UBS

Global Research

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Artificial Intelligence in Finance

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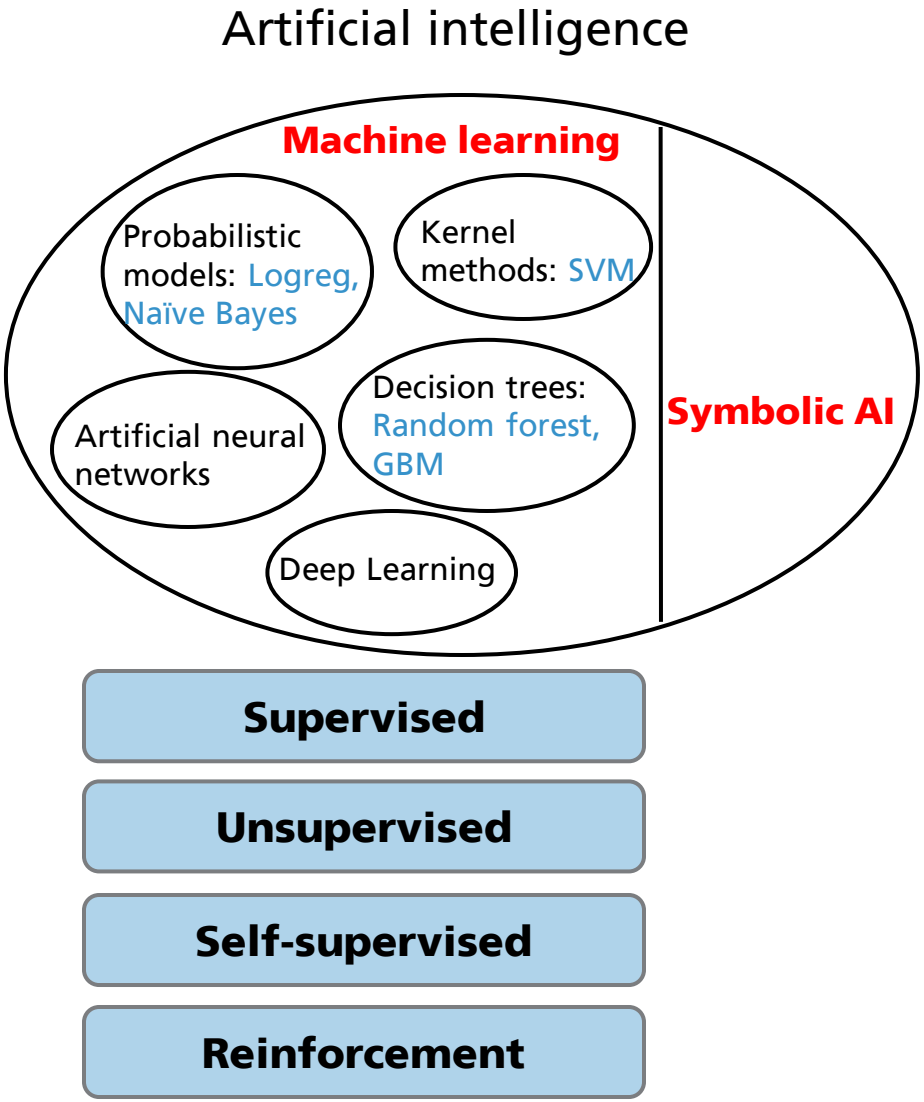
Section 1

Artificial Intelligence vs Machine Learning vs Deep Learning

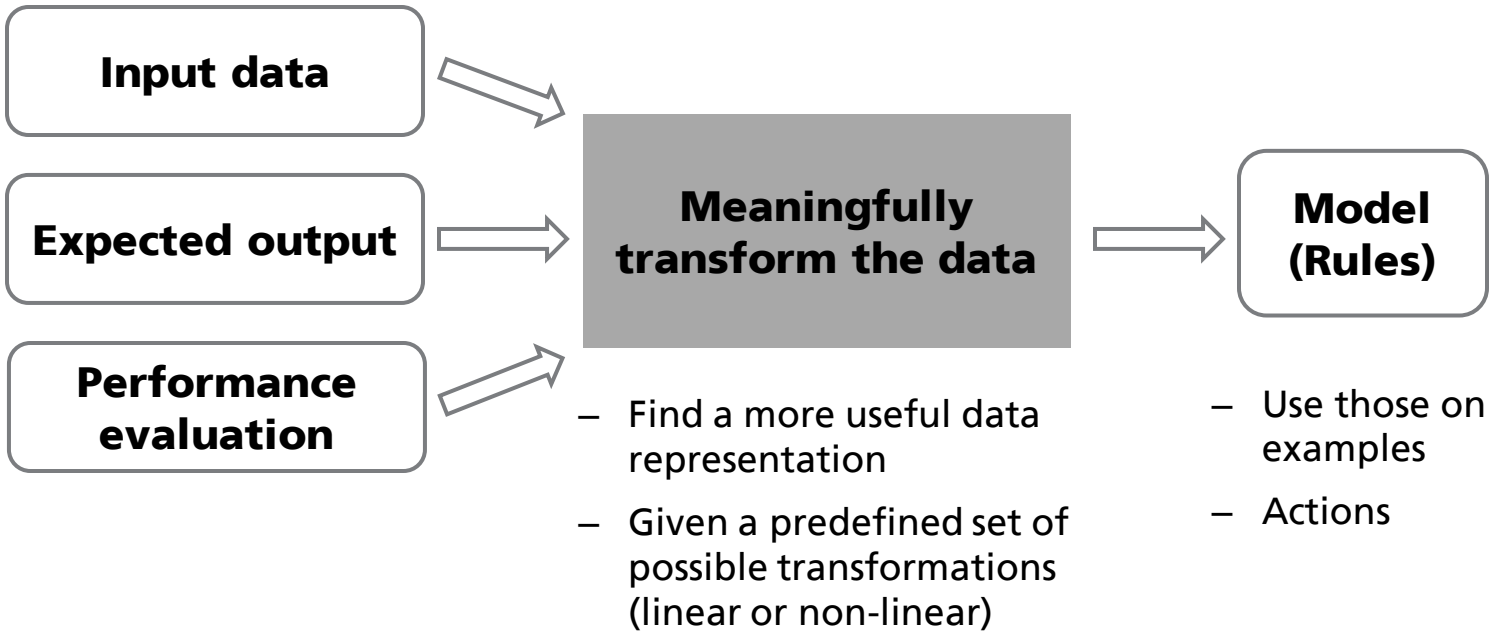
Artificial Intelligence

- "The study of the design of intelligent agents. An agent is something that **acts** in an environment – it does something" (Poole *et al,* 1998*)*
- Symbolic (classical) AI:
  - Dominant approach from 1950s until 1980s
  - Explicitly represent (hard-code) human knowledge using rules and facts
  - Suitable to solve well-defined logical problems
- Machine learning systems
  - Gained popularity in 1990s
  - *Trained* rather than programmed



Source: UBS Quant. For illustrative purposes only.

Machine Learning



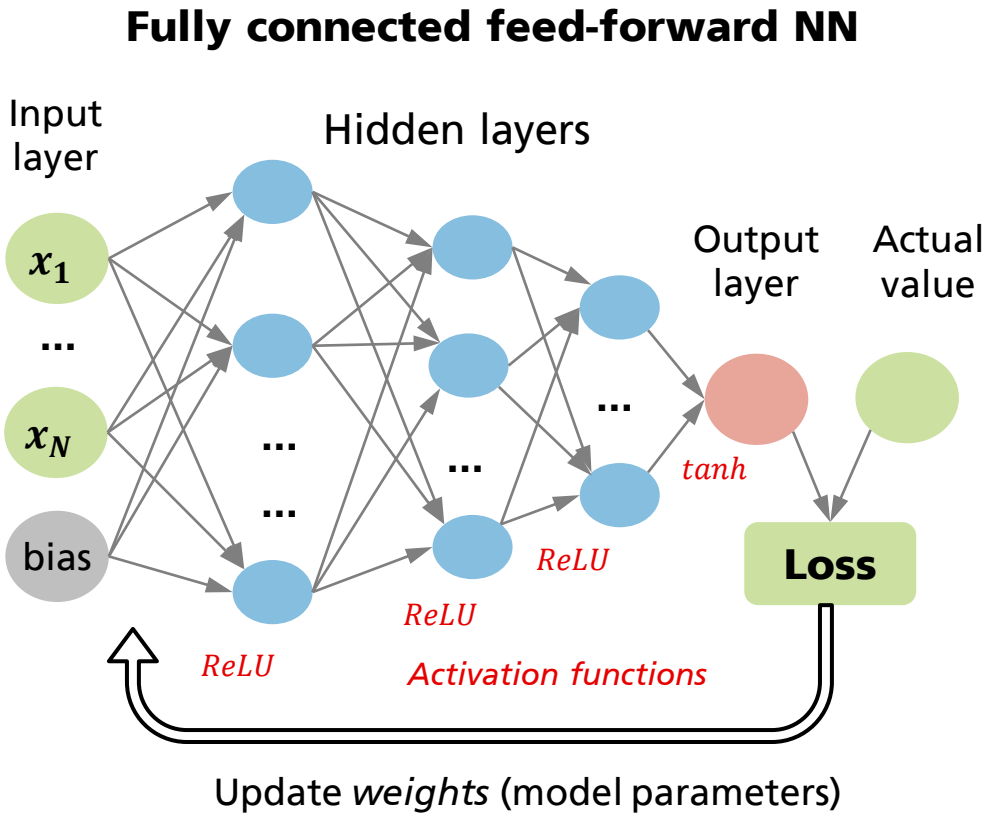
- All of machine learning involves automatically finding transformations that turn data into more useful representation
- Classical machine learning (e.g. SVM) are "shallow" methods
  - Might require extracting useful representations manually – feature engineering

Deep Learning

- Class of machine learning algorithms
  - "Learning": Discover useful representation of some input data, using guidance from a feedback signal
  - "Deep": Use **successive layers** of increasingly useful representations
  - Automates the most crucial step in classical machine learning – feature engineering
- Layered representations are learned via neural networks
- Notable achievements
  - Image classification
  - Self-driving cars
  - Speech recognition, NLP
  - Go!

  } **Perceptual problems**
- Why is deep learning successful?
  - Simplicity
  - Scalability
  - Reusability

Neural networks basics



Source: UBS Quant. For illustrative purposes only.

- Fitting neural networks:
  - Forward propagation: make predictions given some weights
  - Back-propagation: optimise weights (gradient descent + chain rule)

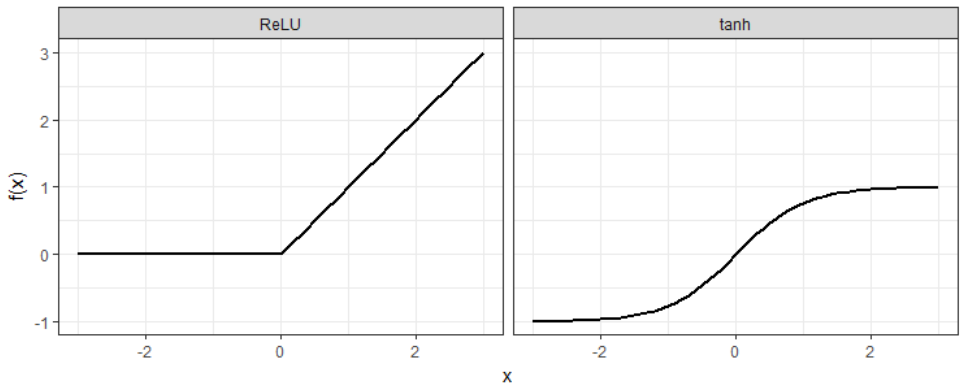
Neural networks basics (2)

- Network configuration
  - Number (and type) of layers
  - Size of layers (number of hidden neurons)

} **Hyperparameters** → tuning

- Activation functions
  - Non-linear (usually), differentiable (almost everywhere)
  - Identity, ReLU, ELU, sigmoid, hyperbolic tangent (tanh), softmax
- Loss functions:
  - Regression: mean squared error (*MSE*)
  - Classification: cross-entropy

Examples of activation functions

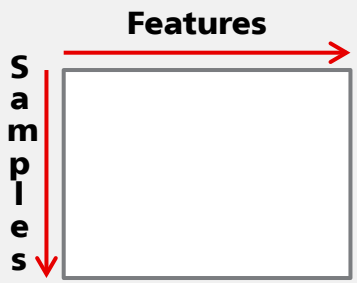


Source: UBS Quant. For illustrative purposes only.

Data formatting

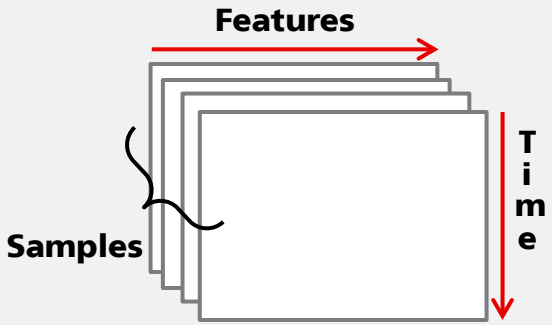
- Data representations:
  - Tensors: multidimensional arrays of numbers

2D Tensor: vector data



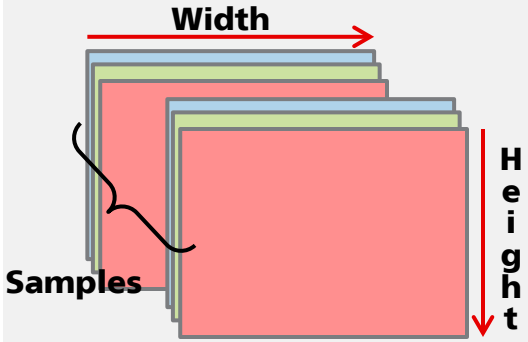
- **House prices**: for each property consider its *value*, *post-code*, *square meters*. Dataset of 100K properties → (100,000; 3)
- **Text documents**: count how many times each word appears in a it. Given a dictionary of 50K common words and 500 documents → (500; 50,000)

3D Tensor: time series



- **Stock prices**: Every minute store *current price*, *highest, lowest* price and volume traded in the past minute. Each trading day is represented as (390; 4) tensor. 1 year worth of data for one stock → (250; 390; 4)

4D Tensor: images



- **Gray-scale images:** 100K images of size 256×256 → (100,000; 256; 256; 1)
- **Colour images**: 100K images of size 256×256 → (100,000; 256; 256; 3)

Source: UBS Quant. For illustrative purposes only.

Networks architectures

- Data representation (usually) determines the type of layers used in networks

Architecture	Suitable for	Data format	Layer type
Fully connected	Simple vector data	2D tensors	Fully (densely) connected
Convolutional (convnets)	Image data	4D tensors	Convolutional layers (e.g. Conv2D)
Recurrent (RNN)	Sequences (time series)	3D tensors	Long-short term memory (LSTM), Gated recurrent unit (GRU)

Machine learning: summary of workflow

- Formulate the problem:
  - What are the inputs and outputs? → Binary/Multiclass/Regression problem
  - Collect and label data

  Hypotheses made:

  (1) Output can be predicted given the inputs

  (2) Collected data is sufficiently informative to learn the relationship
- Choose measure of accuracy and evaluation protocol
  - E.g. MSE, Accuracy, ROC area under the curve
  - Split data in train, validation, test split vs cross validation
- Data preparation:
  - Normalise/scale inputs, format as tensors
  - Feature engineering (especially for small data problems)
- Develop a baseline model
- Develop a model that achieves statistical power (outperforms the baseline model)

Section 2

Deep Learning in Finance

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When does deep learning make sense?

- Structured vs unstructured data
  - Kaggle (platform for machine learning competitions): **Gradient boosting** for structured (tabular) data, **deep learning** for perceptual problems (Chollet 2017)
- Deep learning is very "data hungry"
  - 100K+ samples, according to sklearn's guide to algorithms
  - Relative to the size of the network
- Infrastructure
  - Modern deep learning applications consist of tens/hundreds of layers
  - Computational power

Literature (1): High frequency trading

- *Sequence Classification of the Limit Order Book using Recurrent Neural Networks* (2017), M. Dixon
  - Predicting price flips using spatio-temporal representation of the order book
- *Deep Learning for Spatio-Temporal Modeling: Dynamic Traffic Flows and High Frequency Trading* (2017), V. Sokolov *et al*
  - Predict short-term futures market prices using the depth of the limit-order book
- *Deep Learning for Limit Order Books* (2016), J. Sirignano
  - Model for the order book
- *Classification-Based Financial Markets Prediction Using Deep Neural Networks* (2016), M. Dixon *et al*
  - Predict the direction (up/down/neutral) of commodities and FX futures at 5-minute intervals
  - Prediction accuracy 35%
- *Deep Hedging* (2018), H. Buehler *et al*
  - Hedging portfolios of derivatives in the presence of market frictions (liquidity constraints, transaction costs, etc.)

Literature (2): … and the cross-section of expected returns

- *Deep Learning for Forecasting Stock Returns in the Cross-section* (2018), M. Abe *et al*
  - MSCI Japan, 25 factors as inputs, monthly data
  - Random forest, SVM achieve similar/better results
- *Deep Learning and the Cross-Section of Expected Returns* (2017), M. Messmer
  - CRSP (NYSE, AMEX, NASDAQ), 68 firm characteristics, monthly data
  - "9 out of 200 models indicate an edge over the parsimonious alternative" (linear regression); 75 models have $R^2 < 0$
- *Improving Factor-based Quantitative Investing by Forecasting Company Fundamentals* (2017), J. Alberg *et al*
  - CRSP (NYSE, AMEX, NASDAQ), 20 firm characteristics, scaled by market cap
  - Feed-forward and RNN outperform linear regression and naïve predictor

Literature (3): Macroeconomics forecasting

- *Macroeconomic Indicator Forecasting with Deep Neural Networks* (2017), A. Hall *et al*
  - Forecast unemployment rate using different network configurations, most of which outperform forecasts based on the Survey of Professional Forecasters (SPF)
  - Encoder-decoder shows 89% decrease in MAE compared to SPF
- *Forecasting Spanish Unemployment Using Near Neighbour and Neural Net Techniques* (2014), E. Olmedo
- *Macro Fundamentals or Geopolitical Events? A Textual Analysis of News Events for Crude Oil* (2016), M. Brandt *et al*
  - News analytics (sentiment analysis) to forecast log-returns to oil

Summary

- Limited academic literature
- Deep learning is "data hungry" – potential applications will be in HFT strategies, microstructure modelling
- In most cases linear models perform equally well (badly)
- Prerequisites to developing and deploying a successful deep learning model:
  - *Garbage in, garbage out* – poor quality inputs will produce useless outputs
  - *Alternative data* – e.g. alpha in news sentiment scores from data providers now decays very quickly
  - *Hardware* – given sufficiently large good quality data, proper infrastructure is needed to test and deploy models

Section 3

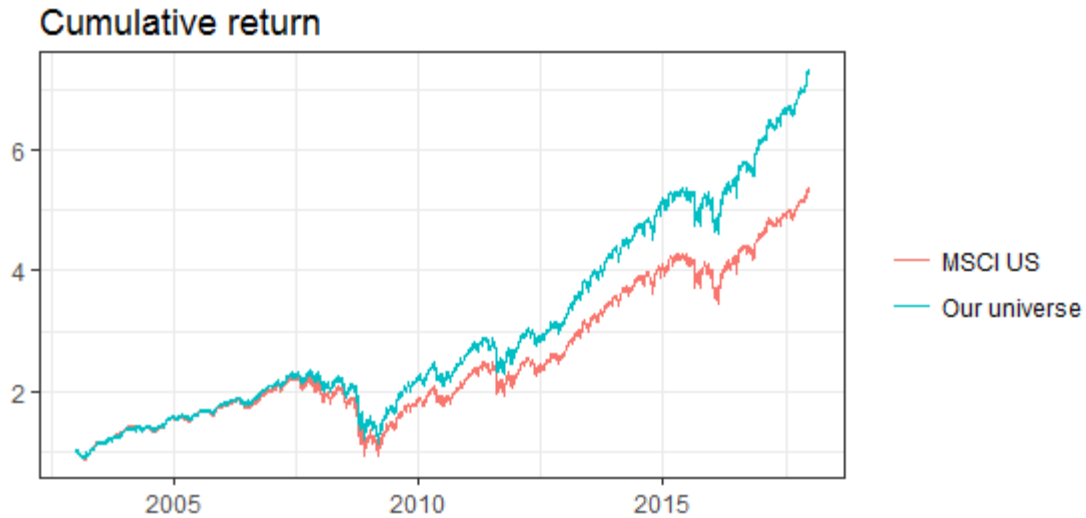
Example 1: Portfolio Returns

Setup (1)

- Example from Introduction to Deep Learning (implementation in TensorFlow/Keras available in recent Quantessentials)
  - n stocks, equally weighted in portfolio

$$r_p(t) = \sum_{i=1}^{n} \frac{1}{n} r_i(t)$$

  - Learn the relationship between all previous stock returns and directional change in the portfolio return
  - Observed data: historical daily returns, $\{X_t\}_{t=1}^{T}$, $X_t = r_1(t), \ldots r_n(t)$
  - The universe is MSCI US, restricted to those companies that have price data throughout the period from January 2003 through Nov 2017 (look-ahead + survival bias)



Source: UBS Quant, MSCI.

Setup (2)

- Inputs: daily returns of 215 stocks
- Target:

$$Y_t = \begin{cases} 1, & r_p(t+1) > \epsilon \\ 0, & |r_p(t+1)| < \epsilon \\ -1, & r_p(t+1) < -\epsilon \end{cases}$$

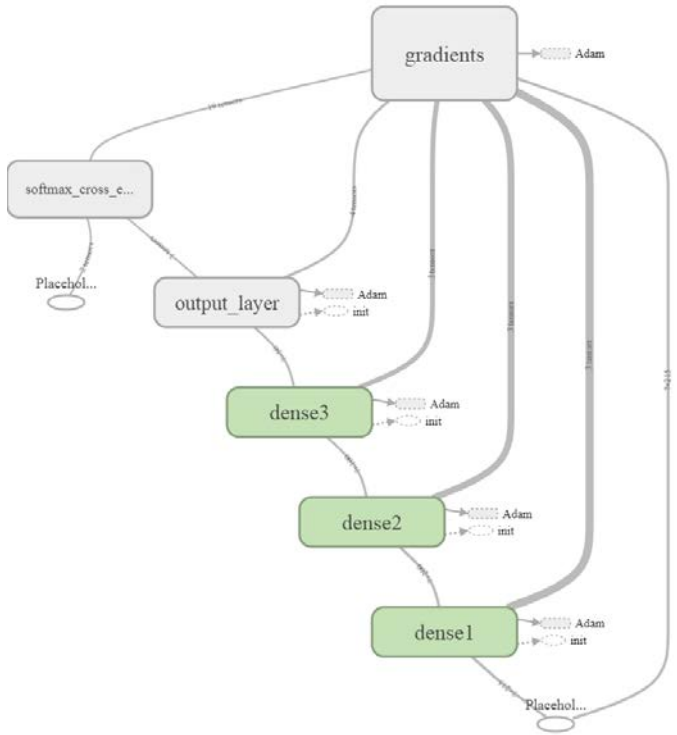
  - ϵ is determined from the training data to avoid class imbalance
- Standardise the inputs (based on the training data)
- One-hot encode the target
  - Example:

$$Y_t = \{0,\ 1,\ 1, -1\} \Rightarrow \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

- Training over 3500 data points, forecast one step ahead

Network architecture

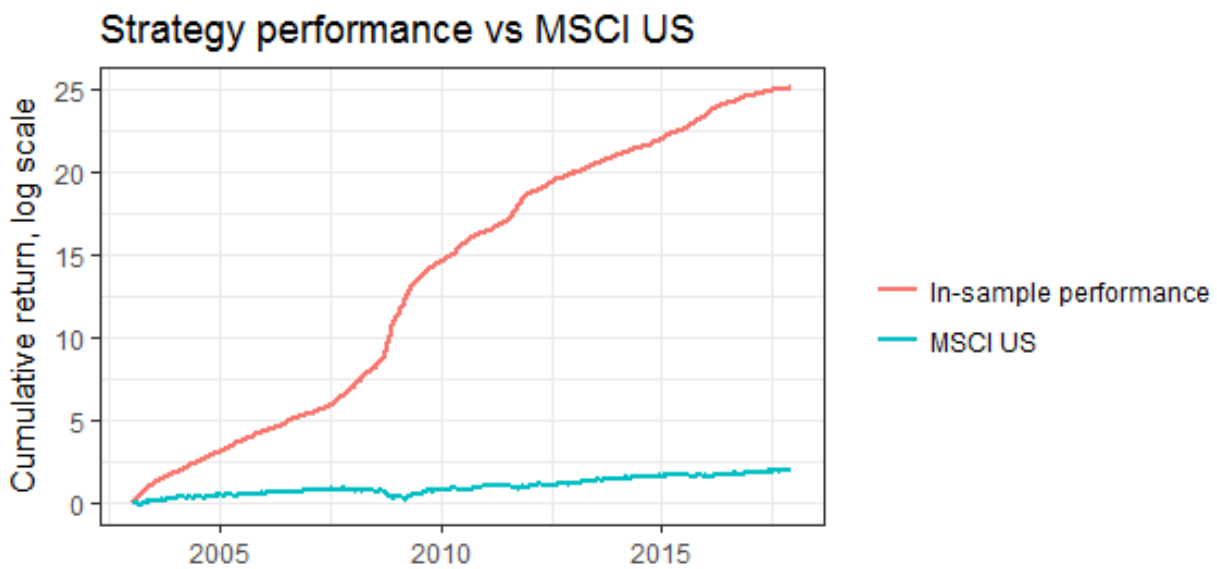
- Fully connected feed-forward
- 3 hidden layers with 200, 100 and 50 neurons and *ReLU* activation function
- Output layer consists of 3 neurons (one for each class), *softmax* activation
- *Cross-entropy* loss function



Source: UBS Quant, generated with TensorBoard.

In-sample results

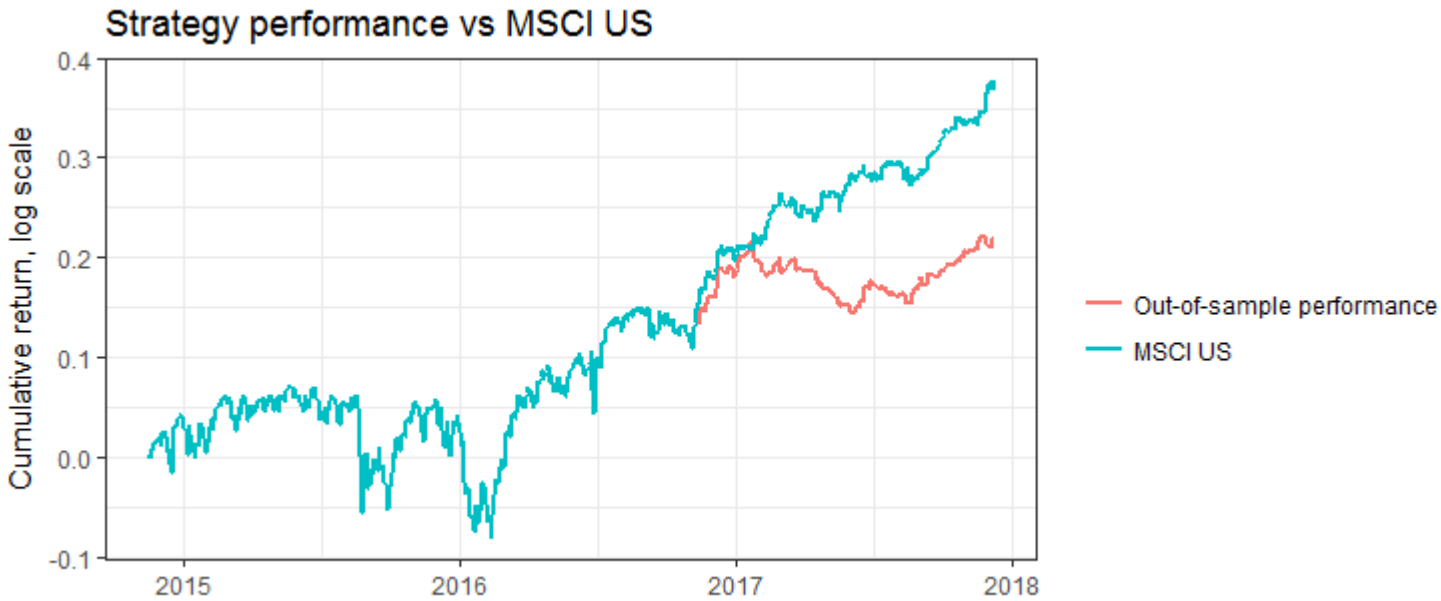
- We train the network on the entire dataset, mini-batch size of 100, 20 epochs (trained with *keras* + *TensorFlow* backend*)*
- In-sample accuracy: **93%**



Source: UBS Quant, MSCI.

Out-of-sample performance

- As one would expect, the deep network predictor is very high variance
- Out-of-sample accuracy (based on 275 samples): ~35%
- Slightly outperforms a naïve logistic regression classifier (accuracy of 33%)



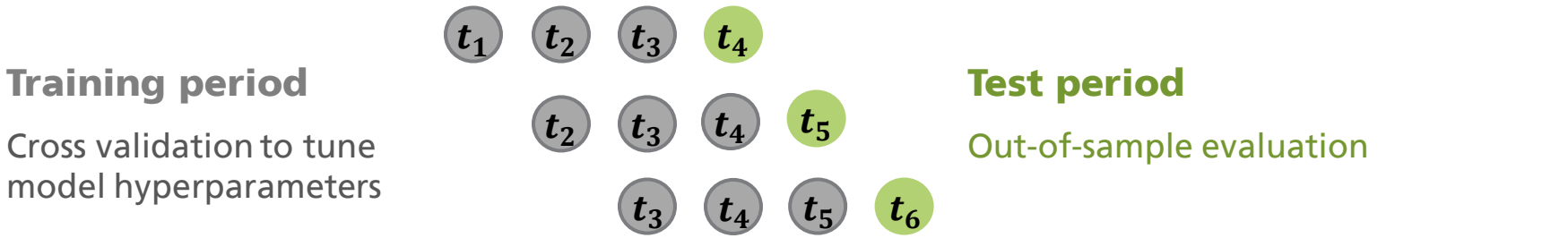
Source: UBS Quant, MSCI.

Section 4

Example 2: Stock Selection Model

Setup

- **Task**: Given a set of stock-specific factors as inputs (fundamental and technical), predict next month return (output)
  - Regression problem
  - Measure of accuracy: mean squared error (MSE)
  - Evaluation protocol: cross validation
- Lookback period – 3 months, forecast 1 step ahead



Source: UBS Quant. For illustrative purposes only.

- Use out-of-sample predictions to rank stocks
  - Universe: MSCI Europe
  - Sample period: monthly data from Jan 2002 though Jan 2018
  - Equally weighted quintile portfolios, rebalanced monthly

Models considered

- Standard linear regression: **Baseline model**
- Linear with shrinkage
  - Elastic net
- Tree-based
  - Random forest
  - Extreme gradient boosting (XGBoost)
- Neural networks
  - Feed-forward fully connected (with and without regularisation)

- Models compared on the basis of:
  - Absolute returns
  - Risk adjusted returns (Sharpe ratio)

Shrinkage methods: LASSO and friends

- Shrink the regression coefficients by imposing constraint on their size
- LASSO regression: L_1constraint
  - Some coefficients are set to zero

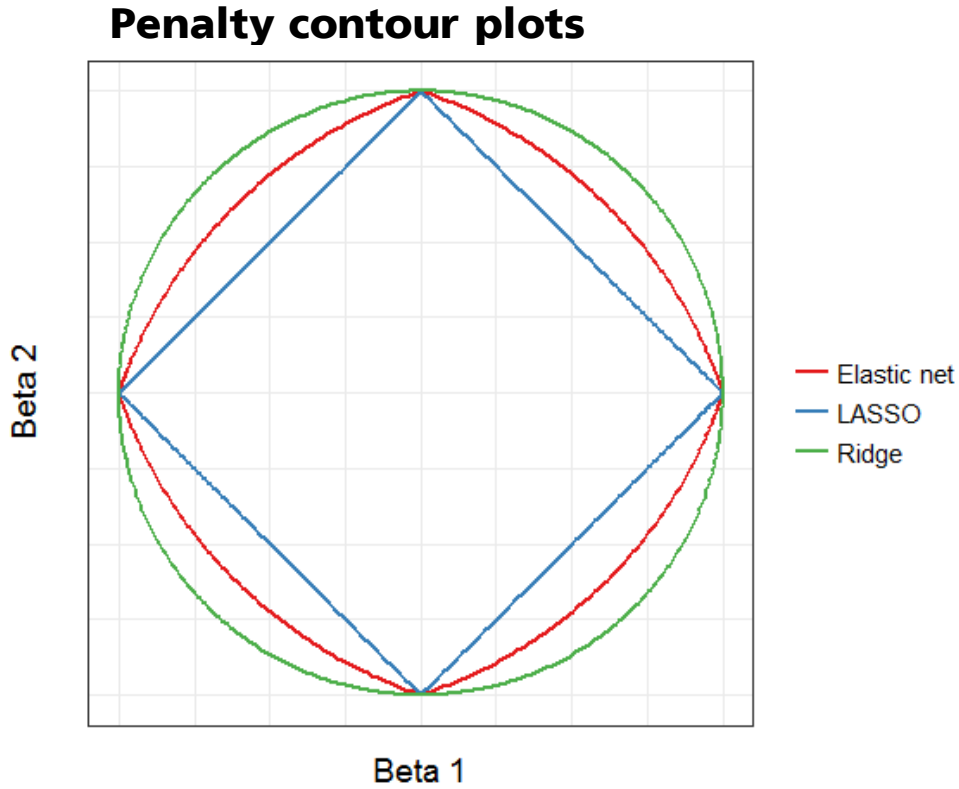
$$\beta^{LASSO} = argmin_{\beta}\left(\|Y - X\beta\|_2^2 + \lambda\|\beta\|_1\right)$$

- Ridge regression: L_2 constraint
  - Coefficients get close to zero

$$\beta^{Ridge} = argmin_{\beta}\left(\|Y - X\beta\|_2^2 + \lambda\|\beta\|_2^2\right)$$

- Elastic net: combines L_1 and L_2

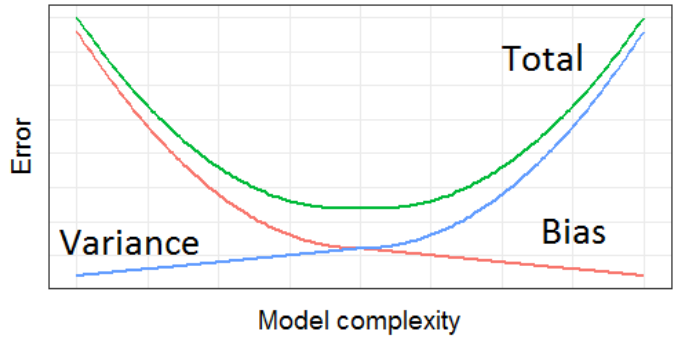
$$\beta^{ENet} = argmin_{\beta}\left(\|Y - X\beta\|_2^2 + (1-\alpha)\lambda\|\beta\|_2^2 + \alpha\lambda\|\beta\|_1\right)$$



Source: UBS Quant. For illustrative purposes only.
Elastic net mixing parameter $\alpha = 0.5$

Trees: Bagging vs Boosting

- Two ways to achieve low error:
  - Reduce variance (generally complex models)
  - Reduce bias (generally simple models)
  - Bias-variance trade-off



Source: UBS Quant. For illustrative purposes only.

Bagging

- Large number of independent, fully grown trees (complex models).
  - Random subset of the data
  - Random subset of the available features
- **Low bias, high variance**
- Reduce variance by averaging
- Random forest

Boosting

- Large number of small trees (simple models)
- **High bias, low variance**
- Small models created and combined iteratively
  - New models address the weak points of the previous models
- AdaBoost, XGBoost

Section 2

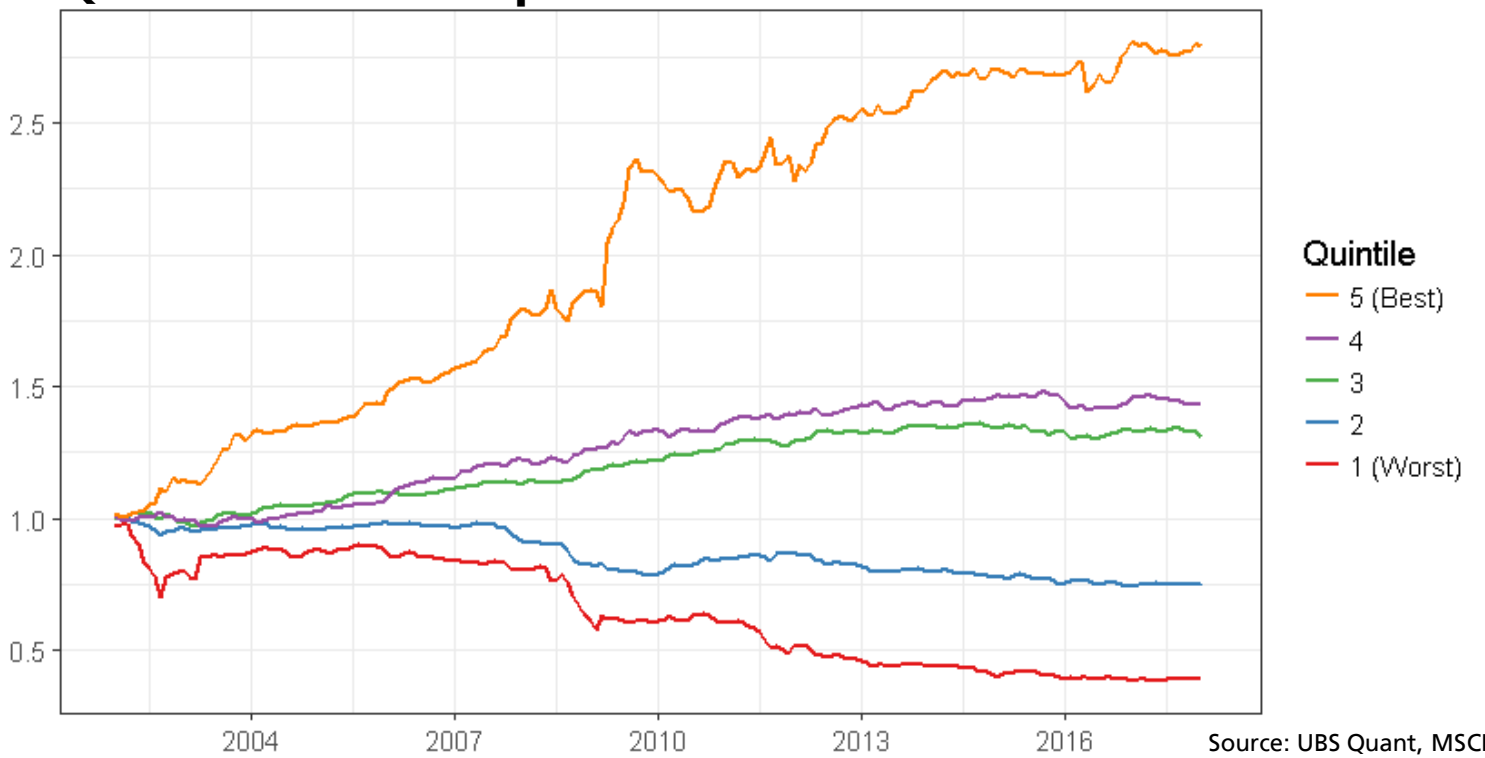
"Horse race" between models – results

Baseline model: linear regression

- No tuning parameters

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	-5.67%	-1.74%	1.69%	2.26%	6.59%
Annualised Std Dev	8.19%	3.04%	2.40%	2.88%	6.24%
Sharpe (Rf=0%)	-0.69	-0.57	0.70	0.78	1.06

Quintile cumulative performance



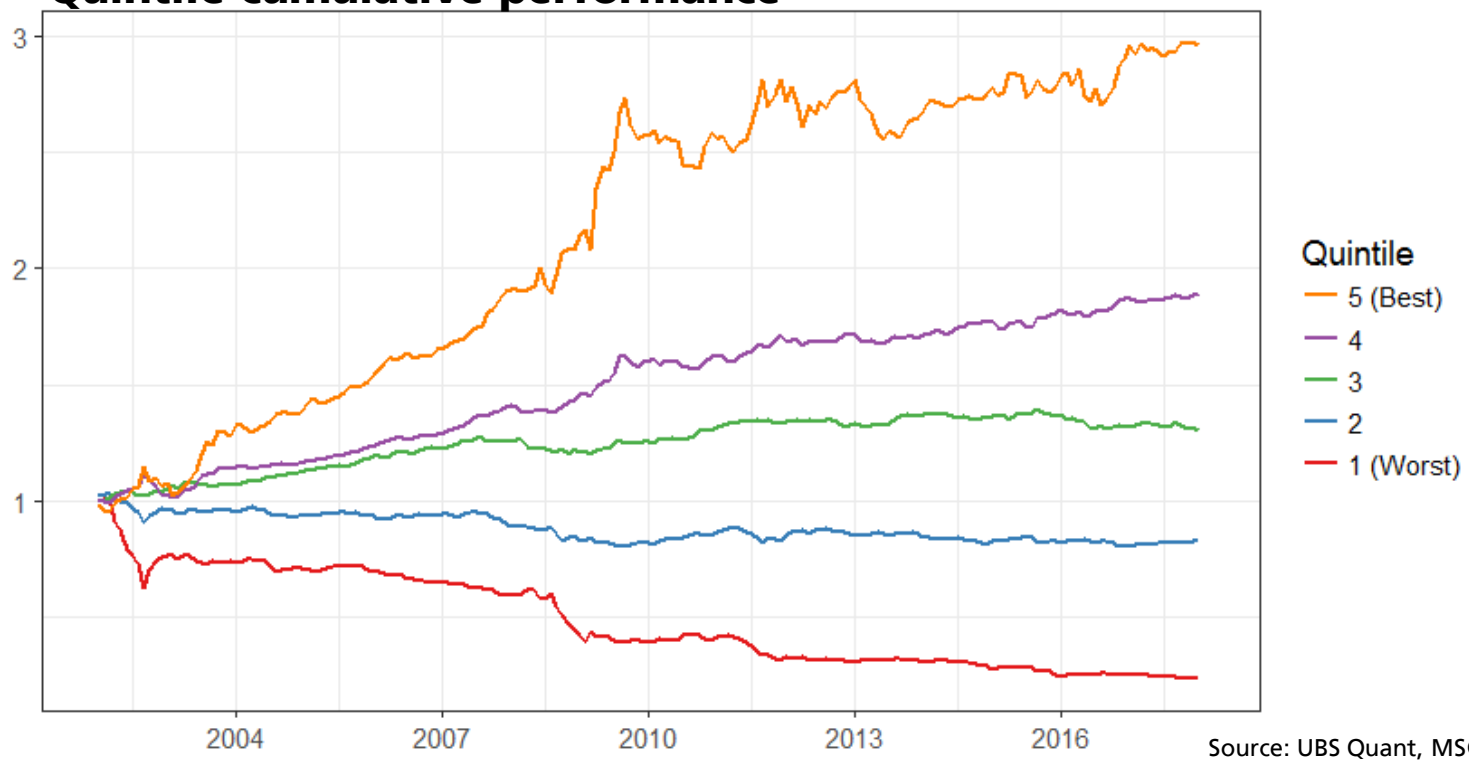
Source: UBS Quant, MSCI. For illustrative purposes only.

Elastic net

- Tuning parameters: λ – regularisation term; α – mixing parameter

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	-8.58%	-1.19%	1.64%	4.04%	6.99%
Annualised Std Dev	10.28%	4.07%	2.69%	4.57%	7.84%
Sharpe (Rf=0%)	-0.83	-0.29	0.61	0.88	0.89

Quintile cumulative performance



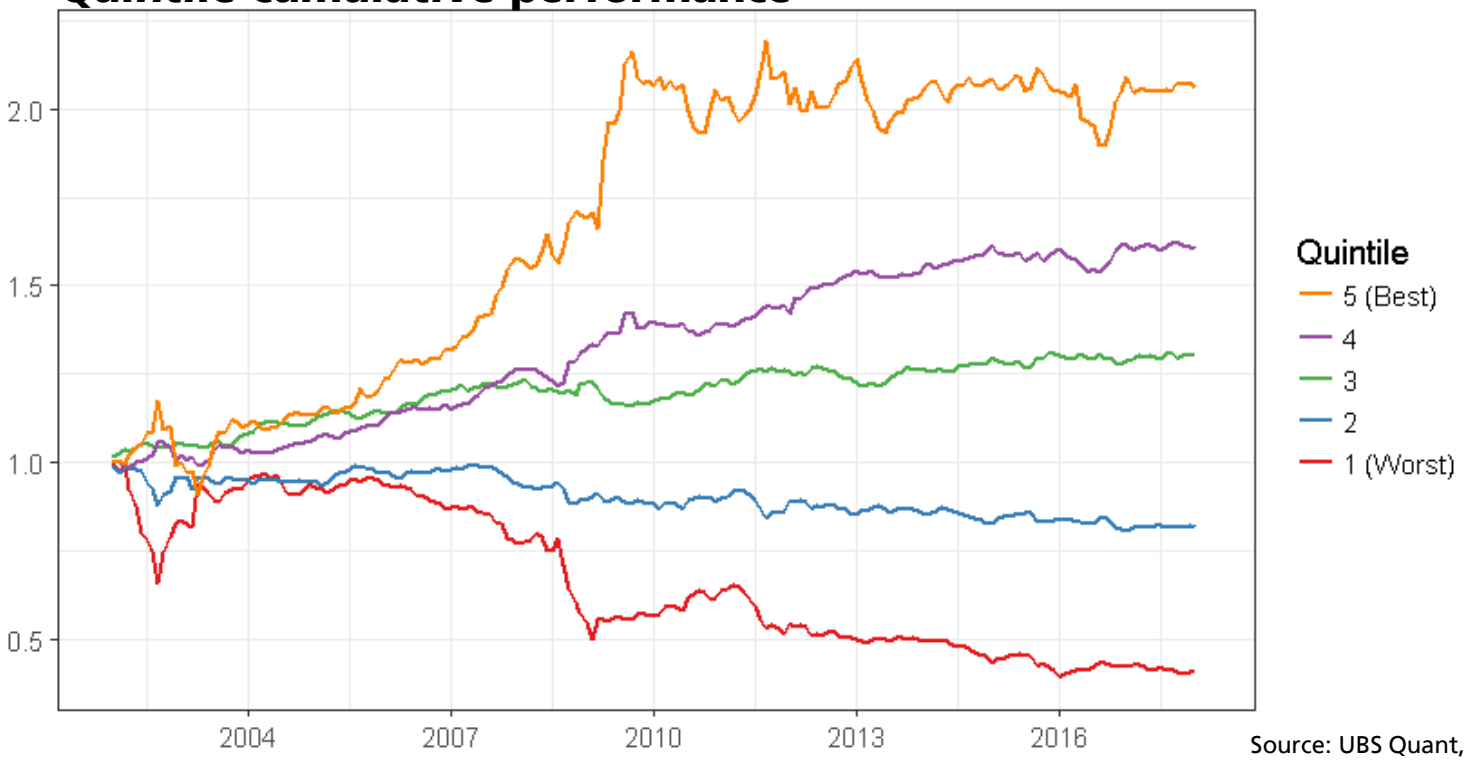
Source: UBS Quant, MSCI. For illustrative purposes only.

Random forest

- Tuning parameter: $mtry$ – number of variables randomly sampled as candidates at each split

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	-7.73%	-1.24%	1.65%	4.27%	6.04%
Annualised Std Dev	10.37%	4.30%	2.60%	4.61%	7.86%
Sharpe (Rf=0%)	-0.75	-0.29	0.63	0.93	0.77

Quintile cumulative performance



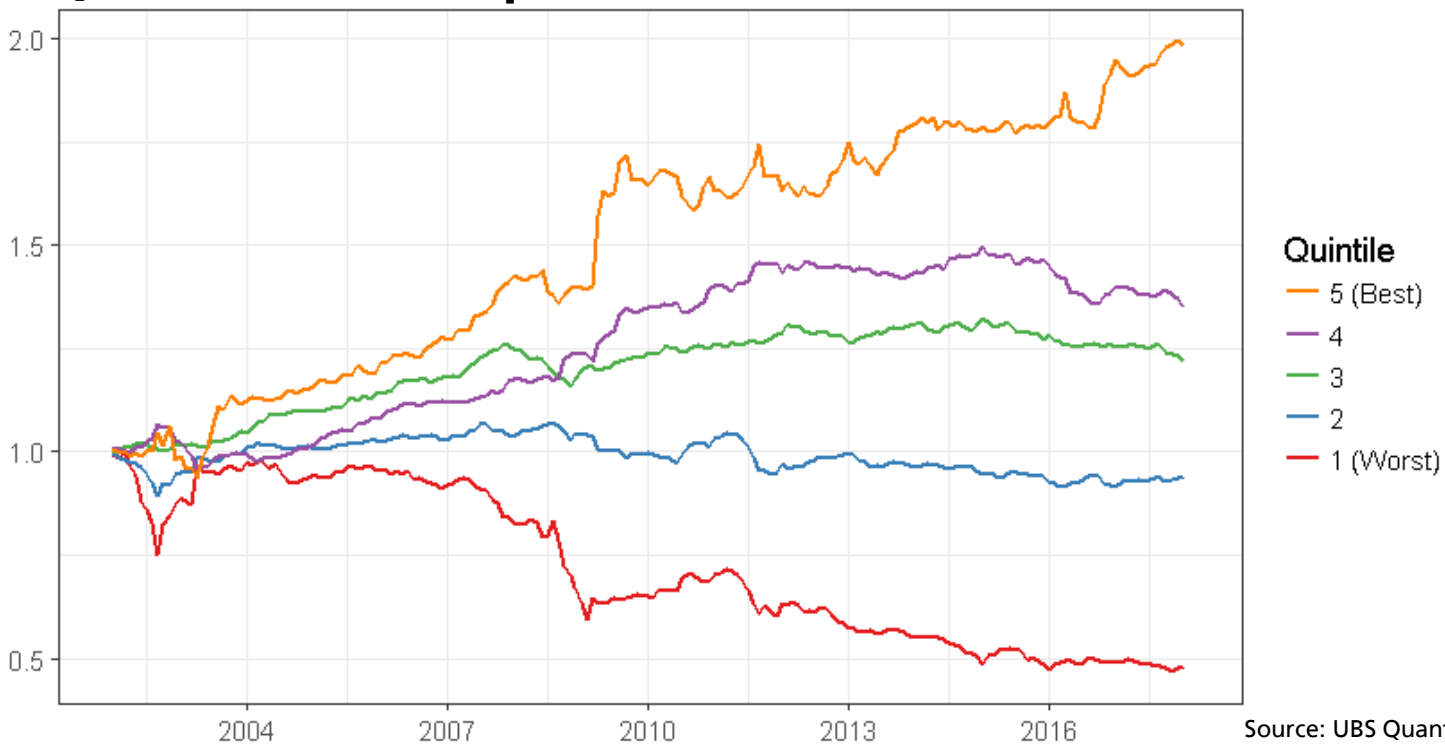
Source: UBS Quant, MSCI. For illustrative purposes only.

XGBoost

- Tuning parameters: $nrounds$ – max number of iterations, $gamma$ – loss reduction required to further partition, max_depth – max depth of a tree, eta – learning rate

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	-4.46%	-0.37%	1.25%	1.88%	4.35%
Annualised Std Dev	8.40%	3.43%	2.33%	3.32%	6.37%
Sharpe (Rf=0%)	-0.53	-0.11	0.54	0.57	0.68

Quintile cumulative performance



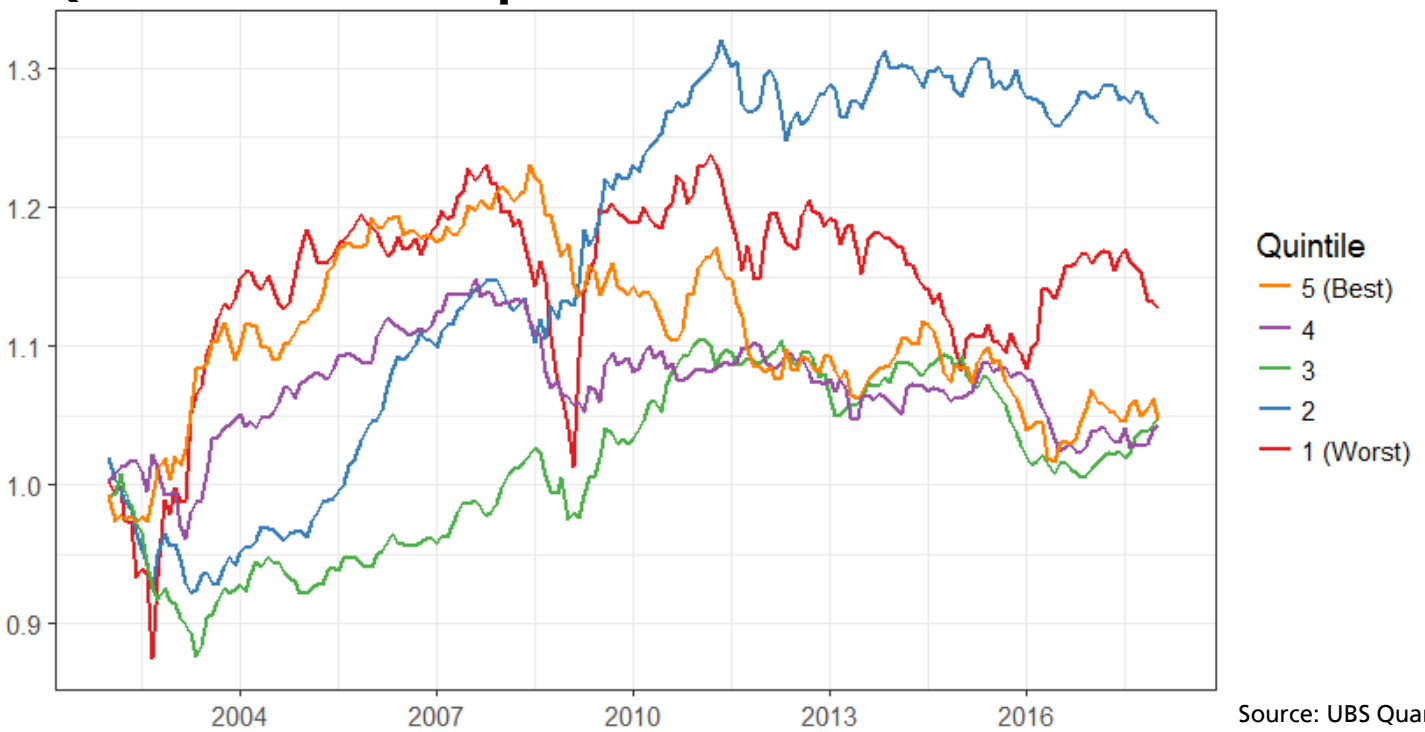
Source: UBS Quant, MSCI. For illustrative purposes only.

Neural network

- 3 hidden layers with ReLU activation, sizes of 256, 128 and 64; identity activation in the output layer. **Total number of parameters: $81,928$**

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	0.74%	1.44%	0.29%	0.26%	0.29%
Annualised Std Dev	5.41%	2.97%	2.72%	2.65%	3.21%
Sharpe (Rf=0%)	0.14	0.49	0.11	0.10	0.09

Quintile cumulative performance



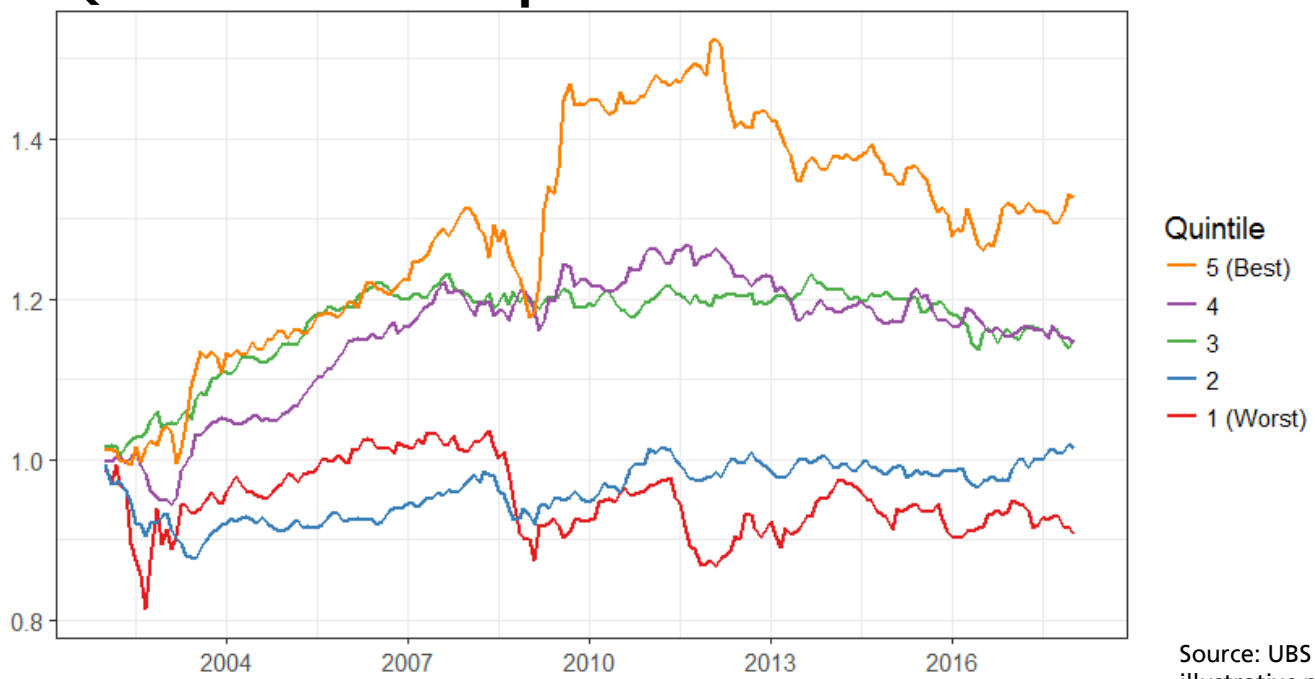
Source: UBS Quant, MSCI. For illustrative purposes only.

Tuning: Does regularisation help?

- Dropout: randomly drop a proportion of hidden (or visible) units (Srivastava *et al*, 2014)
  - Drop 30% of inputs, then 50%, 40%, 30% of units at each hidden layer

	Q1 (Worst)	Q2	Q3	Q4	Q5 (Best)
Annualised return	-0.61%	0.09%	0.88%	0.84%	1.77%
Annualised Std Dev	5.72%	2.81%	2.41%	2.98%	4.74%
Sharpe (Rf=0%)	-0.11	0.03	0.36	0.28	0.37

Quintile cumulative performance

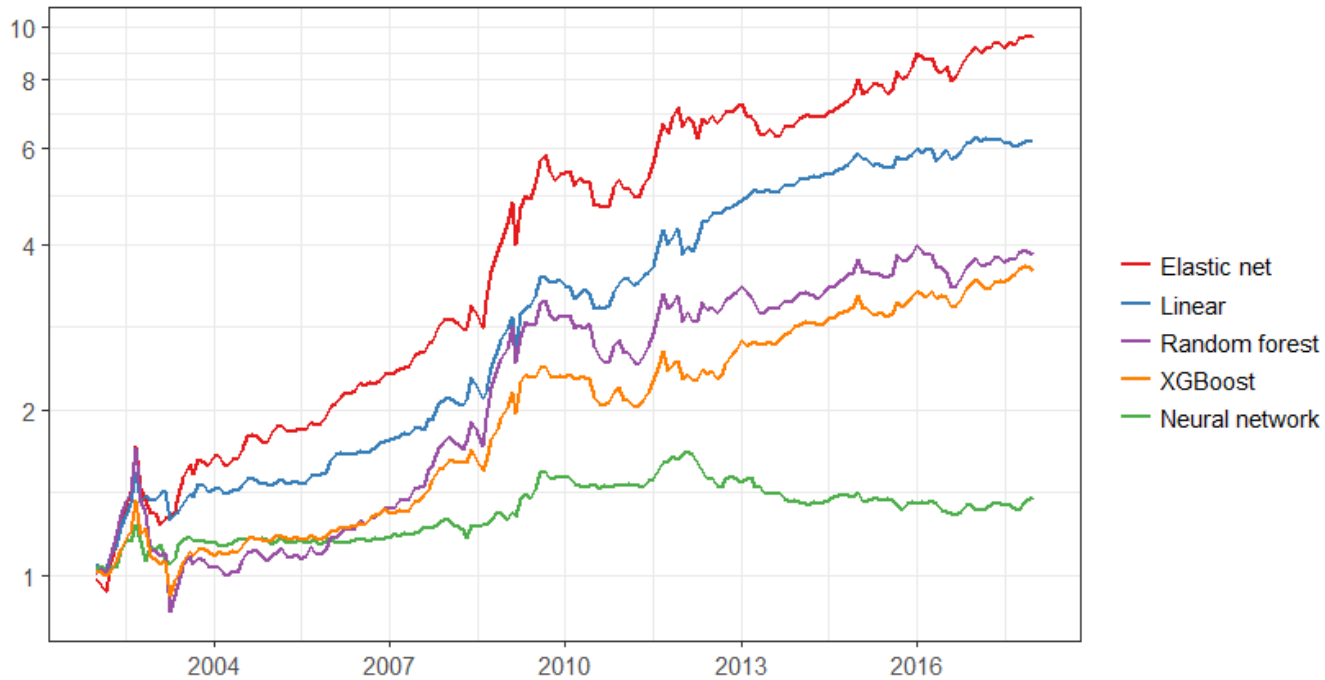


Source: UBS Quant, MSCI. For illustrative purposes only.

Comparing models: long-short

	Linear	Elastic net	Random forest	XGBoost	Neural network
Annualised return	11.96%	**15.11%**	13.09%	8.24%	2.06%
Annualised Std Dev	12.14%	16.43%	16.09%	11.97%	7.48%
Sharpe (Rf=0%)	**0.98**	0.92	0.81	0.69	0.28

Long-short cumulative performance



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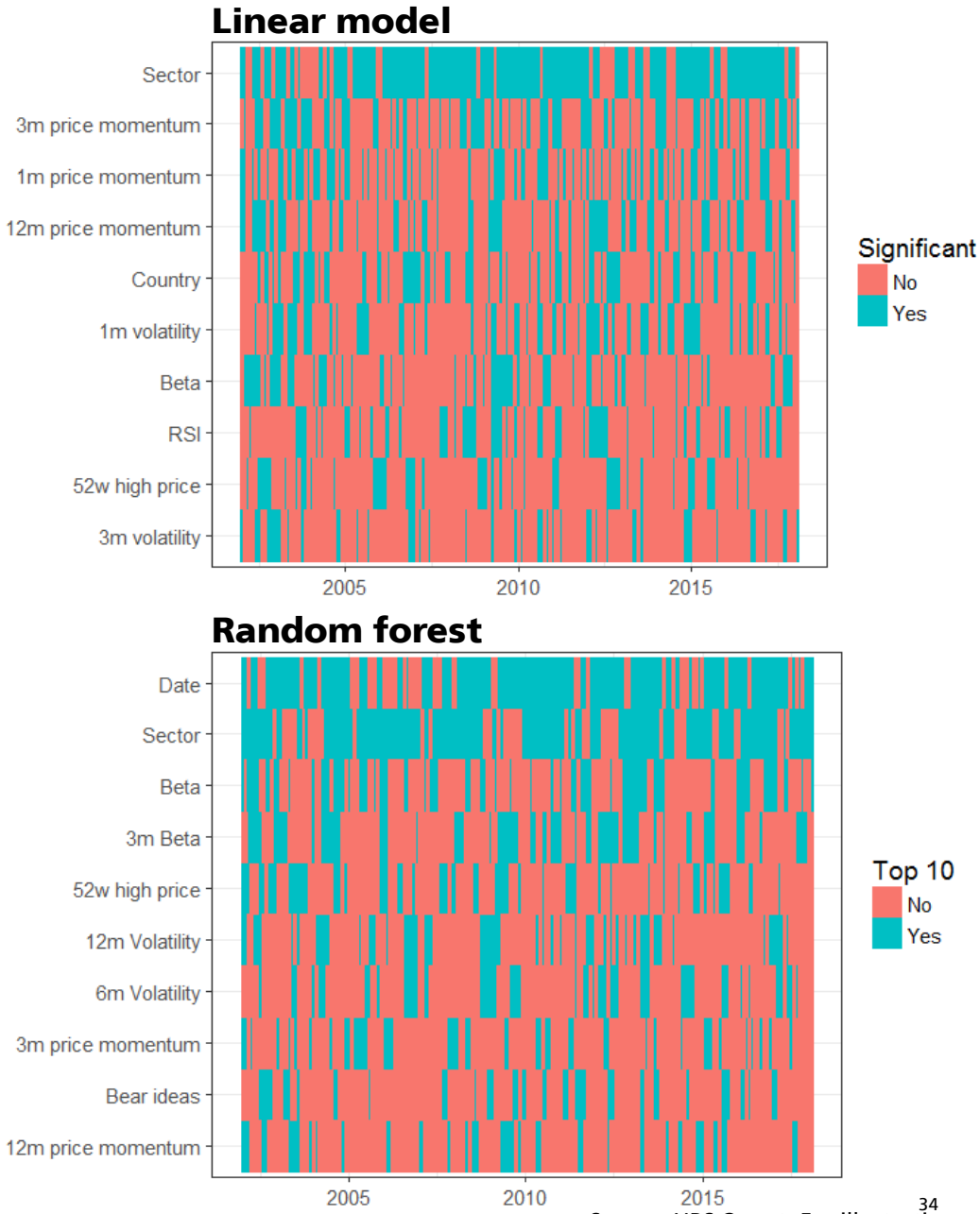
Source: UBS Quant, MSCI. For illustrative purposes only.

Variable importance

- Linear and tree-based models appear to have similar returns
  - What variables drive the predictions?
- Linear models: look at significance of coefficients (at 5% level)
- Random forest: look at variable importance, measured by "mean decrease in accuracy" if that variable is omitted
- Charts show top 10 variables according to measures of importance
- Sector, market beta, short and long term price momentum



Source: UBS Quant. For illustrative purposes only.

AI in finance: challenges

Why is it hard to apply modern machine learning techniques (such as **deep learning** and **boosting**) to financial data?

- Compared to speech/text/images, financial time series have very different characteristics:
  - Low signal to noise ratio (image classifiers fail when noise is added – adversarial examples)
  - More data is hard (impossible) to generate
    "*Strong false assumptions can be better than weak true ones, because a learner with the latter needs more data to avoid overfitting*" (Domingos, 2012)
  - The past is not a good predictor of the future
    "*Machine learning, on the other hand, is applicable to datasets where the past is a good predictor of the future*" (Chollet, 2017)

So what could be the potential applications?

- Text analysis to generate sentiment scores
- (Satellite) Image analysis to gain insights into a given stock or industry
- ….

Conclusion

- Deep learning is a *relatively old* subfield of machine learning, which gained popularity in 2010s
  - Remarkable results on perceptual tasks involving unstructured data
- Boosting: XGBoost (2014)
  - State-of-the art for problems where structured data is available
- A "simple" exercise to predict monthly cross-sectional returns given a large set of inputs → stock-selection model for MSCI Europe
  - The standard linear model performs best (risk-adjusted return)
  - Regularisation (elastic net regression) might be a good idea
  - Non-linear models strictly underperform linear ones (risk-adjusted and absolute returns) in our empirical analysis
  - From the non-linear models random forest does best
  - Neural networks do not appear suitable for the task; dropout helps with overfitting but results remain unconvincing

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Our quantitative models rely on reported financial statement information, consensus earnings forecasts and stock prices. Errors in these numbers are sometimes impossible to prevent (as when an item is misstated by a company). Also, the models employ historical data to estimate the efficacy of stock selection strategies and the relationships among strategies, which may change in the future. Additionally, unusual company-specific events could overwhelm the systematic influence of the strategies used to rank and score stocks.

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Sell	FSR is > 6% below the MRA.	16%	13%
Short-Term Rating	**Definition**	**Coverage[3]**	**IB Services[4]**
Buy	Stock price expected to rise within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%
Sell	Stock price expected to fall within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%

Source: UBS. Rating allocations are as of 31 December 2017.
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