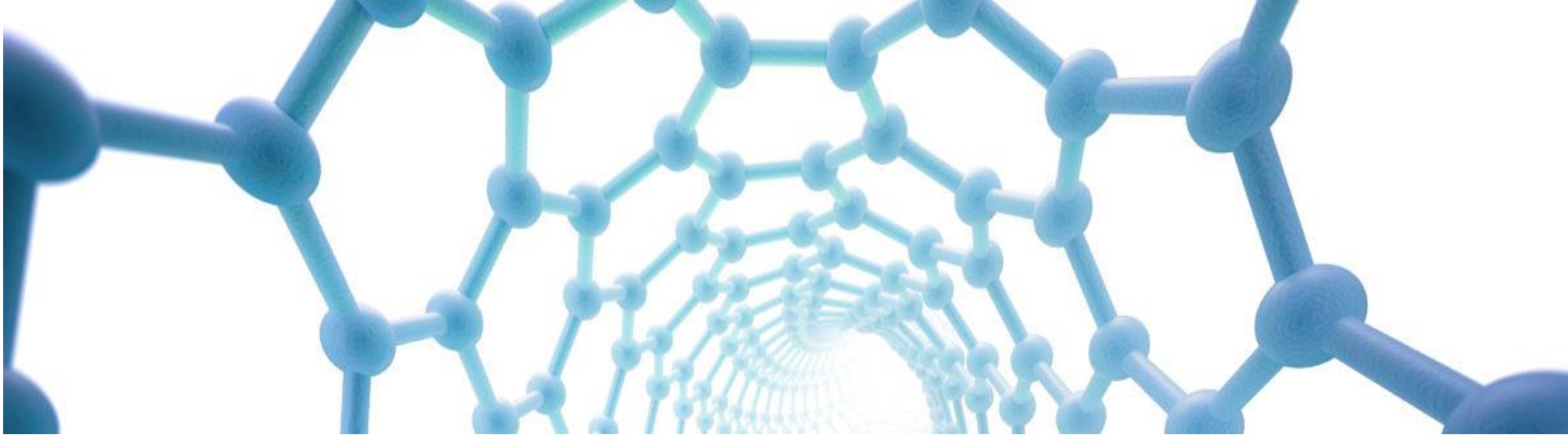


Quantitative Machine Learning for Stock Markets

Sorin Alexe, Ph.D.,

QML Alpha LLC, Stamford, CT, USA

www.qmlalpha.com

Abstract

Recently, there is an increased interest in applying Machine Learning and Artificial Intelligence to the construction of investment strategies. Here we introduce a *Quantitative Machine Learning Platform* for alpha discovery and strategy construction. There are three research layers that can help researchers finding signals that are hidden in large amounts of data:

- Interactive Design
- Machine Learning Tools
- Computer Simulations

The platform offers researchers tools for applying supervised and unsupervised Machine Learning techniques to large collection of data describing time-series systems, where uncertainty plays an important role. Modeling with a programming-free GUI allows researchers to focus on discovery of models based on discriminative and generative Machine Learning algorithms and integrate them in complex decision-making tools. A high level of automation is achieved via the definition of a structured search space and investigation of large samples of strategy candidates.

A brief introduction on portfolio construction will be followed by a demo session on alpha design. For those of you who become interested in learning more about quantitative investment and model construction we can provide access to use this platform to investigate new ideas, discover new models and apply hedging techniques to balance the reward to risk ratio.

Outlines

- History of Investment
- Portfolio Construction
- Finding Alphas
- Evolutionary Framework
- QML Platform Demo Session
- Conclusions

History of Investment - Bonds

- **The First Bond Ever. (~2400 BC)**
  The first recorded bond in history dates back to 2400 B.C. – a stone discovered at Nippur, in Mesopotamia (Iraq).

- **Venetians Create Advanced Bond Markets (1100 AD)**
  Venice began issuing government bonds to fund its wars, known as the presiti. The city continued to evolve its bond market throughout the 14th century, when denizens of Venice could purchase and trade government securities, which paid the owner an endless annuity at a set rate.

Lorenzo de' Medici
Florence, Currency trades

- **The First Official Government Bond**
  The first ever government bond was issued by the Bank of England in 1693 to raise money to fund a war against France. These first bonds were a mix of both lottery and annuity.

History of Investment - Stocks

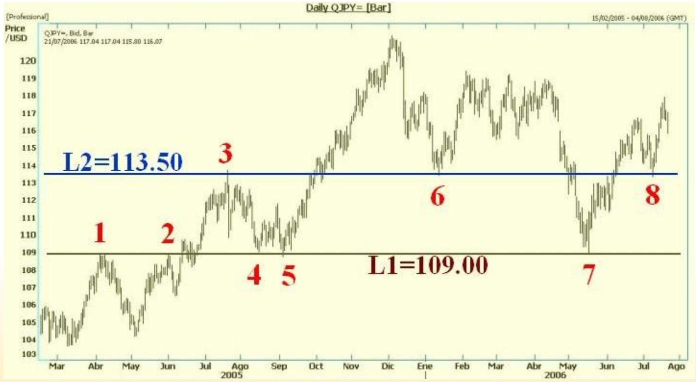
- In the early modern period, the Dutch developed several financial instruments and helped lay the foundations of modern financial system. The Dutch East India Company (VOC) became the first company in history to issue bonds and shares of stock to the general public. In other words, the VOC was officially the first publicly traded company, because it was the first company to be ever actually listed on an official stock exchange.

- The **Dutch East India Company** (Dutch: *Vereenigde Oostindische Compagnie*; **VOC**) was an early megacorporation founded by a government-directed amalgamation of several rival Dutch trading companies (*voorcompagnieën*) in the early 17th century. It was established on March 20, 1602, as a chartered company to trade with India and Indianised Southeast Asian countries when the Dutch government granted it a 21-year monopoly on the Dutch spice trade.

History of Investment - Futures

- In 1697, the **rice** exchange received an official license from the Shogunate (government). By 1710, merchants were trading **futures contracts** based on the perceived **future** value of **rice**. 1710 is the official date at which the modern **futures** exchanges market is thought to have begun

- In finance, **technical analysis** is an analysis methodology for forecasting the direction of prices through the study of past market data, primarily price and volume



- Speculation opportunities appeared:

  Buy a $100 oil future contract, sell a $110 oil future contract

Portfolio Construction

A Portfolio is a basket of securities. Example:

1 million shares IBM and 2 million shares Apple: (W=(1*$132.22 , 2*$190.15))

https://finance.yahoo.com/quote/IBM?p=IBM

https://finance.yahoo.com/quote/AAPl/?p=AAPl

Performance Metrics

- Return: $R_P = \boldsymbol{W}^T \boldsymbol{R}$
- Risk (volatility^2): $Risk_P = \boldsymbol{W}^T \boldsymbol{Q}\ \boldsymbol{W}$

Q – covariance matrix

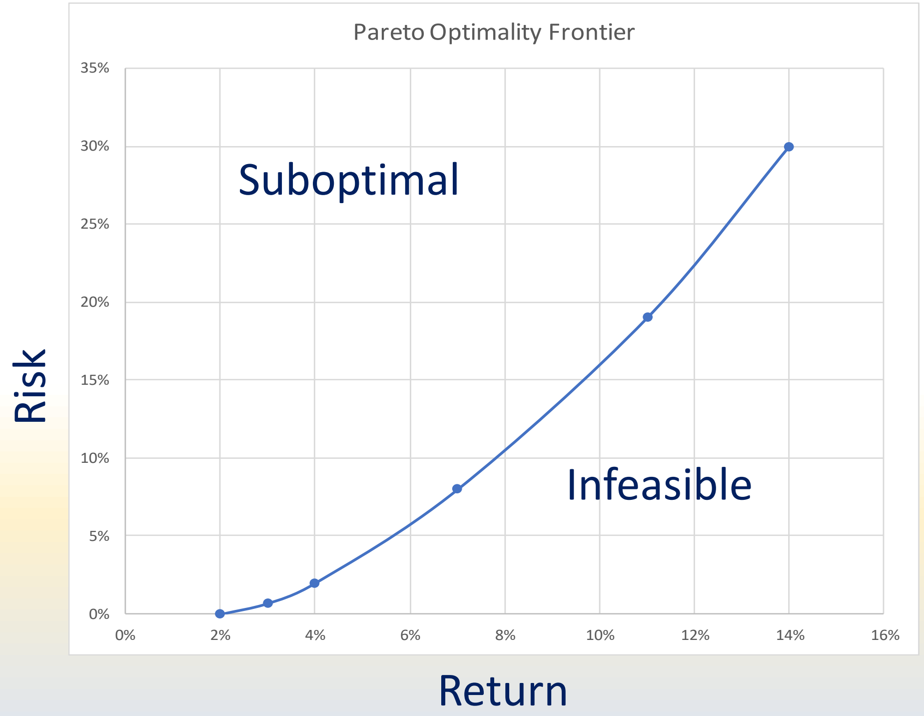
Markowitz Models (1952, later Nobel prize for Economics)

Goal (equivalent formulations)

1. maximize portfolio return for a certain level of risk
2. maximize risk adjusted return
3. minimize risk for a certain target return
4. maximize Sharpe Ratio (R_P / $Risk_P$)

Example

Return	Volatility	SR
2%	0%	infinity
3%	0.70%	4.29
4%	2%	2.00
7%	8%	0.88
11%	19%	0.58
14%	30%	0.47



Estimate R and Q - Two Big Challenges

Estimations for R = **Alpha Models** (signals, predictors, factors):

Economic factors:	Value and Growth
Behavioral patterns:	Momentum and Reversion
Economic cycles	Bulls and Bears

Estimations for Q (factor risk models: style factors, statistical factors, sectors, industries):

$$\boldsymbol{Q} = \boldsymbol{B}^{\boldsymbol{T}}\Sigma\boldsymbol{B} + \Delta^{2}$$

Example: 2000 assets, 20 factors:
Q(2000,2000), B(20,2000), Σ(20,20), Δ^2=diag(2000), i.e., use 41210 numbers to represent2001000 (Q and Σ are symmetric)

Note. If W is orthogonal to all columns of B then $\boldsymbol{W}^{\boldsymbol{T}}\boldsymbol{Q}\boldsymbol{W} = \boldsymbol{W}^{\boldsymbol{T}}\boldsymbol{B}^{\boldsymbol{T}}\Sigma\boldsymbol{B}\boldsymbol{W} + \boldsymbol{W}^{\boldsymbol{T}}\Delta^{2}\boldsymbol{W} = \boldsymbol{W}^{\boldsymbol{T}}\Delta^{2}\boldsymbol{W}$ (specific risk)

Advantage: **Q** is easy to invert via **Woodbury matrix identity:**

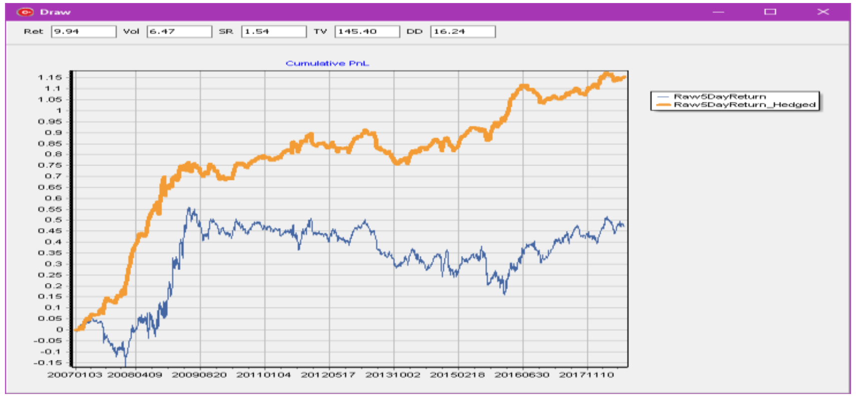
$$(\boldsymbol{A} + \boldsymbol{UCV})^{-1} = \boldsymbol{A}^{-1} - \boldsymbol{A}^{-1}\,\boldsymbol{U}\left(\boldsymbol{C}^{-1} + \boldsymbol{V}\boldsymbol{A}^{-1}\boldsymbol{U}\right)^{-1}\boldsymbol{V}\boldsymbol{A}^{-1}$$

So, an $O(n^3)$ computational complexity becomes $O(n^2)$.

Finding Alphas

Examples:

1. **Fama and French Three Factor Model (CAPM)**: adding size risk and value risk factors to the market risk factor
   https://www.investopedia.com/terms/f/famaandfrenchthreefactormodel.asp



$$R_{it} - R_{ft} = \alpha_{it} + \beta_1(R_{Mt} - R_{ft}) + \beta_2 SMB_t + \beta_3 HML_t + \varepsilon_{it}$$

- R_{it} is the total return of a stock or portfolio, i at time t
- R_{ft} is the risk free rate of return at time t
- R_{Mt} is the total market portfolio return at time t
- R_{it} - R_{ft} is expected excess return
- R_{Mt} - R_{ft} is the excess return on the market portfolio (index)
- SMB_t is the size premium (small minus big)
- HML_t is the value premium (high minus low)
- $\beta_{1,2,3}$ refer to the factor coefficients

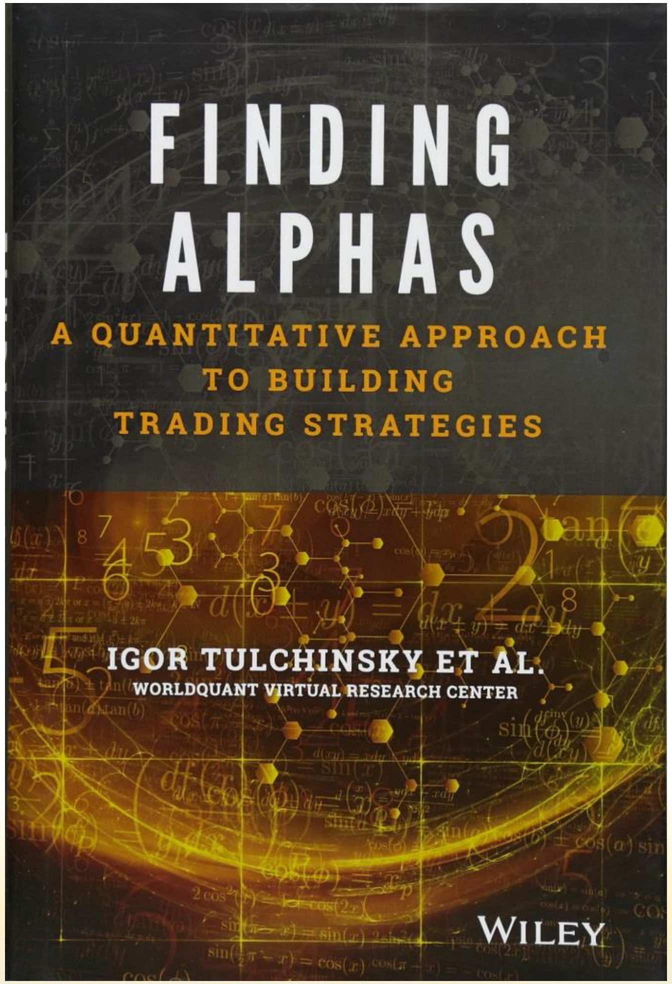
2. **Reversion Model:** negative 5-day returns, factor and group neutralized

   SR: 0.3 → 1.54

3. **Long Term (252 day**) **– Short Term (20)** Momentum spread:

   SR: 0.4 → 1.54

Methods for Finding Alphas



For a long time **linear regression** was the standard for the construction of predictive models in finance.

It used to be present in 90% of the models involved in quantitative investment and trading.

Lately, the Machine Learning approach gains significant visibility. About **30% of the 10000 hedge funds in the USA involve Machine Learning and Artificial Intelligence** algorithms to design their trading strategies.

Igor's design (**WorldQuant**) claims to achieved **26 million alphas**, aiming for 100M. This book is interesting as it does not disclose the techniques of finding alphas, but rather described the framework that should be deployed for a successful implementation. As usual, details remain to be defined.

However, linear regression is just one of the methods that could detect signals and information in data.

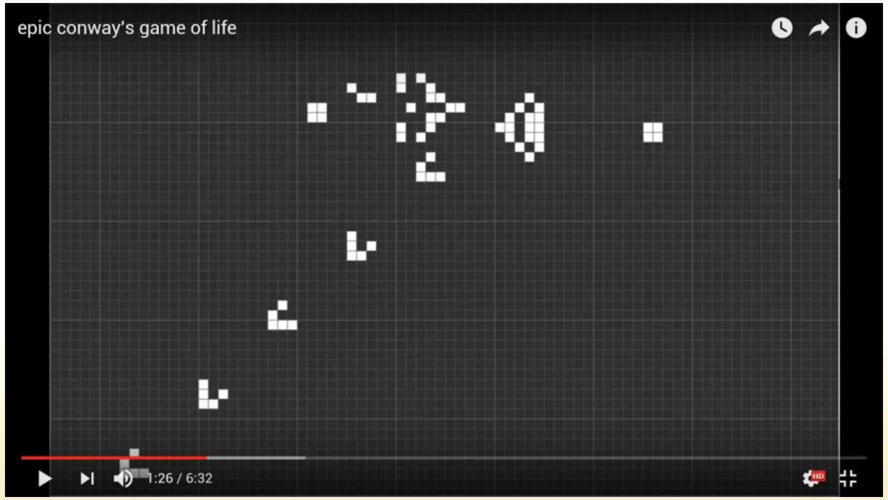
Machine Learning seems to be a better choice, and the financial industry demonstrated an increased appeal in this domain. However, applying ML blindly can be harmful. No algorithm (ready from the shelf) is ready to face the complexity of high noise, uncertain dynamics and low resolution of the market data. The **combination of feature extraction and inductive learning**, adapted to a time series format has been proven to be a feasible approach.

We propose the use of a **kernel of learning techniques** embedded in a **automation framework**. The evolutionary approach is an additional layer on top of Machine Learning traditional or novel algorithms.

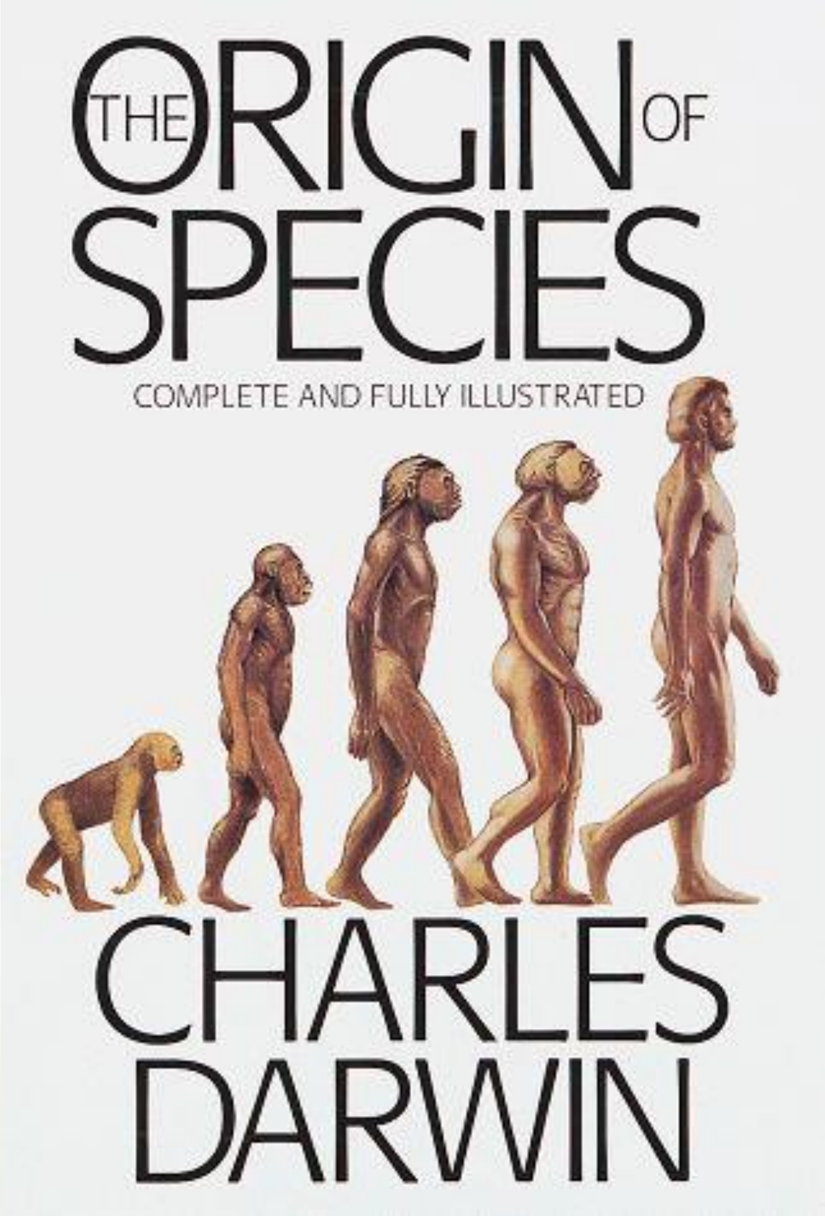
Evolutionary Framework

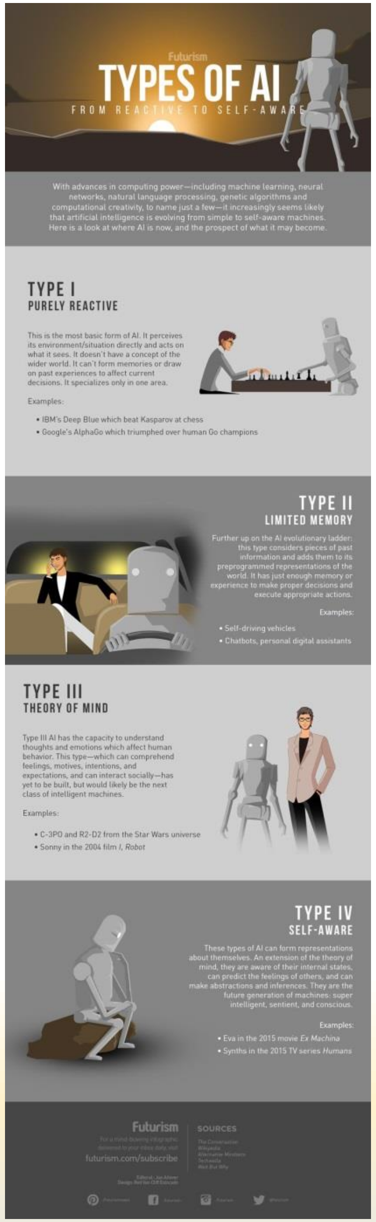
- Large (infinite) number of states
- A system that can represent on state at a time
- A set of operations (transition matrix) that can change the state of the system sequentially
    - Deterministic
    - Stochastic
- A semantics that validates states
- Examples
    - Digital computers: 0/1 (meaning)
    - Biology: Genetic mutations (survivorship)
    - Finance: Collection of all portfolios
      over a common universe (investment grade)

Example: epic John Horton Conway's "game of life"



Evolution in Biology & AI



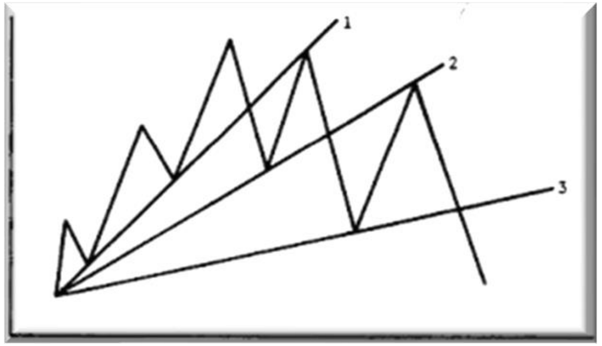


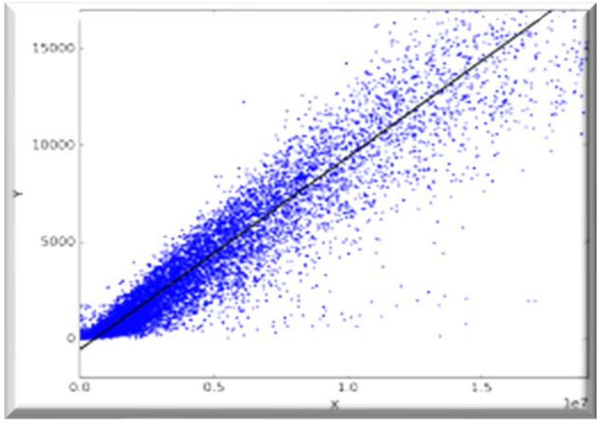
The Machine Arrival

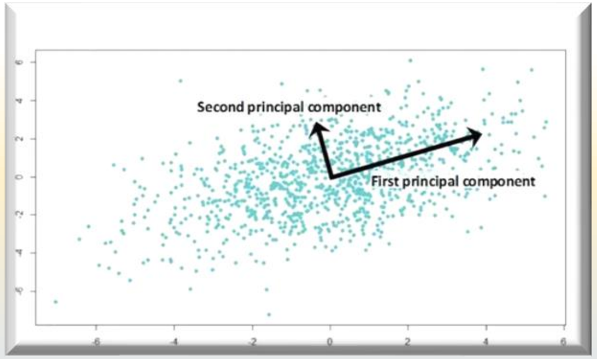
- **Artificial Intelligence is developing at increased speed and starts to have major impact for society, economy and finance.**
- 1997: IBM Deep Blue computer defeated Kasparov in the second chess match
- 2011: IBM Watson computer won 'Jeopardy!'
- 2015: Google's AlphaGo AI defeated a human 9-dan GO champion

Operations and Transformations Kernel

- Mathematical
- Technical Analysis
- Control (risk, holdings and trading)
- ML supervised:
  - Regression (assets and portfolio level predictions)
  - Classification (marginal classifiers could become signals)
  - Aggregation techniques (consensus for signal strength augmentation and noise cancellation)
- ML unsupervised
  - Feature Extraction (risk models)
  - Clustering (groups)



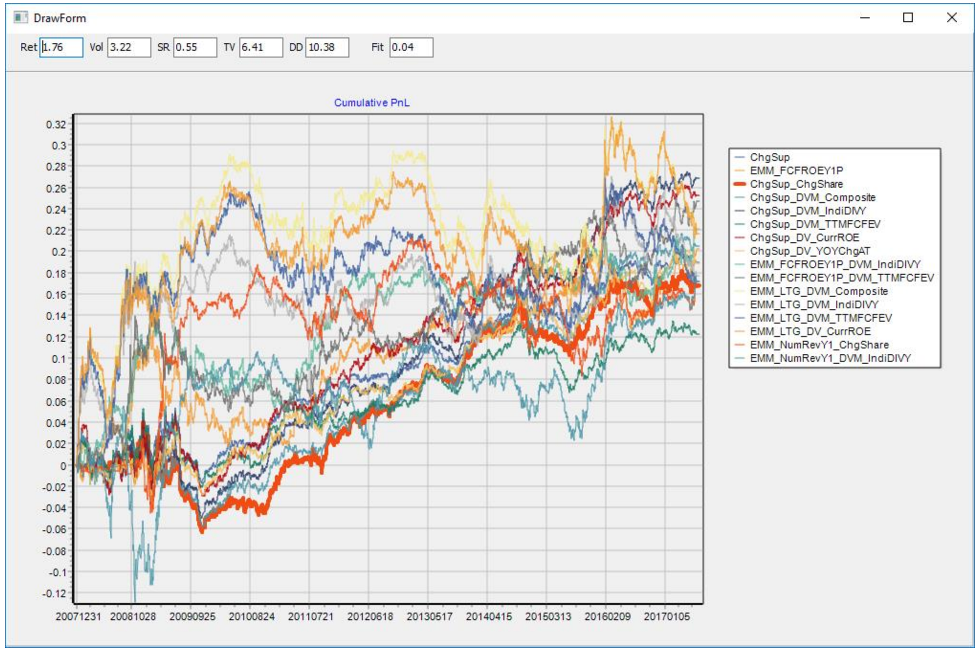




Next Layer: Automation

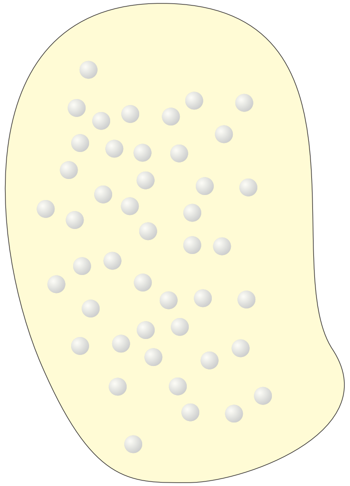
- Natural Computing Approach
- Infinite Space
- Sample large number of hypothesis
- Backtest and filter
- Assemble the findings

Algebra of Portfolios

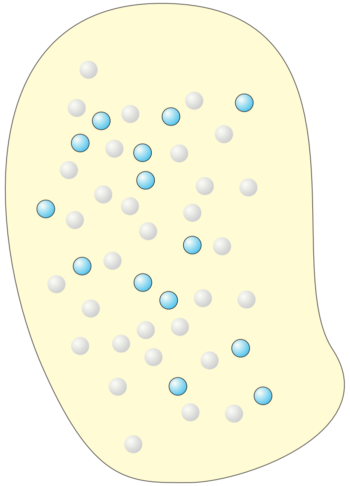


- A portfolio is a set of weights with 2 dimensions:
  - Time (daily)
  - Assets (tickers)
- Performance is based on the economic effect:
  - Profit & Loss
  - Risk exposure
    - Sharpe, Sortino, Sterling and Calmar ratios
- Operations can be applied to a set of portfolios to create new ones:
  - Averaging (mathematical transformations)
  - Learning (ML algorithms and researcher interactions)
  - Hedging (control)
  - Evolutionary

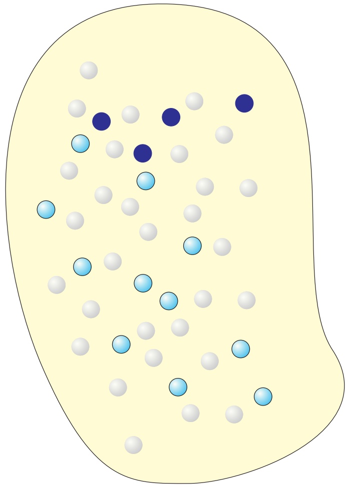
Evolutionary Alpha Discovery



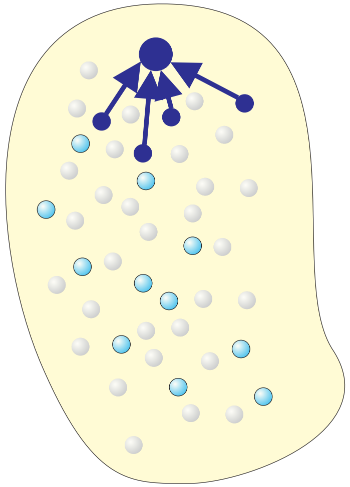
The space of all searchable portfolios



A large number of portfolios is sampled from the search space



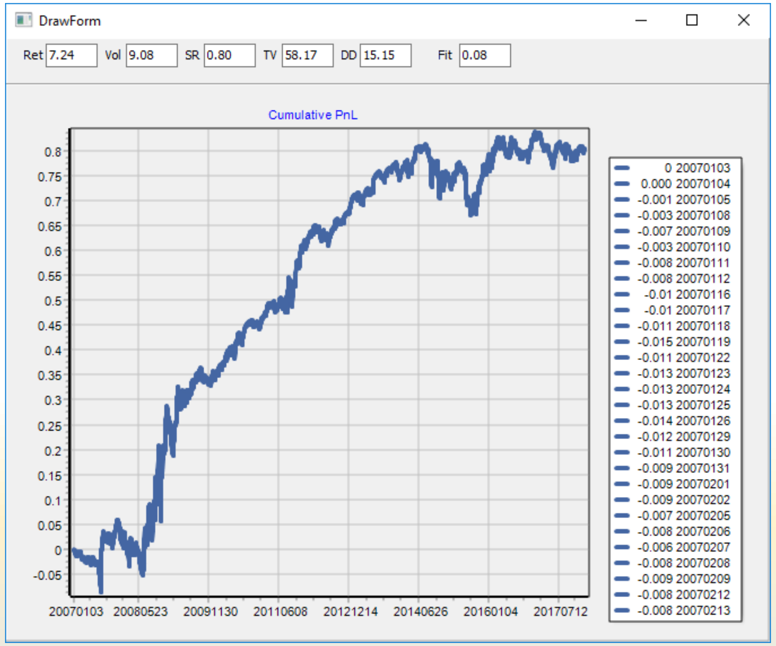
High performing portfolios are retained

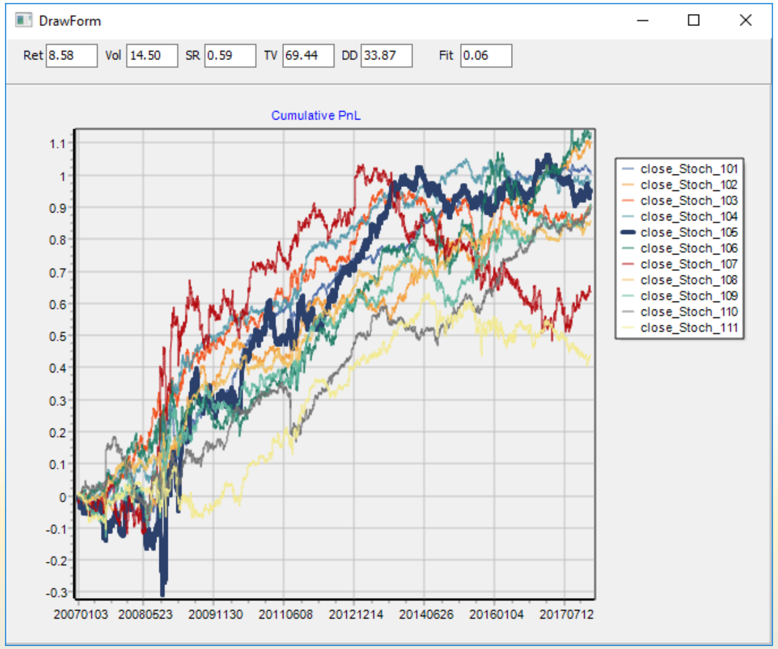


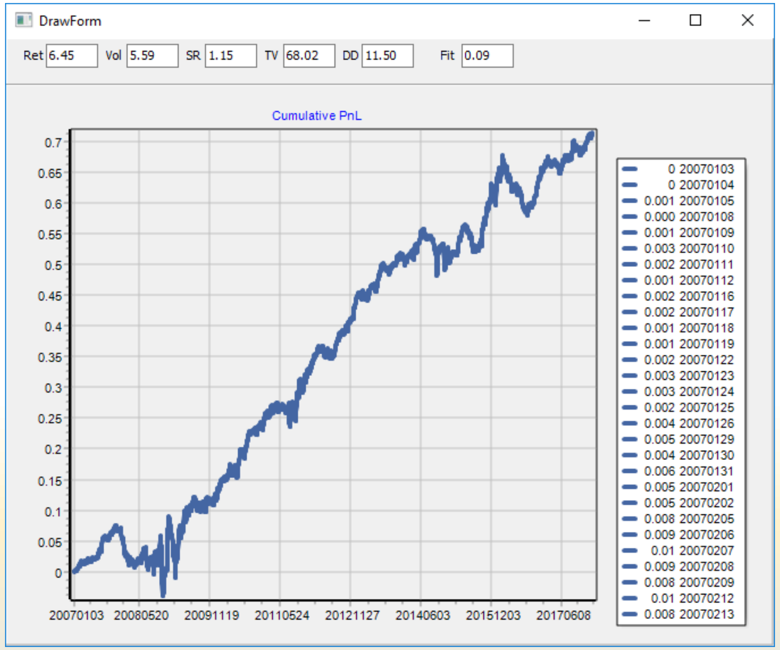
Retained portfolios are combined into one model

Sector Learning

- Start with a portfolio, say Stochastic indicator for 10 days
- Project it on sectors and subindustry neutralize all components
- Apply Mean-Variance optimization







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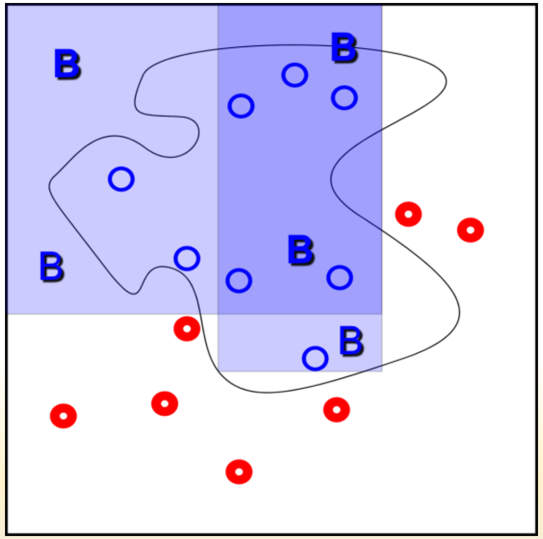
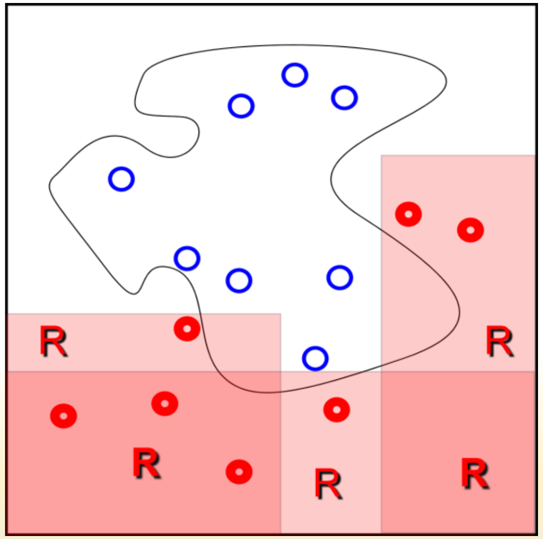
Pattern Based Inductive Learning

- Select 2 explanatory attributes (return and volume)
- Define positive return (in blue) and negative return (red) classes
- Generate positive and negative patterns (rules)
- Construct positive and negative indices
- Build the alpha model as the difference between the positive index and the negative index

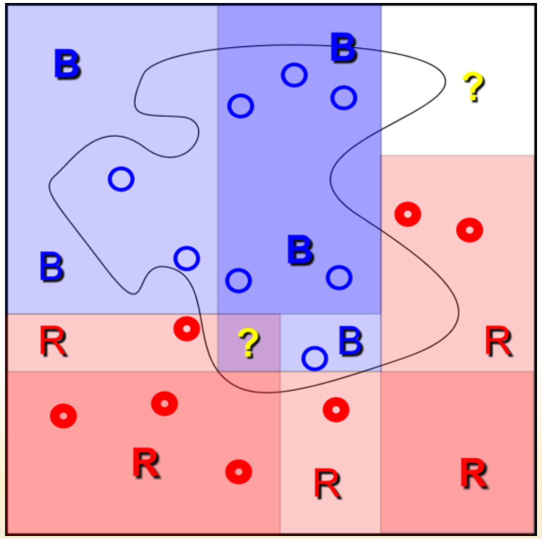
Positive Index



Negative Index



Alpha Model

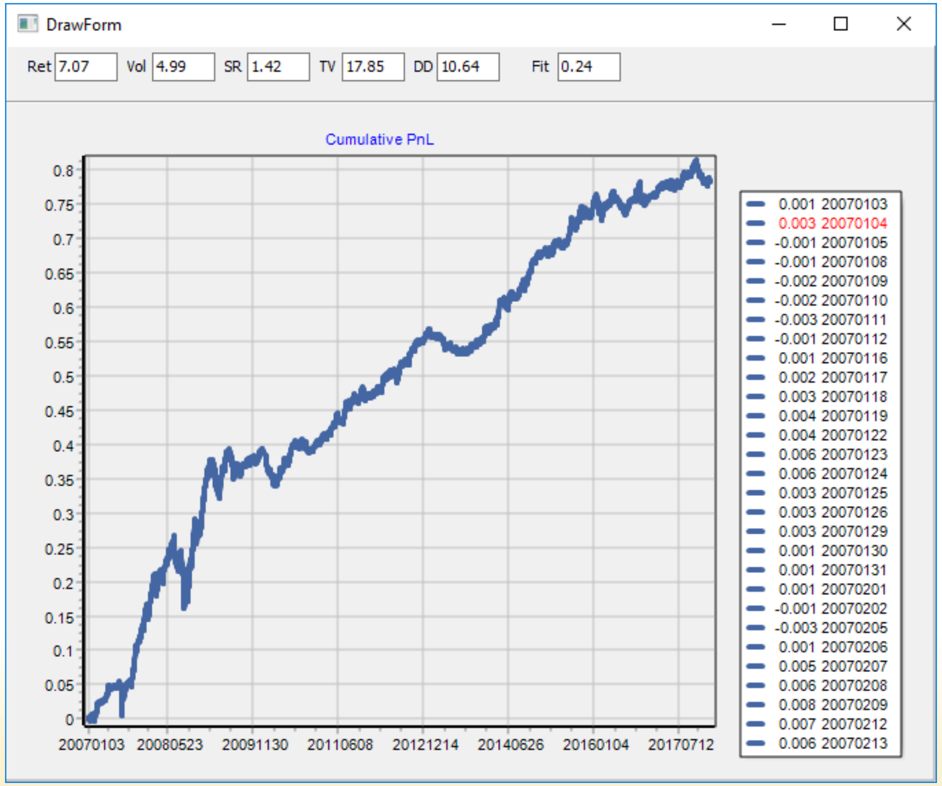


Pattern Based Portfolio

Input: Short Sentiment data (9 attributes, factor neutralized)

Parameters:

- Grid size = 8
- Positive patterns ratio > 51%
- Negative pattern < 49%
- Learning period = 6 years (2 mil data points)



Findings:

- 232 positive patterns
- 24 negative patterns

Portfolio generated: SR = 1.4, PnL = 7%

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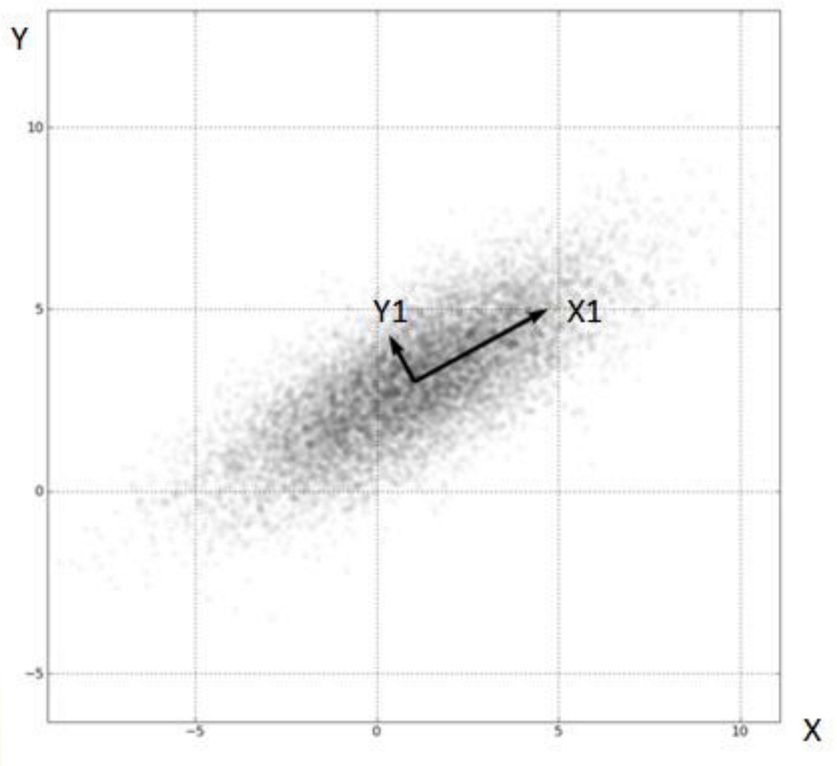
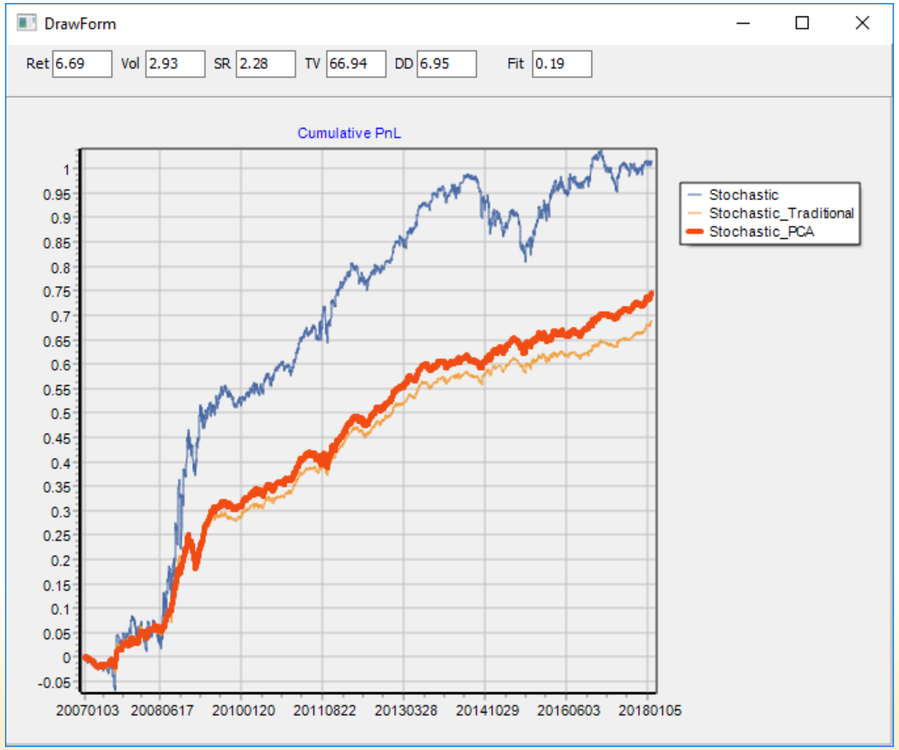
Feature Extraction
Hedging with Risk Models

Alpha Name	Sharpe Ratio	PnL
Stochastic	0.93	9.10%
Stochastic_Traditional	1.87	6.19%
Stochastic_PCA	2.28	6.69%





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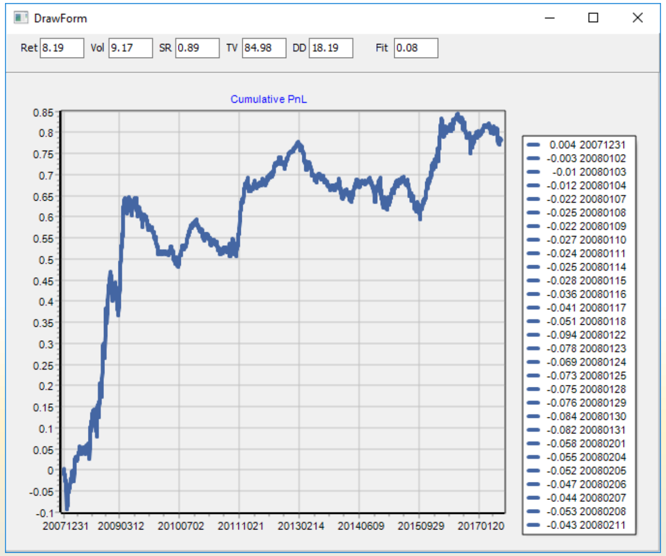
Evolutionary Alpha Discovery

- Use attributes, factors and groups as input variables
- Combine the variables using operations:
  - Technical indicators
  - Hedging operations
  - Aggregation Methods
  - Machine Learning Algorithms



Example: Alpha_01=Expression(Rank(MACD(ret,10,20))*Stochastic(close,5))

Abstractize to a Grammar

[port]=Stochastic([Price],[days])|MACD([Return],[days],[hist])
[Price]=close|high|low|open
[Return]=ret
[Alpha]=[port]*[port]
[days]=5|10
[hist]=20|60|60
[StartSymbol]=[Alpha]

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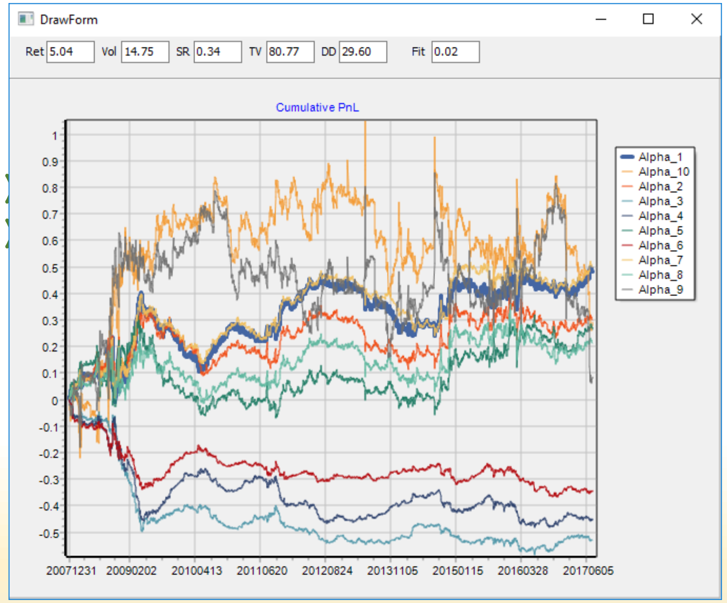
Evolutionary Alpha Discovery

- Generate many “portfolio expressions” of the same kind
- Backtest, select and aggregate/learn


```
MACD(ret,10,60)*Stochastic(low,5)
Stochastic(close,10)*MACD(ret,10,20)
Stochastic(high,5)*Stochastic(open,10)
Stochastic(close,5)*Stochastic(low,10)
Stochastic(close,10)*MACD(ret,5,20)
Stochastic(close,5)*Stochastic(low,5)
MACD(ret,10,60)*Stochastic(high,5)
Stochastic(high,10)*MACD(ret,10,20)
MACD(ret,5,60)*MACD(ret,10,20)
MACD(ret,5,60)*MACD(ret,5,60)
```



Pattern based alpha model

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QML Platform Demo Session

- Interaction

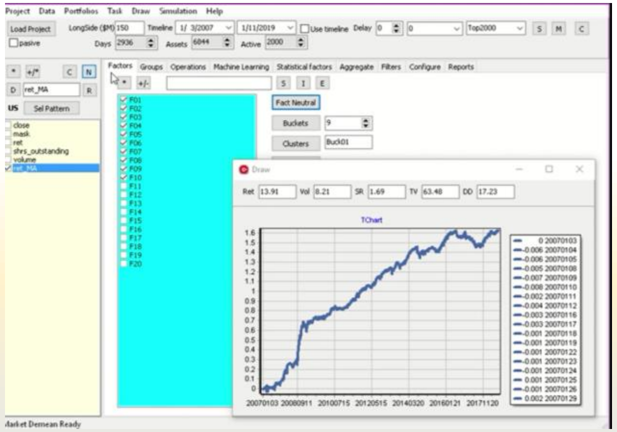
  https://www.youtube.com/edit?o=U&ar=3&video_id=8eBm2R8BbdU

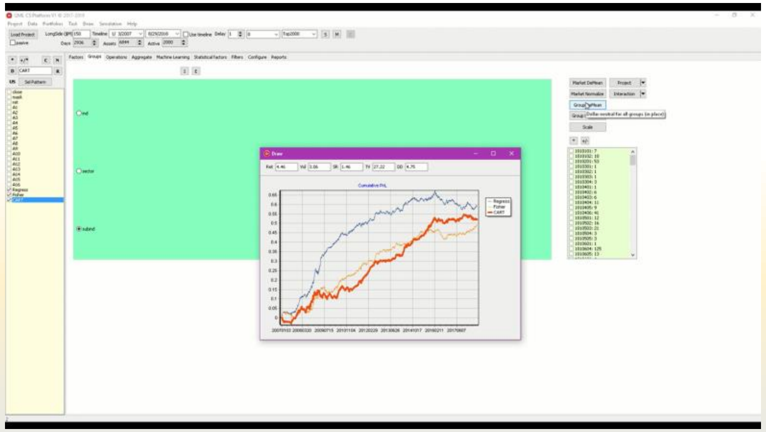
- Machine Learning

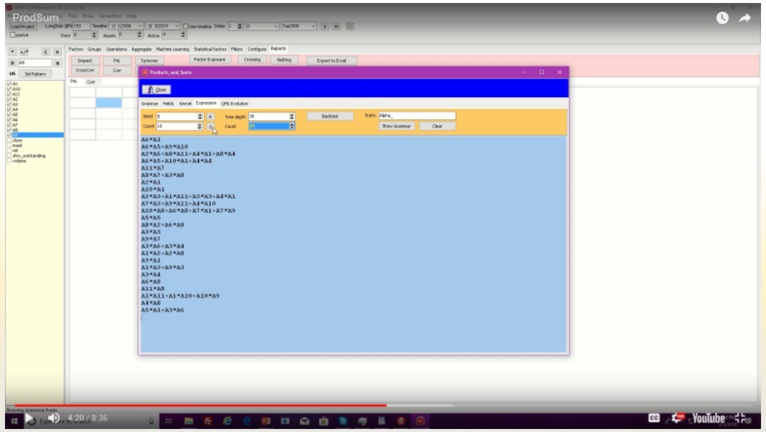
  https://www.youtube.com/edit?o=U&ar=3&video_id=FN-cUhHfLq8

- Evolution

  https://www.youtube.com/edit?o=U&ar=3&video_id=c3CVmEomBc







Conclusions

- Machine Learning is going to transform the society in the near future.
- Financial industry will be affected too: faster and better investment decisions, order flow management and execution
- This raises the question: Is information going to be commoditized? To the point where the value is precisely known? Or is it going to be still an advantage to those on the upfront wave of research?

Hands-on Working Group

For those of you interested, curios and creative we can provide cloud access to the QML Platform , so that you experiment with real data and real portfolio construction problems: alpha discovery, hedging and strategy construction.

Most likely, if you are successfully finding interesting models you might get an internship offer.