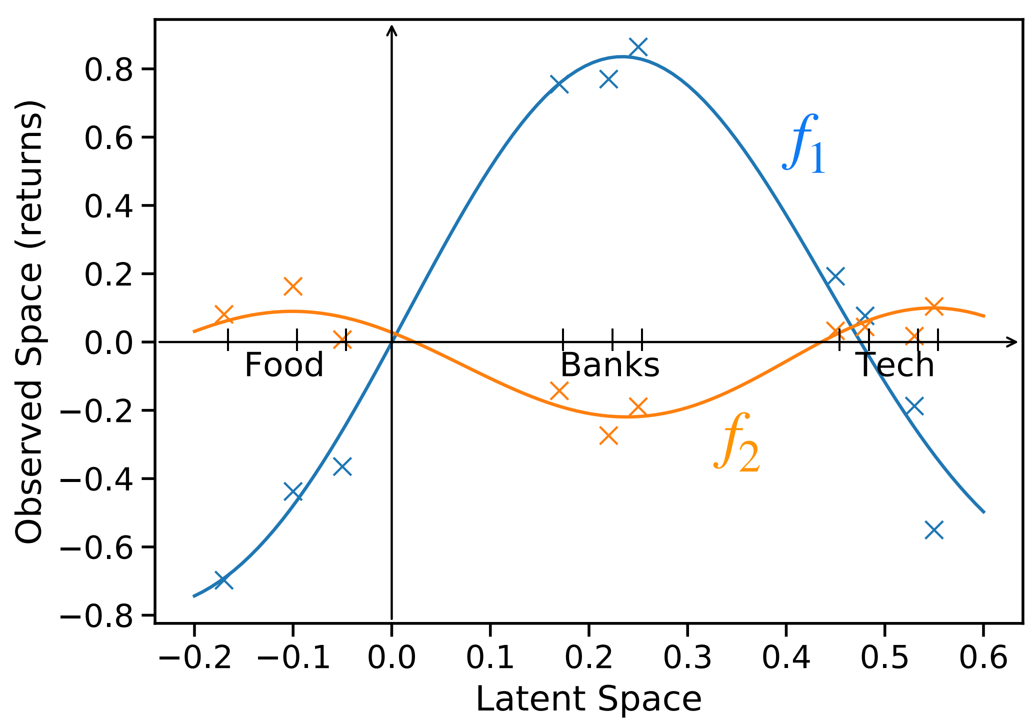
Date



RETURNS	07.07.20	08.07.20	09.07.20	10.07.20
AAPL	−0.31	2.33	0.43	0.17
GOOGL	−0.64	0.92	1.00	1.34
AMZN	−1.86	2.70	3.29	0.55
MSFT	−1.16	2.20	0.70	−0.30
FOOD				
BANK				

Generative Model



	Day1	Day2
Bank1	−0.70	0.08
Bank2	−0.44	0.16
Bank3	−0.36	0.01
Food1	0.75	−0.14
Food2	0.77	−0.27
Food3	0.86	−0.19
Tech1	0.19	0.03
Tech2	0.08	0.04
Tech3	−0.19	0.02
Tech4	−0.55	0.10

Outline

- Gaussian Processes
- Latent Variable Models
- Applications
  - Portfolio Allocation
  - Predicting missing Values
  - Structure Identification

Gaussian Processes

- Non-Parametric Kernel based approach
- Utilize full power of Bayesian statistics
- Complexity increases with the number of data points

Gaussian Processes

Weight space view

$$\Phi : x \rightarrow (\phi_1(x), \phi_2(x), \ldots, \phi_D(x))$$

$$f(x) = \boldsymbol{w}^T \Phi(x)$$

Simple and easy to interpret
but limited flexibility

$$f(x) = \boldsymbol{W}_2 \sigma \left(\boldsymbol{W}_1 \Phi_1(x) \right)$$

Highly flexible
but not interpretable

Function space view

$$k : x, x' \rightarrow k(x, x')$$

Flexibility increases with
number of data points

Mercers Theorem:

$$k(x, x') = \sum_d \lambda_d \phi_d(x) \phi_d(x')$$

$$\phi(x) = x$$
$$k(x, x') = xx'$$

$$\Phi(x) = (x, x^2)$$
$$k(x, x') = xx' + x^2 x'^2$$

$$k(x, x') = (xx' + c)^d$$
$$\Phi(x) = \mathit{polynomials\ up\ to\ order}\ d$$

$$k(x, x') = \exp(-0.5\ (x - x')^2 / \ell^2)$$
$$\Phi(x) = \mathit{infinitly\ many\ basis\ functions}$$

Gaussian Processes

Any finite collection of function values at $x_1, x_2, \ldots, x_N$ is jointly Gaussian distributed

$$p\left(f\left(x_1\right), f\left(x_2\right), \ldots, f\left(x_N\right)\right) = \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{K}) = \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix}, \begin{pmatrix} k_{11} & k_{12} & \cdots & k_{1N} \\ k_{21} & k_{22} & \cdots & k_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ k_{N1} & k_{N2} & \cdots & k_{NN} \end{pmatrix}\right) \qquad k_{ij} = k(x_i, x_j)$$

Common Kernel Functions

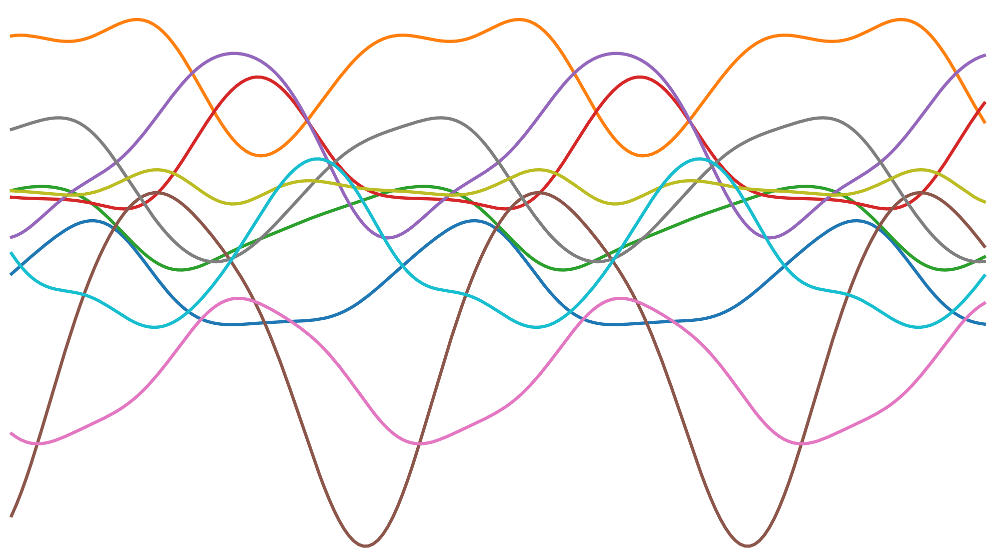
$$k_{linear}(x, x') = xx'$$

$$k_{rbf}(x, x') = \exp\left(-\frac{1}{2\ell^2}(x - x')^2\right)$$

$$k_{ou}(x, x') = \exp\left(-\frac{1}{\ell}|x - x'|\right)$$

$$k_{mat32}(x, x') = \left(1 + \frac{\sqrt{3}|x - x'|}{\ell}\right)\exp\left(-\frac{\sqrt{3}|x - x'|}{\ell}\right)$$

$$k_{periodic}(x, x') = \exp\left(-\frac{2}{\ell^2}\sin^2(|x - x'|)\right)$$

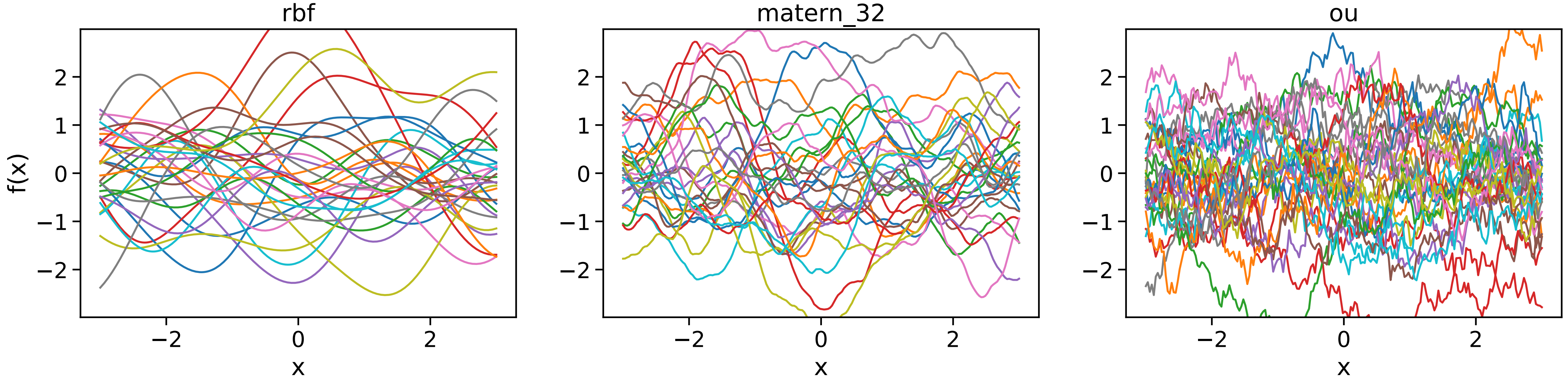


Gaussian Processes

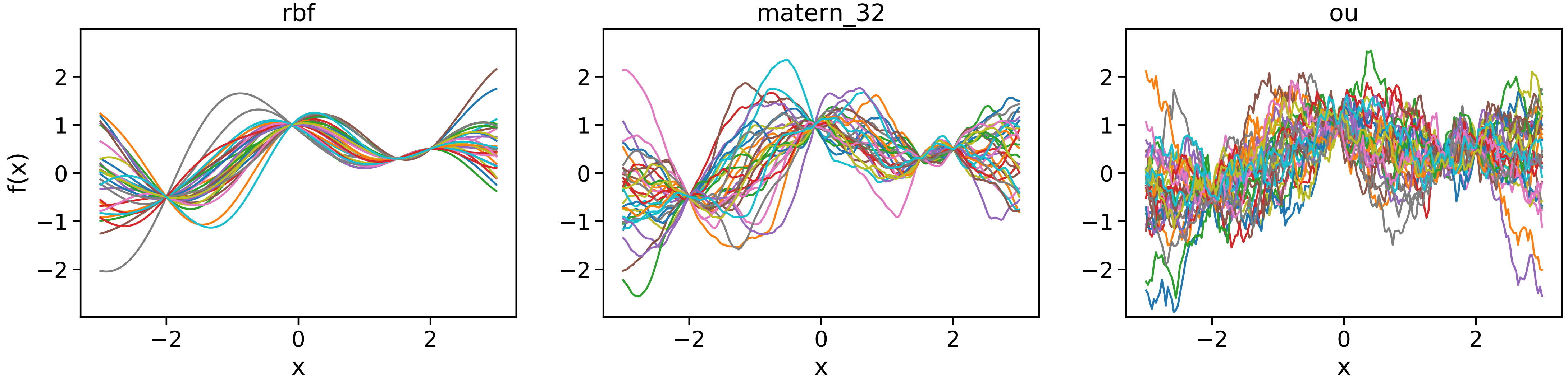
Bayes Theorem

$$p(f\,|\,\mathscr{D}) = \frac{p(\mathscr{D}\,|\,f)p(f)}{p(\mathscr{D})}$$

Prior

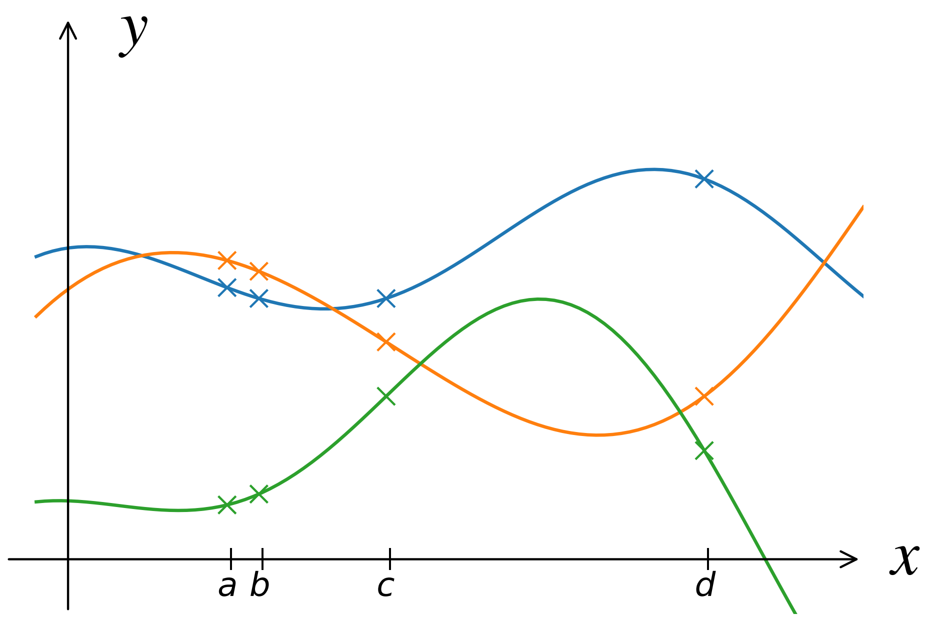


Posterior



Latent Variable Models

$$\boldsymbol{X} \in \mathbb{R}^{N\times Q} \quad \xrightarrow{f} \quad \boldsymbol{Y} \in \mathbb{R}^{N\times D}$$



$$\begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} \xrightarrow{f_i} \begin{pmatrix} a_1 & a_2 & a_3 & \\ b_1 & b_2 & b_3 & \cdots \\ c_1 & c_2 & c_3 & \\ d_1 & d_2 & d_3 & \end{pmatrix}$$

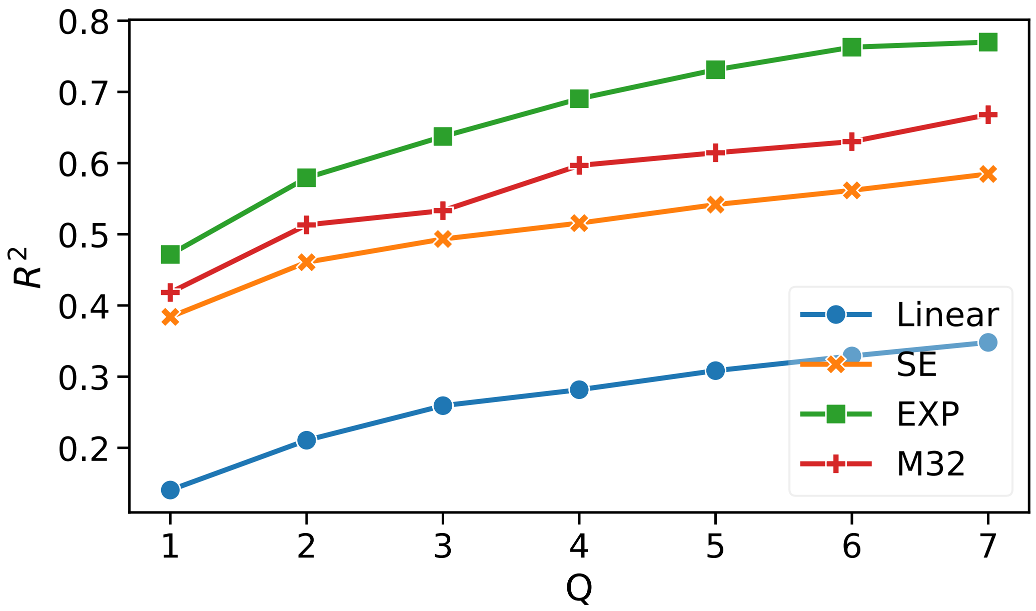
- Can we infer the hidden state $\boldsymbol{X}$ only by looking at $\boldsymbol{Y}$? Yes
- Inference using GPs also gives us the covariance $\boldsymbol{K}$ between different points

Experiments

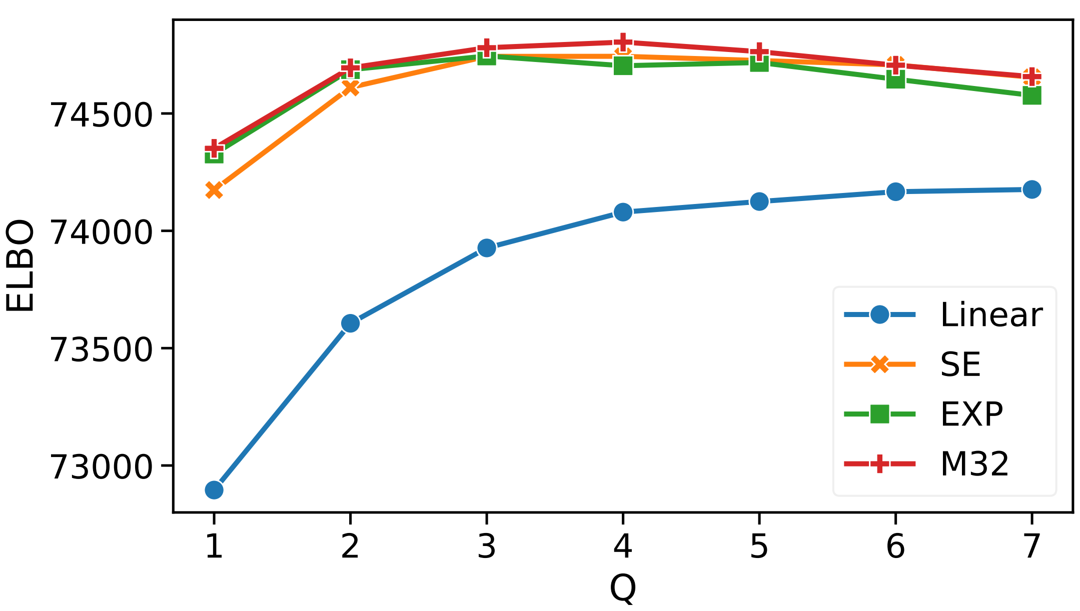
Use Variational Bayes for the inference - data $Y \in \mathbb{R}^{N \times D}$

Approximate the true posterior with a simple distribution

R^2 - Variance of the data captured by the model



ELBO - Lower bound to the marginal likelihood



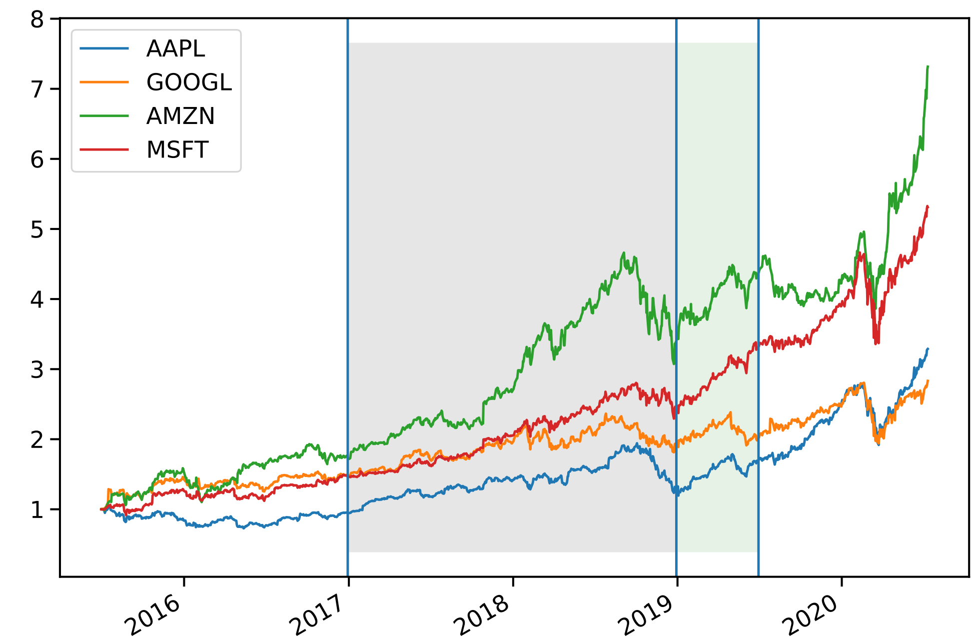
Portfolio Allocation

Given N stocks, how should I weight them to get an optimal portfolio?

Markowitz Portfolio Theory

$$\boldsymbol{w}_{opt} = \min_{\boldsymbol{w}} \left(\boldsymbol{w}^T \boldsymbol{K} \boldsymbol{w} - q \boldsymbol{w}^T \boldsymbol{\mu} \right)$$

Learn weights on previous 2 years
Hold portfolio for next 6 months



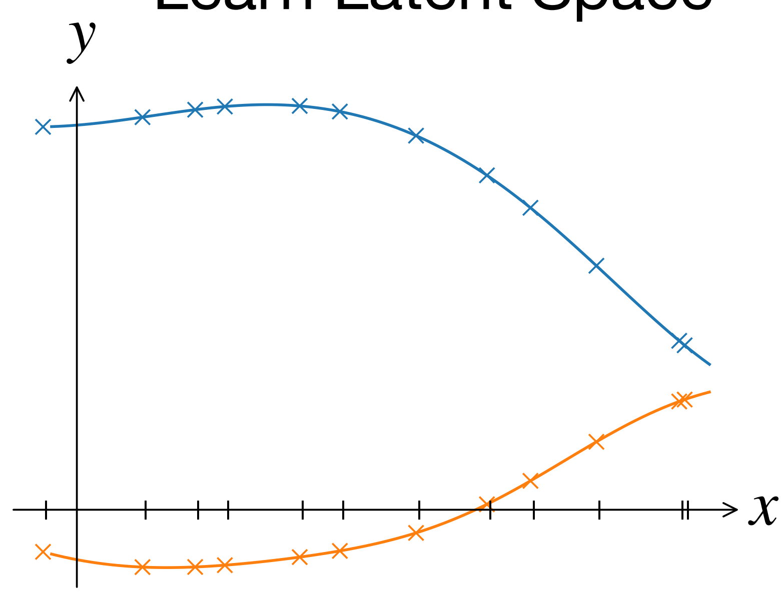
Backtesting on S&P500 from 2002 to 2018

Model	Linear	SE	EXP	M32	Sample Cov	Ledoit Wolf	Eq. Weighted
Mean	0.142	0.151	0.155	0.158	0.149	0.148	0.182
Std	0.158	0.156	0.154	0.153	0.159	0.159	0.232
Sharpe ratio	0.901	0.969	1.008	1.029	0.934	0.931	0.786

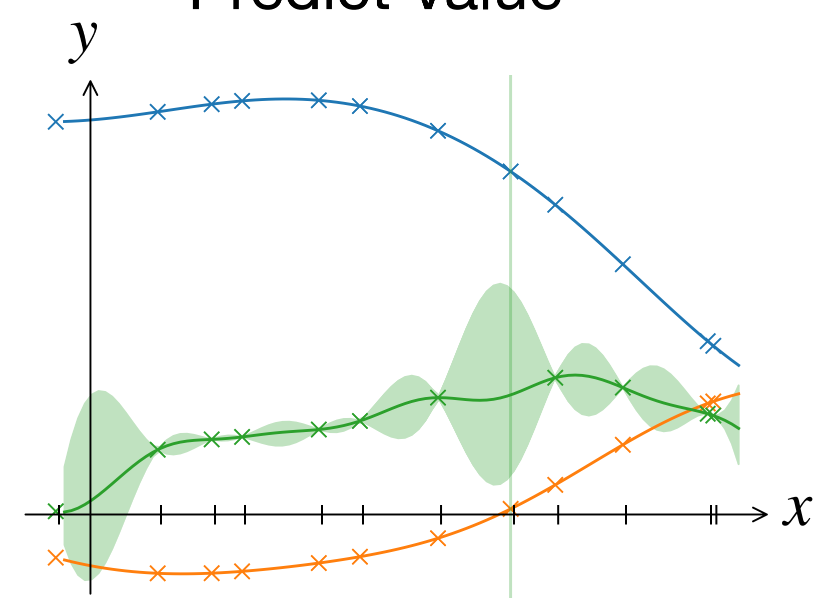
Predict Missing Values

$$\left(\begin{array}{cccc} & a_1 & a_2 & a_3 \\ \cdots & b_1 & b_2 & NaN \\ & c_1 & c_2 & c_3 \\ & d_1 & d_2 & d_3 \end{array} \right)$$

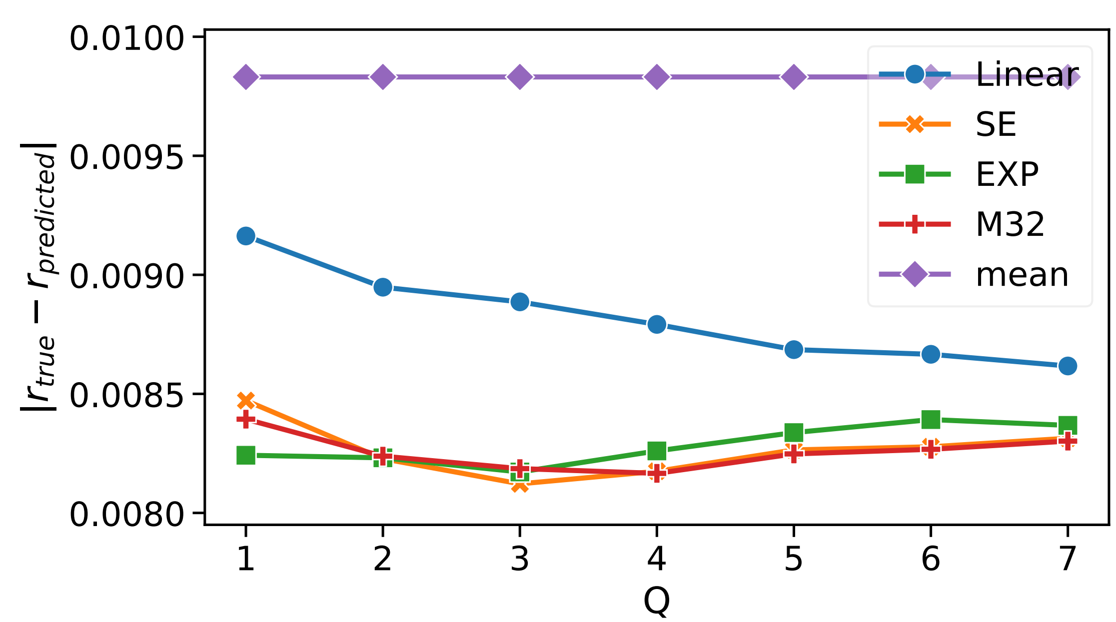
Learn Latent Space



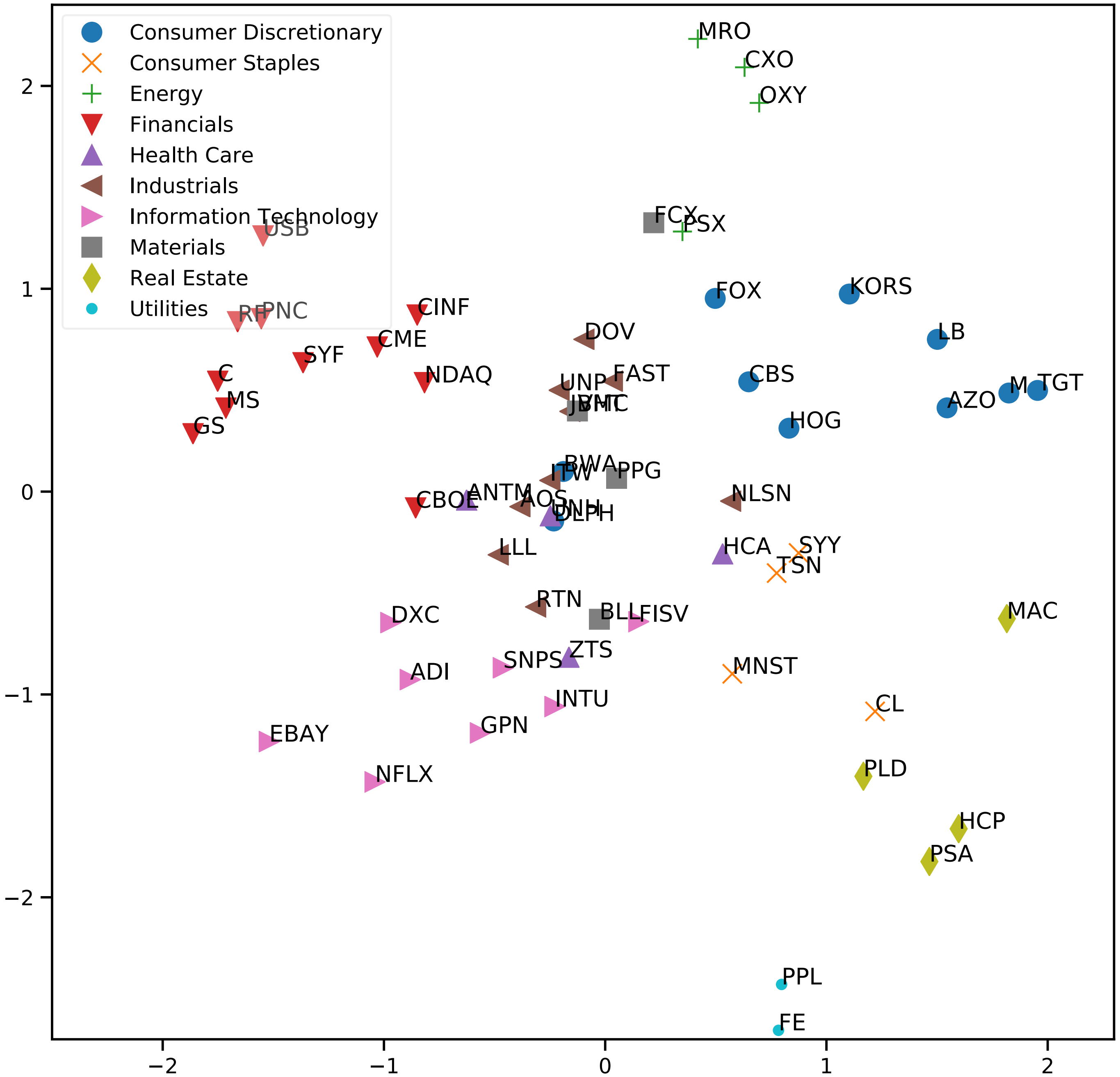
Predict Value



Prediction of missing values for held out dataset

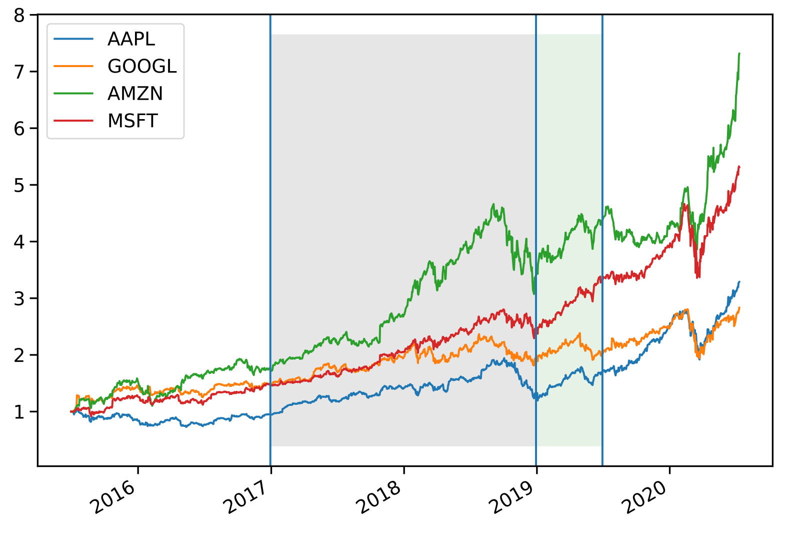


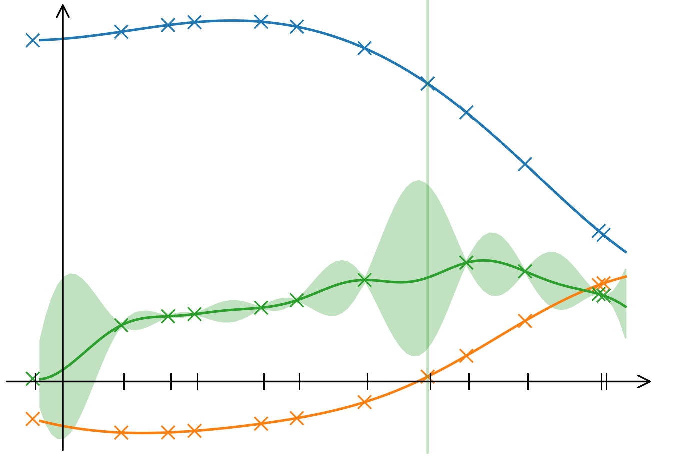
Visualization of Latent Space

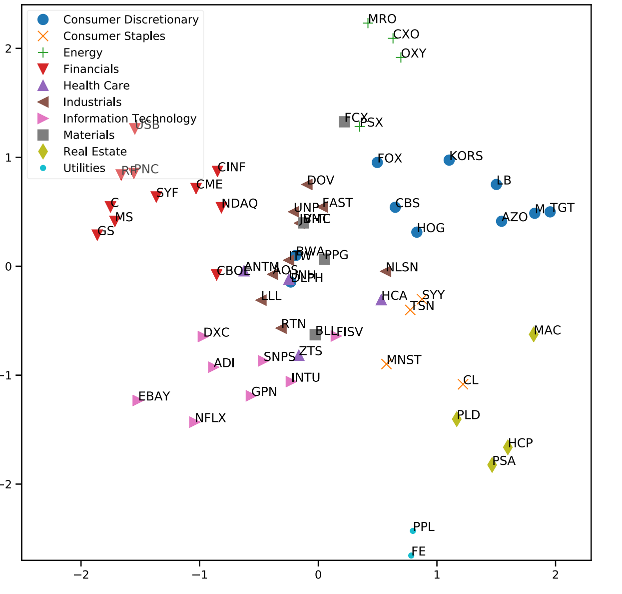


Summary

- Use of Gaussian Processes in Finance
- Build Portfolio based on the Covariance between Stocks
- Better Predictor for Missing values
- Latent Space Structure Identification







Summary

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https://github.com/RSNirwan/GPLVMsInFinance

Applications of Gaussian Process Latent Variable Models in Finance
RS Nirwan, N Bertschinger - Proceedings of SAI Intelligent Systems Conference, 2019