Machine Learning for High-Fidelity Prediction and Optimization of Concrete Properties

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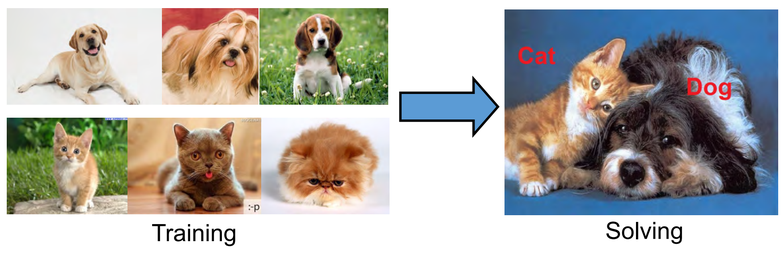
Introduction

- **Machine Learning (ML):**

A computer algorithm learns "cause-effect" correlations during training, and then leverages such knowledge to make predictions in new data-domains.



Training Solving

- **Types of machine learning algorithms:**
  - **Supervised learning**: The algorithm trains the machine using the training dataset, and generate reasonable predictions for the response to the new dataset.
  - **Unsupervised learning**: Find the underlying structure or distribution of the dataset without any training process.
- **Applications:**
  - Online recommendation offer
  - Self-Driving car

Why ML for Concrete?

- Extremely large compositional degrees of freedom (i.e., permutations and combinations of mixture design variables can significantly influence on properties).
- Materials theory based models cannot make a good prediction on properties of concrete (i.e., chloride concentration on the surface of concrete (Figure1)).
- Non-linear relationships between mixture design variables and properties of concrete (i.e., coarse aggregate content vs. modulus of elasticity (Figure 2)).

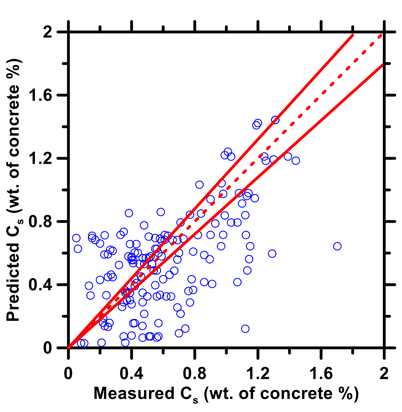


Figure 1 – Materials theory based model predicts the chloride concentration on the surface of concrete (C_s) in an inaccurate manner.

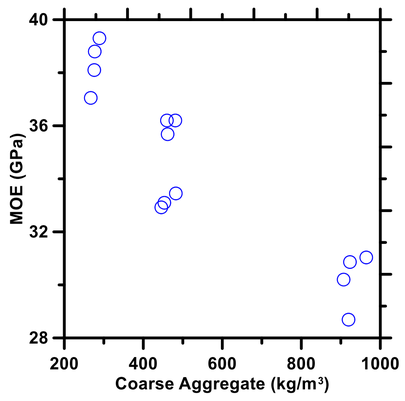


Figure 2 – The non-linear relationship between modulus of Elasticity (MOE) of concrete and the content of coarse aggregate. All other variables are same in this case.

Acknowledgments

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References

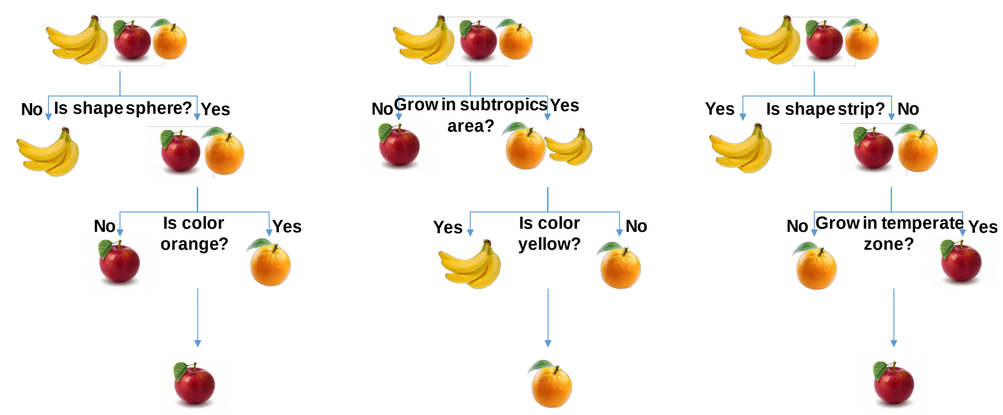
[1] J.-S. Chou and C.-F. Tsai, "Concrete compressive strength analysis using a combined classification and regression technique," *Automation in Construction*, vol. 24, pp. 52–60, Jul. 2012.

[2] J.-S. Chou, C.-F. Tsai, A.-D. Pham, and Y.-H. Lu, "Machine learning in concrete strength simulations: Multi-nation data analytics," *Construction and Building Materials*, vol. 73, pp. 771–780, Dec. 2014.

[3] L. Sachan, "Logistic Regression Vs Decision Trees Vs SVM: Part I." https://www.edvancer.in/logistic-regression-vs-decision-trees-vs-svm-part1/ .

Machine Learning Models

Random Forest (RF)



Random Forest:

- A model grows several decision trees with yes and no questions.

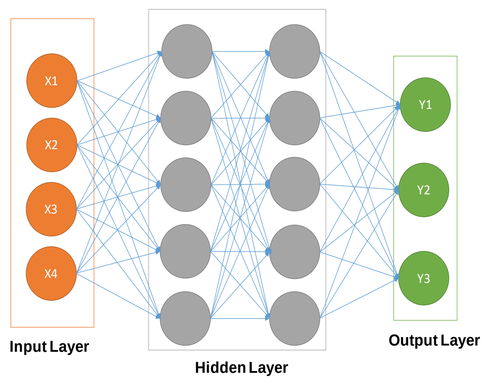
Advantages:

- Good for both classification and regression task
- Minimum overfitting
- High accuracy on large and high-dimensional dataset

Limitation:

- Due to complex structure, the prediction process may be slowly and ineffectively for real-time predictions.

Multilayer Perceptron — Artificial Neural Network (MLP-ANN)



Multilayer Perceptron:
A model consists of one input layer, several hidden layers, and one output layer. Neurons of each layer independently compute and pass the results to the next layer.

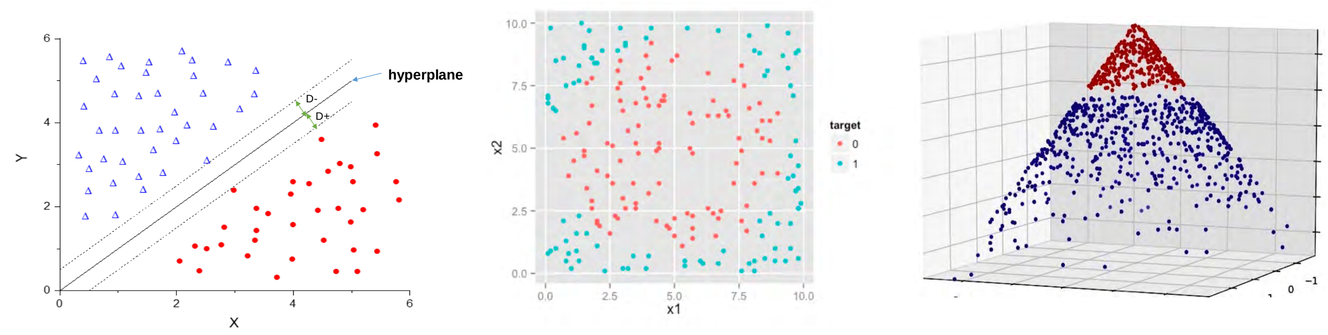
Advantages:

- Sufficient hidden layers can approximate any continuous function to any desired accuracy
- Ability to learn conditional probabilities
- Effective on non-linear regression

Limitation:

- May get stuck at the local minimum point
- Need large dataset for training

Support Vector Machine (SVM)



Support Vector Machine:
A model separate the dataset into different categories with clear gaps in a high or infinite dimensional space.

Advantages:

- Good for both classification and regression task
- Effective on high dimensional space
- Effective when number of dimensions > number of samples

Limitation:

- The accuracy depends on choice of the kernel
- Overfitting with non-optimized parameter setting

Results

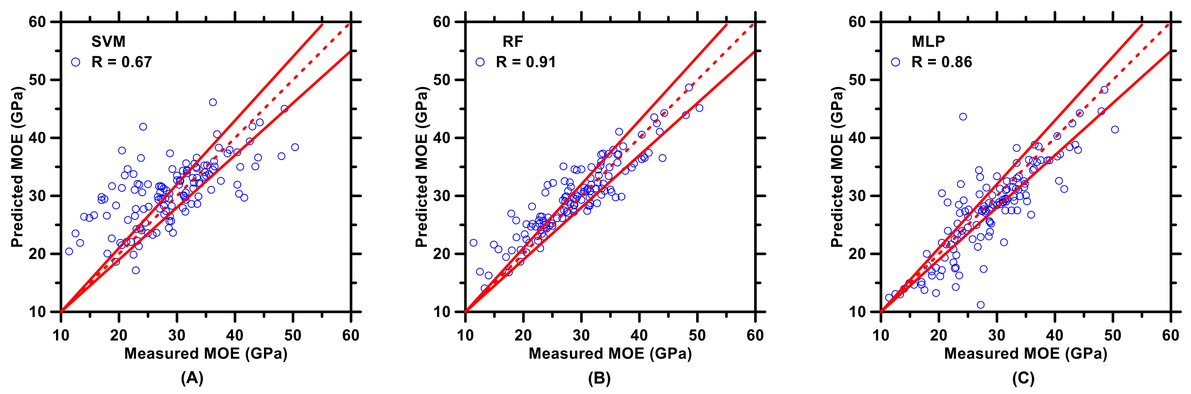


Figure A-C shows that three machine learning models predicted modulus of elasticity (MOE) of concrete. **The RF model exhibits the best performance.**

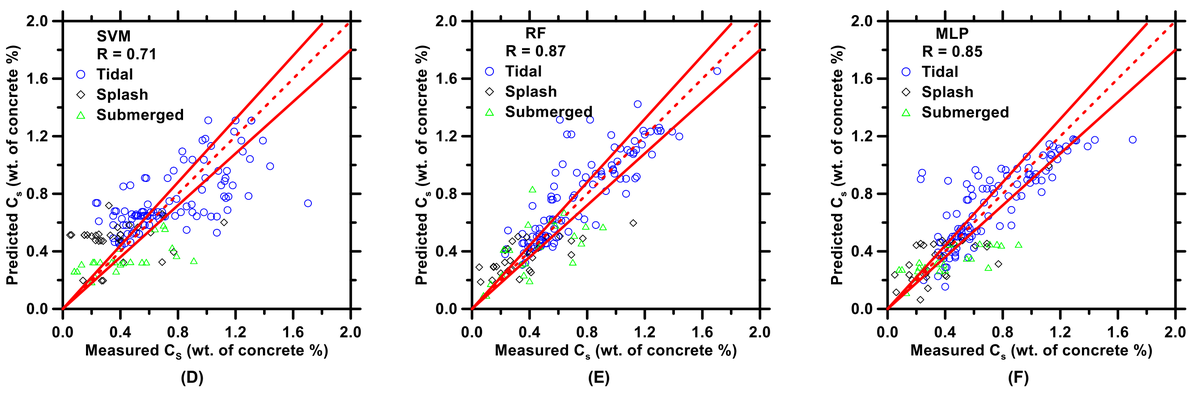


Figure D-F shows that three machine learning models predicted chloride concentration on the surface of concrete (C_s) under three environments. **The RF model exhibits the best performance.**

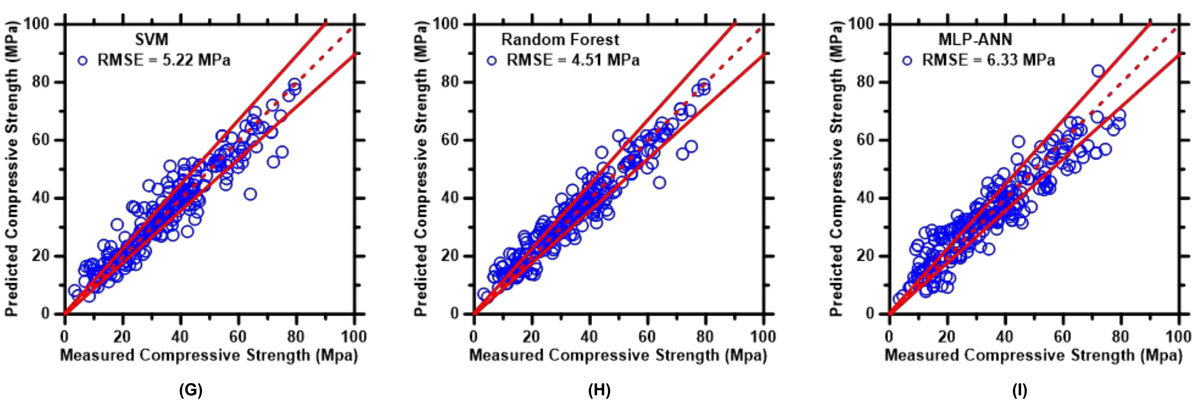


Figure G-I shows that three machine learning models predicted the compressive strength of concrete. **The RF model exhibits the best performance.**