Artificial Intelligence Machine Learning in Marine Hydrodynamics

by

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Machine Learning Disciplines

• Statistics (Frequentist & Bayesian)

• Information Theory (Shannon Entropy – Kullbak-Liebler Divergence)

• Convex Optimization Theory (Lagrangian & Fenchel Dual)

• Computation (Gradient Descent, Markov-Chain Monte Carlo)

• Functional Analysis (SVM-Positive Definite Kernels)

• Physics (Field Methods, Variational Bayesian Formulations)
Formulation of ML Algorithms

Design Matrix: \([\tilde{X}_1^{T}, \ldots, D, Y]_{n=1, \ldots, N} ; N(\text{Samples}) \times (D + 1)(\text{Input Features} + \text{Output})\); 

\[ p(Y, \tilde{X}) = p(Y|\tilde{X})p(\tilde{X}) \]

Bayes Rule: 
\[ p(\tilde{X}|Y) = \frac{p(Y|\tilde{X})p(\tilde{X})}{p(Y)} = \frac{p(Y|\tilde{X})p(\tilde{X})}{\int d\tilde{X} p(Y|\tilde{X})p(\tilde{X})} \]

\( p(Y|\tilde{X}) \): Supervised Learning; Density of Output Conditional on Observed Input
\( p(\tilde{X}) \): Unsupervised Learning of \( \tilde{X} \); Density Estimation / Prior
\( p(\tilde{X}|Y) \): Density of Input Conditional on Observed Output / Feature Selection

\[ \hat{Y} = F(\tilde{X}) = \sum_{i=1}^{M} \beta_i h_i(\tilde{X}; \alpha_i) \]

\( h \): Linear, Spline, Sigmoid, Gaussian, Decision Tree

\[ \min_{\alpha, \beta, \lambda, M} \left[ \sum_{n=1}^{N_{\text{Train}}} \text{Loss}[Y_n, \hat{Y}_n] + \lambda \| h \|_p \right], \text{ } p-\text{Norm Penalized Loss} \]
Machine Learning Algorithms

- Linear & Polynomial Regression (Ridge L2, Lasso L1, Splines)
- Artificial Neural Networks – Deep Learning
- Support Vector Machines – L2 Norm Kernel “Trick”
- Decision Trees – Boosting (AdaBoost, XGBoost, DeepBoost)
- Random Forests (Bootstrapping, Random Subsampling)
Model-Predictive Control of Floating Wind Turbines and Wave Energy Converters

SVM Forecasts of Seastate Elevations: RMS Error 5-10% Hs

Sponsor: DOE, ONR
Viscous Loads on a Liquefied Natural Gas Carrier

Sponsor: ONR
Free-Decay Test – Liquid LNG
Gaussian SVM Kernel Model for Viscous Load

Training data set--Liquid cargo, With keels

Test data set--Liquid cargo, With keels