

A Machine Learning Framework for Stock Selection

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Abstract—This paper demonstrates how to apply machine learning algorithms to distinguish “good” stocks from the “bad” stocks. To this end, we construct 244 technical and fundamental features to characterize each stock, and label stocks according to their ranking with respect to the return-to-volatility ratio. Algorithms ranging from traditional statistical learning methods to recently popular deep learning method, e.g. Logistic Regression (LR), Random Forest (RF), Deep Neural Network (DNN), and the Stacking, are trained to solve the classification task. Genetic Algorithm (GA) is also used to implement feature selection. The effectiveness of the stock selection strategy is validated in Chinese stock market in both statistical and practical aspects, showing that: 1) Stacking outperforms other models reaching an AUC score of 0.972; 2) Genetic Algorithm picks a subset of 114 features and the prediction performances of all models remain almost unchanged after the selection procedure, which suggests some features are indeed redundant; 3) LR and DNN are radical models; RF is risk-neutral model; Stacking is somewhere between DNN and RF. 4) The portfolios constructed by our models outperform market average in back tests.

Index Terms—Quantitative Finance; Stock Selection; Machine Learning; Deep Learning; Feature Selection;

I. INTRODUCTION

There are mainly three types of trading strategies to construct in financial machine learning industry, i.e. asset selection [1], which selects potentially most profitable assets to invest, portfolio management [2], which distributes fund into the assets to optimize the risk-profit profile, and timing [3], which determines the apposite time to enter or leave the market. Effective asset selection is the bedrock of the whole trading system, without which the investment will be an irreparable disaster even if the most advanced portfolio management and timing strategies are deployed, and we therefore focus on asset selection, to be more specific, stock selection problem, in this article.

The essence of stock selection is to distinguish the “good” stocks from the “bad” stocks, which lies into the scenario of classification problem. To implement the classification system, some natural questions emerge: 1) how to label stock instances correctly? 2) what machine learning algorithms shall we choose? 3) what features to consider and how to select the best subset of features? 4) how to evaluate models’ performances?

For question 1), we rank stocks according to the return-to-volatility ratio and label the top and bottom Q percent stocks as positive and negative respectively [5]. The stocks ranking

in the middle of all candidates are discarded. This labeling technique enjoys two major advantages: Firstly, profitability and risk are both taken into account to give a comprehensive measure of stocks’ performances, which is exactly the basic idea of Sharpe Ratio [15]; Secondly, only the stocks whose behaviors are archetypical are used to train the classifiers, by which the ambiguous noisy information is filtered out.

For question 2), we train learning algorithms ranging from traditional statistical learning methods to recently popular deep learning method, e.g. Logistic Regression (LR) [11], Random Forest (RF) [10], Deep Neural Network (DNN) [14], and the Stacking [12], to solve the classification task. The Stacking architecture we used is a two-dimensional LR model whose inputs are the outputs of trained RF and DNN. By Stacking, we pack heterogeneous machine learning models into a single ensemble model which outperforms its every individual component. Further note that financial time series data is non-stationary and its signal-noise ratio is low, which engender the over-fitting problem [4], especially for DNN. Hence, state-of-the-art mechanisms such as Dropout [8], Batch-Normalization [9] and Model Regularization [14] are applied to DNN to alleviate the issue.

For question 3), 244 technical and fundamental features are constructed to characterize each stock while some of the features may be redundant which introduce noise and increase the computational burden, and therefore effective features subset selection is crucial. In this work, we apply the Genetic Algorithm (GA) [7] to conduct globally optimal subset searching in a search space with exponential cardinality, which outperforms random selection greatly in our experiments.

For question 4), the effectiveness of selection strategy is validated in Chinese stock market in both statistical and practical aspects. We first use the traditional train-test evaluation to examine the prediction performance of our models. Then we use the outputs of models to construct portfolios to trade in real historical market competing with the market average.

The evaluation result shows that: 1) Stacking of RF and DNN outperforms other models reaching an AUC score of 0.972; 2) GA picks a subset of 114 features and the prediction performances of all models remain almost unchanged after the selection procedure, which suggests some features are indeed redundant. 3) LR and DNN are radical investment models; RF is risk-neutral model; Stacking’s risk profile is somewhere

between DNN and RF. 4) The portfolios constructed by our models outperform market average in back tests.

The implementation¹ of the proposed stock selection strategy is available at Github and a data sample is also shared.

II. DATASET CONSTRUCTION

A. Tail and Head Label

Say there are M stock candidates and T days historical stock data. We use feature vector $X_i(t) \in R^n$ to characterize the behavior of the i^{th} stock up to the t^{th} trading day and assign the return-to-volatility ratio $y_i(t, f)$ to $X_i(t)$ assessing the performance of the i^{th} stock during trading period $[t+1, t+f]$, where f is the length of the forward window.

For each t under consideration, we obtain a set of feature vectors $\{X_i(t) | i \in \{1, 2, \dots, M\}\}$ and a set of return-to-volatility ratios $\{y_i(t, f) | i \in \{1, 2, \dots, M\}\}$. We rank stocks with respect to their return-to-volatility ratios and then do the following manipulations:

- Label the top Q percent as positive, i.e. $y_i(t, f) := 1$;
- Label the bottom Q percent as negative, i.e. $y_i(t, f) := 0$;
- Discard the samples in the middle.

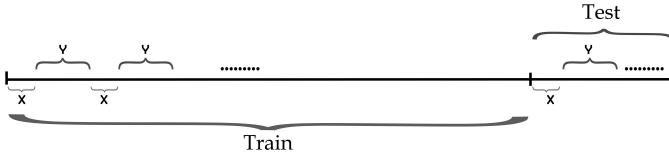


Fig. 1. Data Split

To avoid data overlapping, at most $\lfloor \frac{2QM}{100(1+f)} \rfloor$ samples can be labeled. Fig. 1. shows how to split data.

B. Feature Vector

We construct 244 fundamental and technical features to characterize each stock at different trading days. Appendix lists the name of the constructed features.

III. GENETIC ALGORITHM BASED FEATURE SELECTION

Genetic Algorithm (GA) is a metaheuristic inspired by Darwin Natural Selection, where a population of individuals, representing a collection of candidate solutions to an optimization problem, are evolved towards better results through iteration. Each individual is assigned with a chromosome which can be mutated or crossed. The pipeline of GA is given by Fig. 2.

A. Chromosome

In this work, each individual's chromosome is an encoding of a subset of features. Specifically, each individual's chromosome is vector $C \in \{0, 1\}^n$, such that C 's i^{th} component:

$$C_i := \begin{cases} 1 & \text{if the } i^{th} \text{ feature is selected} \\ 0 & \text{else} \end{cases} \quad (1)$$

where n denotes the total number of features, which is 244 in our case.

¹<https://github.com/fxy96/Stock-Selection-a-Framework>

B. Initialization

Suppose that the population size is 100. We initialize the 0^{th} generation by randomly generating 100 binary vectors independently identically distributed with $Binomial(244, 0.5)$.

For each individual, we need to check if the sum of its chromosome's components is not less than 1 to ensure the subset it represents is not empty. If the condition doesn't hold, we need to regenerate this individual.

C. Fitness

To assess how good an individual is, we need to assign fitness to each individual. An individual is defined to be superior to the other if its fitness is bigger.

In our work, we define the fitness of an individual as the AUC score of a machine learning model trained on the corresponding features subset.

To be specific, for each individual, we use its chromosome to obtain a features subset and we train a logistic regression model on the training dataset only considering the corresponding features subset. Then we evaluate the LR model on the testing set and get the AUC value, which is set to be the fitness of the individual.

D. Selection

After the computation of finesse, we can construct a probability distribution over the population by normalizing all individuals' fitnesses and we select elites with respect to the distribution. Specifically, we randomly sample 100 individuals from the current population with replacement to form the next generation. The individuals with bigger fitnesses have bigger opportunities to be picked out.

E. Crossover

For each pair of sampled individuals obtained from the previous selection procedure, with probability 0.2 we implement the crossover mechanism, i.e. we randomly select a position on chromosome and exchange the genes of the two individuals at this position.

F. Mutation

After crossover, for each sampled individuals, with probability 0.1 we carry out the mutation procedure, i.e. we randomly select a component on this individual's chromosome and alter its value.

G. Evolution

In each iteration, we repeat the above manipulations and record the best individual. Generally, the average fitness of the population will become increasing better as the iteration goes on and this is the reason why we call GA as evolutionary process. After 100 iterations, we terminate the evolution and selects the best individual as the best features subset representation.

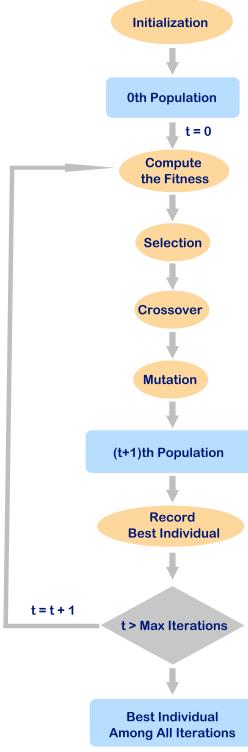


Fig. 2. Pipeline of GA

IV. PREDICTIVE MODELS

In this section, we will discuss the details of models we use in our work, which are: Logistic Regression (LR), Random Forest (RF), Deep Neural Network (DNN), and the Stacking of RF and DNN.

A. Logistic Regression

LR is a classical statistical learning algorithm, which models the conditional probability of positive sample given the feature vector using the logistic function, i.e.

$$P\{Y = 1|X = x\} = \sigma(\beta \cdot x + b) \quad (2)$$

, where $\sigma(t) = \frac{1}{1+e^{-t}}$ is the logistic function and $\beta \in R^n$, $b \in R$ are the linear coefficients.

The key to implement LR is to estimate the linear coefficients from historical labeled data, where in this paper, we apply the Stochastic Gradient Descent (SGD) with Nesterov momentum and learning rate decay [16] algorithm to minimize the log-likelihood loss function to this purpose.

Although LR is a rather simple model, which results in relatively poor predictive ability, yet it is extensively used in financial machine learning industry since it is unlikely to suffer from over-fitting. **Table 1** shows the hyperparameters of LR.

B. Random Forest

RF is a state-of-the-art machine learning technique that trains a collection of decision trees and makes classification prediction by averaging the output of each tree. The trees in

Hyperparameter	Value
Initial Learning Rate	10^{-2}
Learning Rate Decay Rate	10^{-6}
Training Epochs	20
Momentum Coefficient	0.9

TABLE I
LR HYPERPARAMETERS

forest are trained on different bootstrapping samples of training dataset and focus on different random feature subsets to break model correlation.

It is proven, by both industry and academia, that RF can effectively decrease variance of model without increasing bias, i.e. conquers over-fitting problem, and therefore RF is a promising predictive method in finance machine learning industry, where over-fitting is a common problem. **Table 2** shows the hyperparameters of RF.

Hyperparameter	Value
Number of Trees	100
Maximal Tree Depth	4
Minimal Samples Number of Split	2
Minimal Impurity of Split	10^{-7}

TABLE II
RF HYPERPARAMETERS

C. Deep Neural Network

DNN, a technique that recently witnessed tremendous success in various tasks such as computer vision, speech recognition and gaming [17,18,19], is a potential power predictor in financial application. While DNN is prone to be stuck in poor local optimum if the training environment is highly noisy, and therefore effective mechanisms preventing over-fitting must be deployed if we want to use DNN in financial market.

In this work, we implement a three-layer neural network to classify stocks, where Dropout, Batch-Normalization and L_2 Regularization are used to avoid over-fitting. Its training is done through SGD with Nesterov momentum and learning rate decay. For most cases, the network converges after 20 epochs. **Table 3** and **Table 4** demonstrate network architecture and hyperparameters respectively.

Layer	Shape
Input Tensor	$128 \times n$
Fully Connected Layer with L_2 Regularizer	$128 \times \lfloor \frac{n}{2} \rfloor$
ReLU Activation	$128 \times \lfloor \frac{n}{2} \rfloor$
Dropout Layer	$128 \times \lfloor \frac{n}{2} \rfloor$
Fully Connected Layer with L_2 Regularizer	$128 \times \lfloor \frac{n}{4} \rfloor$
ReLU Activation	$128 \times \lfloor \frac{n}{4} \rfloor$
Batch-Normalization Layer	$128 \times \lfloor \frac{n}{4} \rfloor$
Fully Connected Layer with L_2 Regularizer	128×2
Softmax Activation	128×2

TABLE III
NETWORK STRUCTURE

Hyperparameter	Value
Dropout Rate	0.5
L_2 Penalty Coefficient	0.01
Momentum Coefficient	0.9
Initial Learning Rate	10^{-3}
Learning Rate Decay Rate	10^{-6}
Training Epochs	20

TABLE IV
NETWORK HYPERPARAMETERS

D. Stacking of RF and DNN

Stacking is a technique to ensemble multiple learning algorithms, where a meta-level algorithm is trained to make a final prediction using the outputs of based-level algorithms as features. Generally, the stacking model will outperform its each based-level model due to its smoothing nature and ability to credit the classifiers which perform well and discredit those which predict badly. Theoretically, stacking is most effective if its based-level algorithms are uncorrelated.

In this work, RF and DNN are used as based-level classifiers and LR is selected as meta-level algorithm. We first partition the original training dataset into three disjoint sets, named as Train-1, Train-2, and Validation.

Train-1 and Train-2 serve as the training set of based-level classifiers, in which the DNN is trained on the concatenation of Train-1 and Train-2 and RF is trained solely on Train-2. By training like this, the two based-level algorithms' behaviors will be significantly uncorrelated , which is the prerequisite for a well-performed stacking, for two reasons: 1) RF and DNN belong to, in nature, two utterly different types of algorithms; 2) DNN is trained in a "Fore-Sighted" way while RF is trained in a "Short-Sighted" way. Validation is then used to train the meta-level LR model, where the inputs to LR is the predictions from trained-DNN and trained-RF on the Validation.

The pipeline of training our stacking model is shown in Fig. 3..

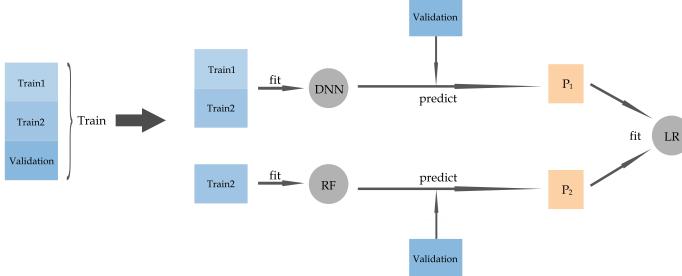


Fig. 3. Pipeline of Training Stacking

V. RESULT PRESENTATION AND EMPIRICAL ANALYSIS

In this section, we present our result and analyze it from both statistical aspect and practical (portfolio management) aspect.

A. Statistical Analysis

Table 5 and **Table 6** demonstrate the statistical indexes of different models before and after GA feature selection. The training dataset is constructed from Chinese stock data ranging from 2012.08.08 to 2013.02.01 and the testing dataset is constructed from 2013.02.04 to 2013.03.08. **Fig. 4.** shows the pipeline of our statistical evaluation procedure.

	LR	RF	DNN	Stack
AUC	0.964	0.965	0.970	0.972
Accuracy	0.903	0.918	0.913	0.919
Precision	0.871	0.916	0.875	0.904
Recall	0.945	0.922	0.963	0.938
F1	0.907	0.919	0.917	0.921
TPR	0.945	0.922	0.963	0.938
FPR	0.139	0.084	0.138	0.099

TABLE V
STATISTICAL INDEXES BEFORE FEATURE SELECTION

	LR	RF	DNN	Stack
AUC	0.966	0.970	0.958	0.973
Accuracy	0.908	0.918	0.869	0.927
Precision	0.886	0.919	0.819	0.919
Recall	0.936	0.916	0.946	0.936
F1	0.911	0.918	0.878	0.928
TPR	0.936	0.916	0.946	0.936
FPR	0.119	0.079	0.207	0.081

TABLE VI
STATISTICAL INDEXES AFTER FEATURE SELECTION

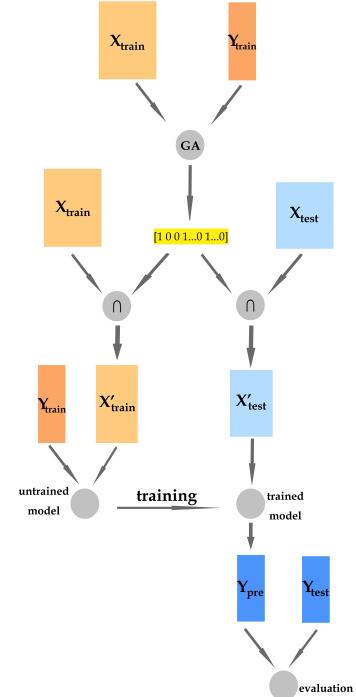


Fig. 4. Pipeline of Statistical Evaluation

As we can see from **Table 5** and **Table 6**:

- Stacking of DNN and RF outperforms other models before and after feature selection reaching the highest AUC score, which shows the promising prospect of ensemble learning in financial market.
- All the statistical indexes remain almost unchanged before and after feature selection, which shows some features are indeed redundant.
- For both LR and DNN models, their Recall scores are notably higher than their Precision scores, which indicates, in plain English, LR and DNN are radical investment models. While for RF, its Recall score is commensurate to its Precision score, suggesting that RF is more likely to be a risk-neutral investment model. As for Stacking, its risk profile is somewhere between RF and DNN since it is a combination of RF and DNN.

B. Portfolio Analysis

There is a setback of our statistical evaluation procedure, i.e. only the stocks in the Q percent tail and head are included in the test sets, which means we only test our model in the unequivocal test samples. Therefore, a more close-to-reality evaluation is needed.

To this end, for each model, we use its output, which is a vector of scalers ranging from zero to one, to construct portfolio and trade it in historical market competing with the market average. Fig. 5., Fig. 6., and Fig. 7. demonstrate the back test results showing that our stock selection strategy can construct profitable portfolios conquering the market average.

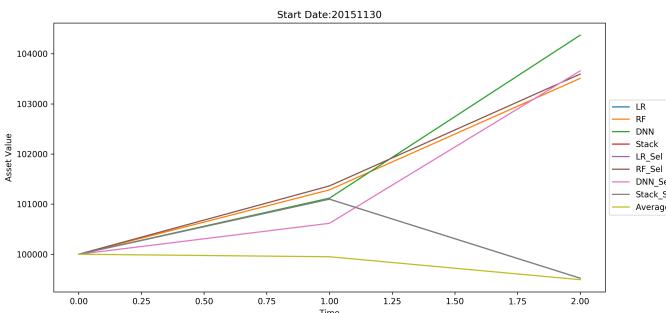


Fig. 5. Portfolio Management starts from 2015.11.30

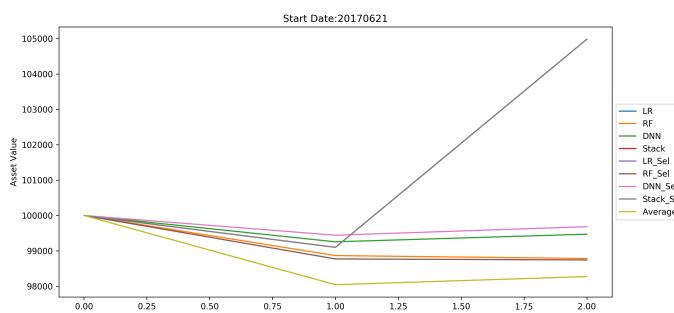


Fig. 6. Portfolio Management starts from 2017.06.21

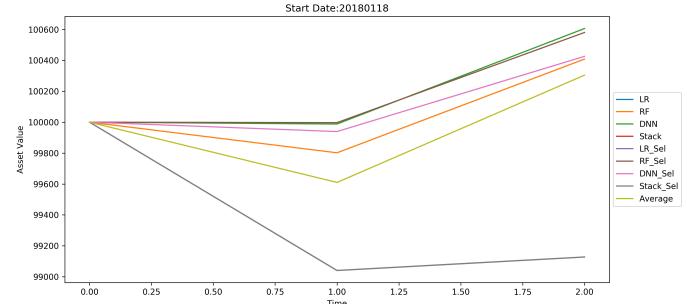


Fig. 7. Portfolio Management starts from 2018.01.18

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APPENDIX

AccountsPayablesTDays	AccountsPayablesTRate	AdminiExpenseRate	ARTDays
AdminExpenseRate	ARTDays	ARTRate	ASSI
ARTRate	ASSI	BLEV	BondsPayableToAsset
BLEV	BondsPayableToAsset	CashRateOfSales	CashToCurrentLiability
CashRateOfSales	CashToCurrentLiability	CMRA	CTOP
CMRA	CTOP	CTP5	CurrentAssetsRatio
CTP5	CurrentAssetsRatio	CurrentAssetsTRate	CurrentAssetsTRate
CurrentAssetsTRate	CurrentRatio	DAVOL10	DAVOL10
DAVOL10	DAVOL20	DAVOL5	DAVOL20
DAVOL5	DDNBT	DDNCR	DDNBT
DDNCR	DDNSR	DebtEquityRatio	DDNSR
DebtEquityRatio	DebtsAssetRatio	DHIL0	DebtsAssetRatio
DHIL0	DilutedEPS	DVRAT	DilutedEPS
DVRAT	EBITToTOR	EGRO	EBITToTOR
EGRO	EMA10	EMA10	EMA10
EMA120	EMA20	EMA120	EMA20
EMAS	EMA60	EMA5	EMA60
EPS	EquityFixedAssetRatio	EPS	EquityFixedAssetRatio
EquityToAsset	EquityRate	EquityToAsset	EquityRate
ETOP	ETP5	ETOP	ETP5
FinancialExpenseRate	FinancingCashGrowRate	FinancialExpenseRate	FinancingCashGrowRate
FixAssetRatio	FixedAssetsTRate	FixAssetRatio	FixedAssetsTRate
GrossIncomeRatio	HBETA	GrossIncomeRatio	HBETA
HSIGMA	IntangibleAssetRatio	HSIGMA	IntangibleAssetRatio
InventoryTDays	InventoryTRate	InventoryTDays	InventoryTRate
InvestCashGrowRate	LCAP	InvestCashGrowRate	LCAP
LFLO	LongDebtToAsset	LFLO	LongDebtToAsset
LongDebtToWorkingCapital	LongTermDebtToAsset	LongDebtToWorkingCapital	LongTermDebtToAsset
MA10	MA10	MA10	MA120
MA20	MA120	MA20	MA5
MA60	MA5	MA60	MAWVAD
MFI	MAWVAD	MFI	MLEV
NetAssetGrowRate	MLEV	NetAssetGrowRate	NetProfitGrowRate
NetProfitRatio	NetProfitGrowRate	NetProfitRatio	NOCFToOperatingNI
NonCurrentAssetsRatio	NOCFToOperatingNI	NonCurrentAssetsRatio	NPParentCompanyGrowRate
NPToTOR	NPParentCompanyGrowRate	NPToTOR	OperatingExpenseRate
OperatingProfitGrowRate	OperatingExpenseRate	OperatingProfitGrowRate	OperatingProfitRatio
OperatingProfitToTOR	OperatingProfitRatio	OperatingProfitToTOR	OperatingRevenueGrowRate
OperCashGrowRate	OperCashInToCurrentLiability	OperCashGrowRate	OperCashInToCurrentLiability
PB	PCF	PB	PCF
PE	PS	PE	PS
PSY	QuickRatio	PSY	QuickRatio
REVS10	REVS20	REVS10	REVS20
REVS5	ROA	REVS5	ROA
ROA5	ROE	ROA5	ROE
ROE5	RSI	ROE5	RSI
RSTR12	RSTR24	RSTR12	RSTR24
SalesCostRatio	SaleServiceCashToOR	SalesCostRatio	SaleServiceCashToOR
SUE	TaxRatio	SUE	TaxRatio
TOBT	TotalAssetGrowRate	TOBT	TotalAssetGrowRate
TotalAssetsTRate	TotalProfitCostRatio	TotalAssetsTRate	TotalAssetGrowRate
TotalProfitGrowRate	VOL10	TotalProfitGrowRate	TotalProfitCostRatio
VOL120	VOL20	VOL120	VOL10
VOL240	VOL5	VOL240	VOL20
VOL60	WVAD	VOL60	VOL5
REC	DAREC	REC	WVAD
GREC	FY12P	GREC	DAREC
DAREV	GREV	DAREV	FY12P
SFY12P	DASREV	SFY12P	GREV
GSREV	FEARNG	GSREV	DASREV
FSALESG	TA2EV	FSALESG	FEARNG
		CFO2EV	TA2EV
			ACCA