
Quantitative Trading

A lecture for Prof Gu's AIML 73 Class

By: Avi Thaker

Lecture Highlights

- » What is Quantitative Trading?
- » Common Trading Strategies
- » Overview of Neural Networks and Deep Learning Frameworks
- » Deep Dive – Aerial Imagery and Wheat Futures
- » Next Steps and Lessons Learned

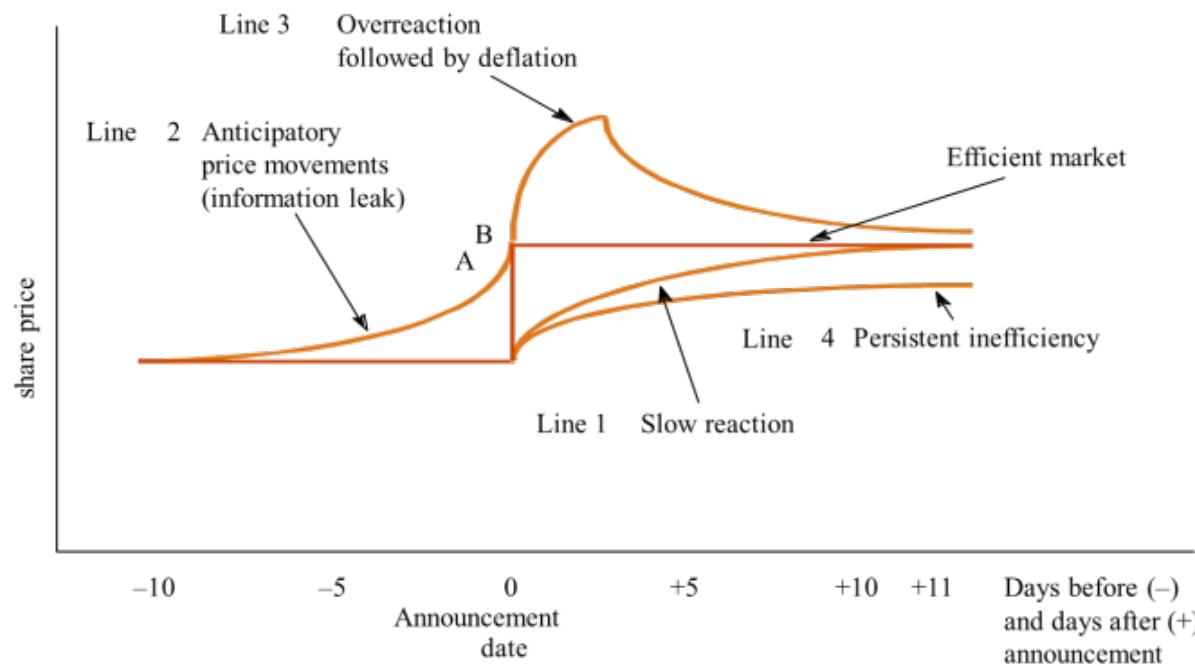


<https://finance.yahoo.com/news/boston-stock-exchange-partners-tzero-141455388.html>

What is Quantitative Trading?

Quantitative Trading

- » Market efficiency causes prices to incorporate and reflect all relevant information
 - Impossible to "beat the market"
- » Warren Buffett? Citadel? Virtu?
 - *When filing for its IPO in March 2014, it was disclosed that during five years Virtu Financial made profit 1,277 out of 1,278 days, losing money just one day.*

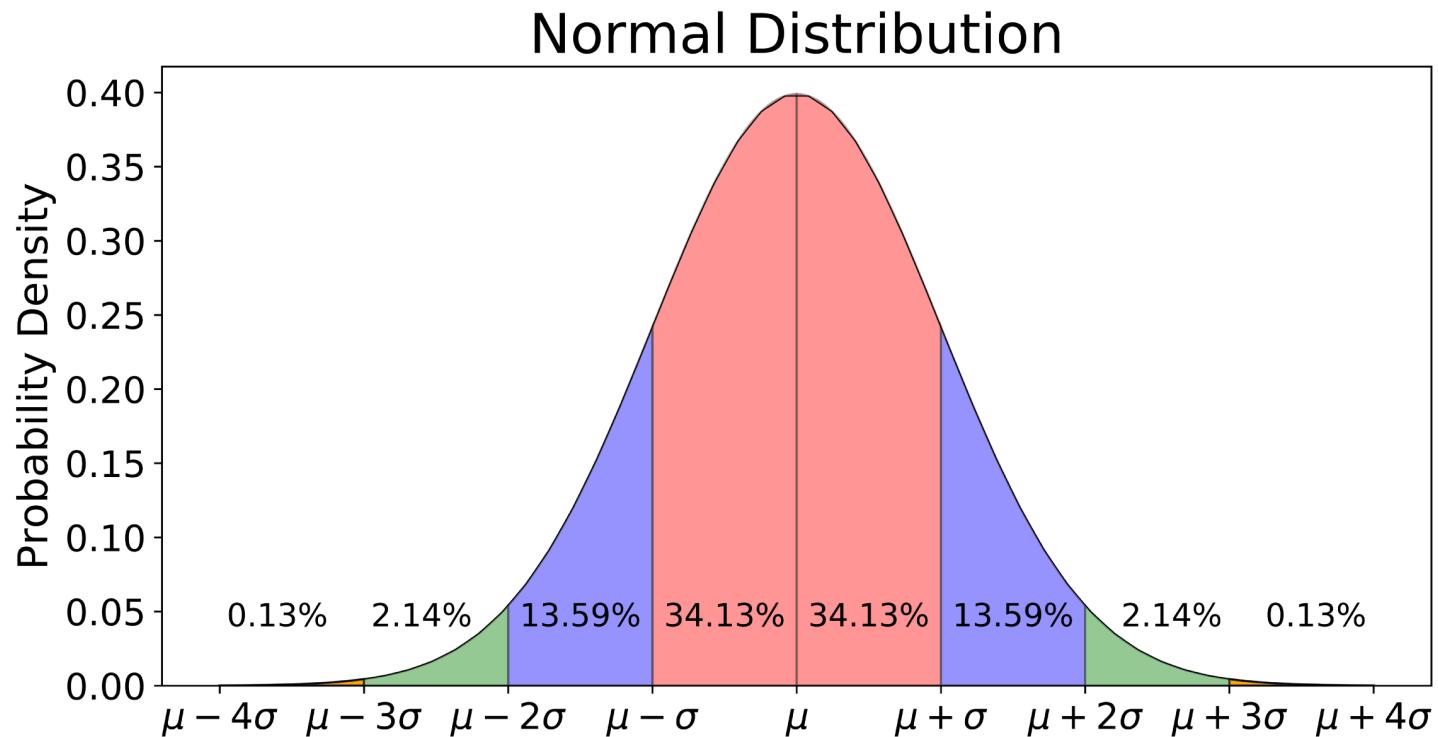


Statistical Sampling

- » Some investors are simply lucky
- » If you were to have a bunch of monkeys throw darts at a wall and use that to pick stocks you will have some major outperformers.

"In statistical terms, I figure I have traded about 2 million contracts, with an average profit of \$70 per contract (after slippage of perhaps \$20). This average is approximately 700 standard deviations away from randomness."

~ The Education of a Speculator



Quantitative Trading

- » The implementation and execution of trading strategies in a systematic and disciplined function.
- » Components
 - Strategy Identification
 - Strategy Backtesting
 - Execution System
 - Risk Management

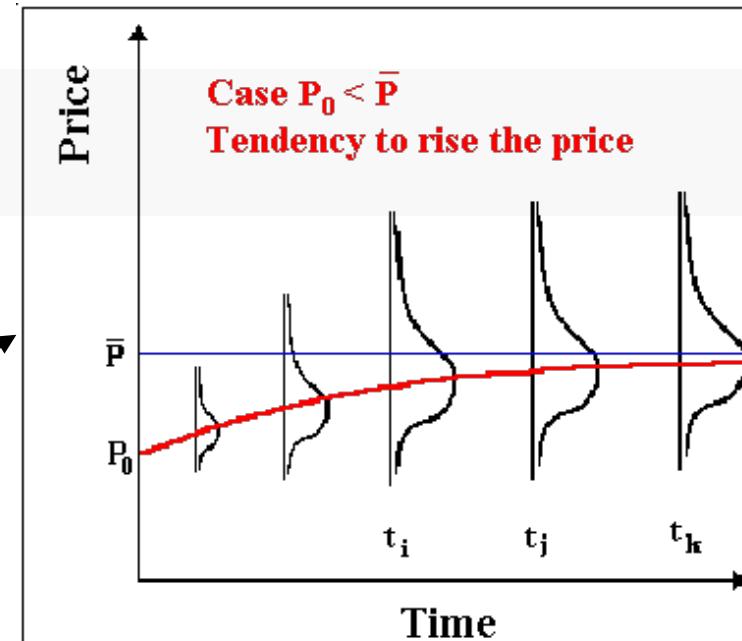


Kinds of Strategies

- » Arbitrage
- » Alpha Taking – Predicting the market
 - Mean reverting
 - Momentum
- » Market Making
- » Index/Pairs Trading
 - Can be part of any of the above
- » Other

Alpha Taking

- » Believes the product will move one direction
 - » Mean Reverting – price reverts back to a “average” price, Bollinger Bands
 - Stochastic Math
 - » Trend following / Momentum
 - Price will move in one direction
 - Impulse response filters



<http://marcoagd.usuarios.rdc.puc-rio.br/revers.html>



Stockcharts.com

Market Making: Limit Order Execution

Bids	Price	Asks
	100.03	2,1
	100.02	3,7,8
	100.01	5,2,15
	100	1,2,5
1,2	99.99	
2,5,8	99.98	
3,8,1,5,3	99.97	
2,3	99.85	

Place limit order
of 2 lots at 99.99

Market Making: Limit Order Execution

Bids	Price	Asks
	100.03	2,1
	100.02	3,7,8
	100.01	5,2,15
	100	1,2,5
1,2,5	99.99	
2,5,8	99.98	
3,8,1,5,3	99.97	
2,3	99.85	

Fill at 99.99, this becomes removed, and position advances. A trade happens

Another order is placed behind you

People cancel their orders

Market Making: Limit Order Execution

Bids	Price	Asks
	100.03	2,1
	100.02	3,7,8
	100.01	5,2,15
	100	1,2,5
2,5	99.99	
2	99.98	
3,8,1,5,3	99.97	
2,3	99.85	

After an order is filled you move up in the queue, until
you either are filled or cancel the order

We are now first in the queue

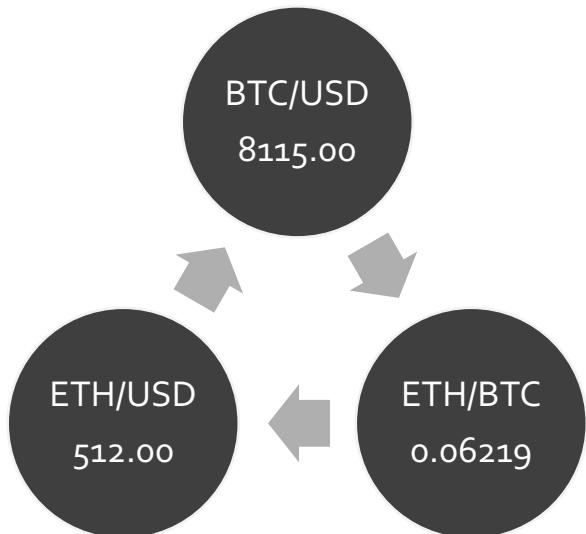
Technical Indicators

- » Technical indicators are mostly **useless** on their own
- » Must identify a market phenomenon and statistically validate it
- » Simplicity and understandability usually are better

- ▶ Accumulation/Distribution (AD)
- ▶ Average Directional Movement (ADX)
- ▶ Absolute Price Oscillator (APO)
- ▶ Aroon Oscillator (ARO)
- ▶ Average True Range (ATR)
- ▶ Bollinger Band (BBANDS)
- ▶ Directional Movement Indicators (DMI)
- ▶ Exponential (EMA)
- ▶ Fill Indicator (FILL)
- ▶ Ichimoku (ICH)
- ▶ Keltner Channel (KC)
- ▶ Linear Regression (LR)
- ▶ Moving Average Convergence Divergence (MACD)
- ▶ On Balance Volume (OBV)
- ▶ Relative Strength Indicator (RSI)
- ▶ Parabolic Sar (SAR)
- ▶ Simple Moving Average (SMA)
- ▶ Triple Exponential Moving Average (TEMA)
- ▶ Triangular Moving Average (TRIMA)
- ▶ Triple Exponential Moving Average Oscillator (TRIX)
- ▶ Time Series Forecast (TSF)
- ▶ TT Cumulative Vol Delta (TT CVD)
- ▶ Ultimate Oscillator (ULTOSC)
- ▶ Volume Delta (Vol Δ)
- ▶ Volume Weighted Average Price (VWAP)
- ▶
- ▶

Arbitrage

Inter Exchange Arb (Triangle)



8115 USD -> 1 BTC
1 BTC -> 16.079 ETH
16.079 ETH -> 8232.83 USD
Net: 117.83 USD

Cross Exchange Arb Console output Crypto

```
[0.0404%, 'BTC/USD', <ccxt.gdax.gdax>, <ccxt.bitstamp.bitstamp>]  
[0.0332%, 'ETH/USD', <ccxt.gdax.gdax>, <ccxt.bitstamp.bitstamp>]
```



Buy BTC on GDAX transfer it to Bitstamp
Sell BTC for USD on Bitstamp
Net: 3.28 USD

ETF Creation/Redemption

- » Authorized participant (market maker, institutional investor, specialist) borrows stock shares and places them in a trust to form ETF **creation units** – bundles of stock units
- » Trust provides shares to the AP, and shares sold to public on open market
- » Redeeming ETF
 - Sell shares on open market
 - Form a creation unit and exchange for underlying security
 - Tax efficient

Creation Unit	Last Trade	Bid	Ask	Size	Net	Percentage
AMD	13.7	13.69	13.7	100	1370	16.31%
INTC	35.16	35.16	35.17	100	3516	41.85%
AAPL	140.64	140.63	140.64	25	3516	41.85%
Creation Unit	84.02			100	8402	100.00%

ETF / Index Arbitrage

Unit	Last	Trade	Bid	Ask	Size	Net	Percentage
AMD	13.7	13.69	13.7	100	1370	16.31%	
INTC	35.16	35.16	35.17	100	3516	41.85%	
AAPL	140.64	140.63	140.64	25	3516	41.85%	
Creation Unit	84.02	84.01	84.03	100	8402	100.00%	

- » This is the most common strategy employed by most quant firms and banks
 - Jane Street, AQR, Jump Trading
- » You need to be **fast** or have **flow**
 - Some of you may have done this in the game
- » Arbitrage happens when ETF trades at a discount or premium to the NAV
 - **Institutional:** When ETF price > NAV, the AP will sell shares it received during creation and make a spread between the cost of the assets it bought for the ETF issuer and the selling price from the ETF shares. AP can also buy the underlying shares that compose the ETF directly at lower prices, sell ETF shares on the open market at the higher price, capturing the spread.
 - **Individuals:** When the ETF is selling at a premium (or discount), individuals can buy (short) the underlying securities in the same proportions and short (or buy) the ETF. Limited by liquidity and spread
 - If inside the spread need to know if the ETF goes to share price or share price goes to ETF price
- » Do this at an international level with ADR's

Example	Price
Calculated Ask	84.03
Calculated Bid	84.0075
ETF Bid	84.04
ETF Ask	84.05

What is the potential profit of this trade?

Deal Flow

- » Bank will trade all of the positions on behalf of FTSE Russell (moves ~20 Billion in a few hours) for a single client
 - Buys up in anticipation of the trade and sells their own shares to the client
 - Massive market moves
- » Legalized insider trading and market manipulation due to sheer size of orders
- » Goldman actually pays Russell (and the like) for their order flow!
- » Robinhood and Citadel!

Winners and losers since 2015 Russell rebalance

Market capitalization and stock price percentage changes from June 26, 2015 to June 17, 2016

TOP MARKET CAP INCREASES



TOP MARKET CAP DECLINES



Source: Thomson Reuters

Staff, 19/06/2016



Other: News Sentiment

» Thesis:

- Twitter and other news sources (Reuters, etc.) can give me an information advantage

» Execution

- Train an ML model to understand Donald Trump's Tweets, trade the resulting market sentiment

» Example:

- <https://www.kaggle.com/c/two-sigma-financial-news>

Donald J. Trump

@realDonaldTrump

Follow

Boeing is building a brand new 747 Air Force One for future presidents, but costs are out of control, more than \$4 billion. Cancel order!

RETWEETS 12,173 LIKES 35,368

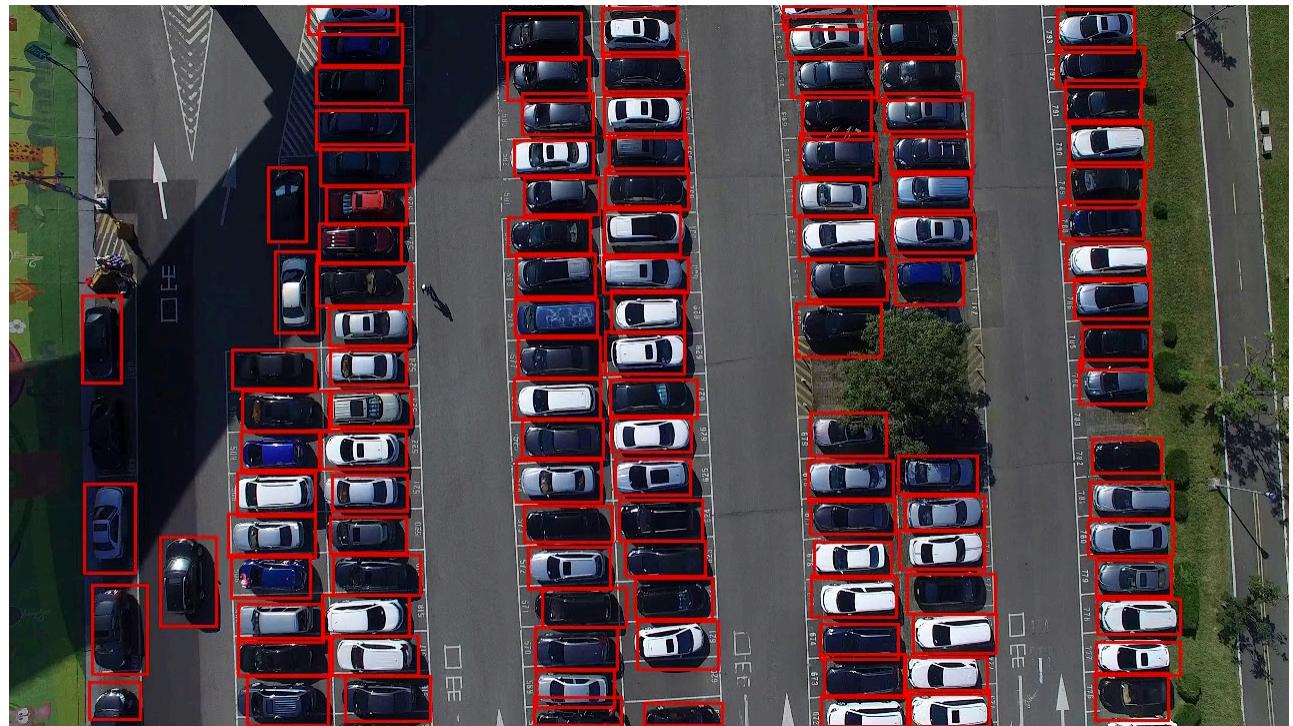
8:52 AM - 6 Dec 2016

5.5K 12K 35K



Other: Drone Car Counting

- » Thesis:
 - Storefront business's financial performance strongly correlated with number of visitors
- » Execution:
 - Use image processing to count the number of cars over time in parking lots
 - Possible to forecast better than market



<https://www.youtube.com/watch?v=HK9r3qFmA7o>

Other: Credit Card Spend and Offline Attribution



- » Thesis:
 - Consumer spending directly correlates with business performance
- » Execution:
 - Buy aggregated customer data from financial companies
 - Offline attribution
 - See if a person searches online and then buys from a store



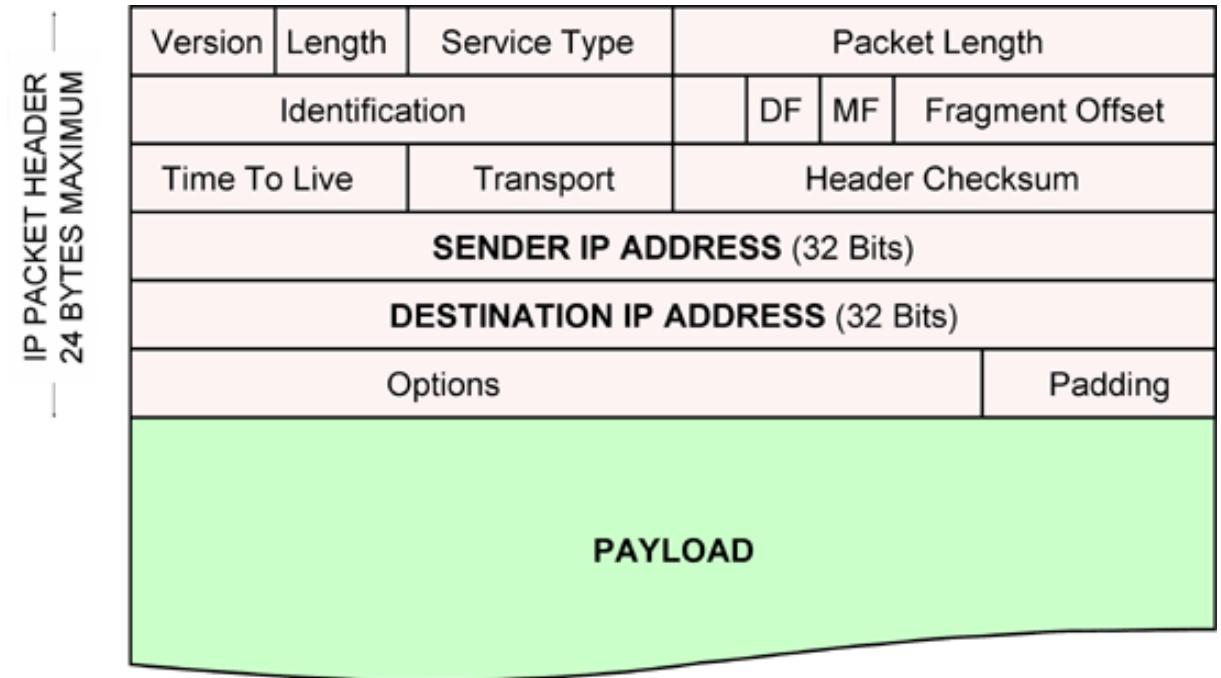
Other: Packet Spoofing

» Thesis:

- Being first in the queue at the start of the day will give me a queuing advantage as I can make the market or understand where the market is trading at

» Execution:

- Malformed packets may not look like an order with intent to cancel – this will give me an information / time advantage
- "*Rule 575, Disruptive Practices Prohibited, prohibits the entering of an order or causing the entry of an order with the intent to cancel the order before execution or to modify the order to avoid execution. This practice is commonly known as spoofing.*"
- cme.com



<https://www.teracomtraining.com/tutorials/teracom-tutorial-IP-packets.htm>

Other: A Listing of Samples

- » Red Lipstick Effect
- » Depth of drinks at movie theatres
- » Time spent at shopping malls
- » Scraping Reddit
- » Long term company health
- » Identifying when darkpools are in play
- » Identifying true insider trading
- » Published insider information
- » Causal Relations from cold calling
- » Size of booths at career fairs
- » Predicting success and failure of startups for private equity
- » Sports / e-sports Betting

Deep Dive

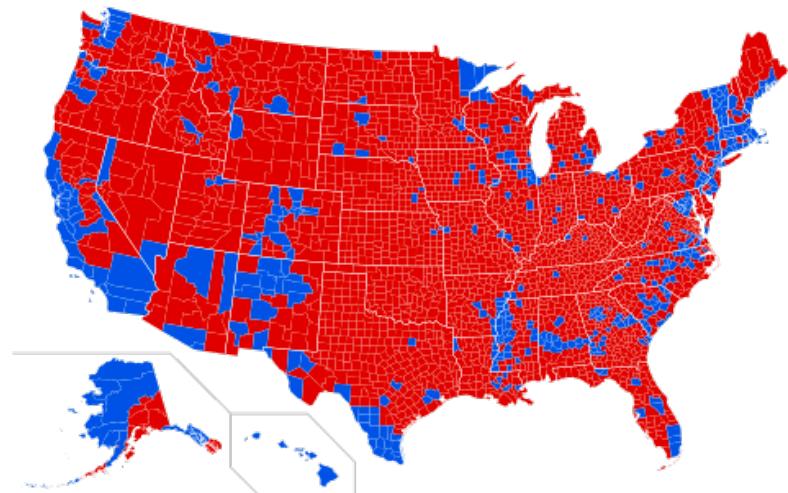
Looking at the Presidential
Election



Overview

- » Use a DNN and features to predict the Trump election and the expected market reaction
- » Python utilizing Tensorflow
- » https://github.com/athaker/econ_136
- » Identify the sources of data and the resulting outputs
- » What features do you think are most important to the model?

Candidate	Party	Electoral Votes	Popular Votes
Donald J. Trump	Republican	304	62,980,160
Hillary R. Clinton	Democratic	227	65,845,063
Gary Johnson	Libertarian	0	4,488,931
Jill Stein	Green	0	1,457,050
Evan McMullin	Independent	0	728,830



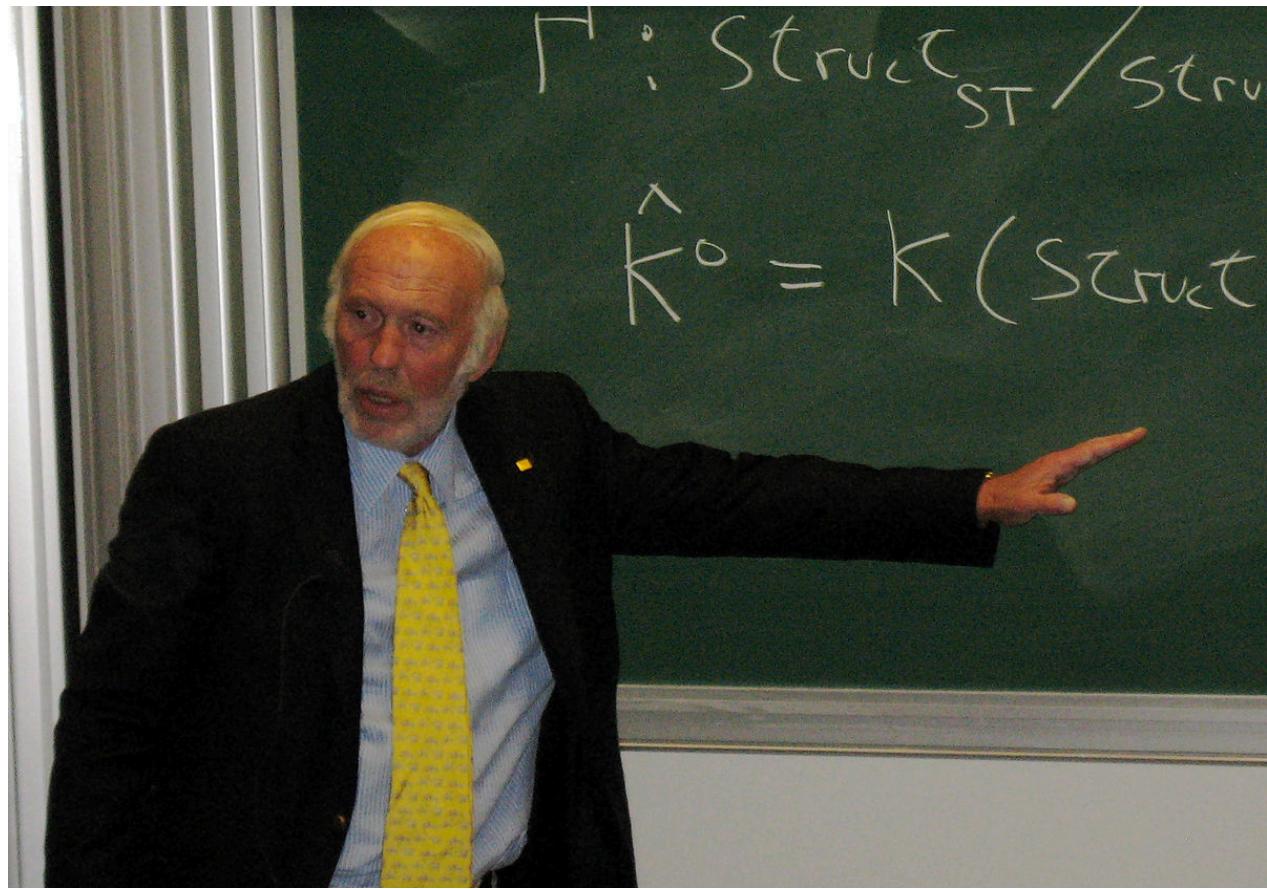
Data Engineering

- » Arguably the most important thing in Deep/Machine Learning
- » High quality labels and features drive model performance
 - Perfect features would be forward looking
- » Personally, I look for model insensitivity*
- » Look for model biases
 - Forward looking bias
 - Curve fitting bias
 - Survivorship bias
 - Psychological bias

*I do not have a formal rigorous approach to this, but I strive for models to get similar results with similar features, i.e. features mean something

Follow Along with Code

https://github.com/athaker/econ_136

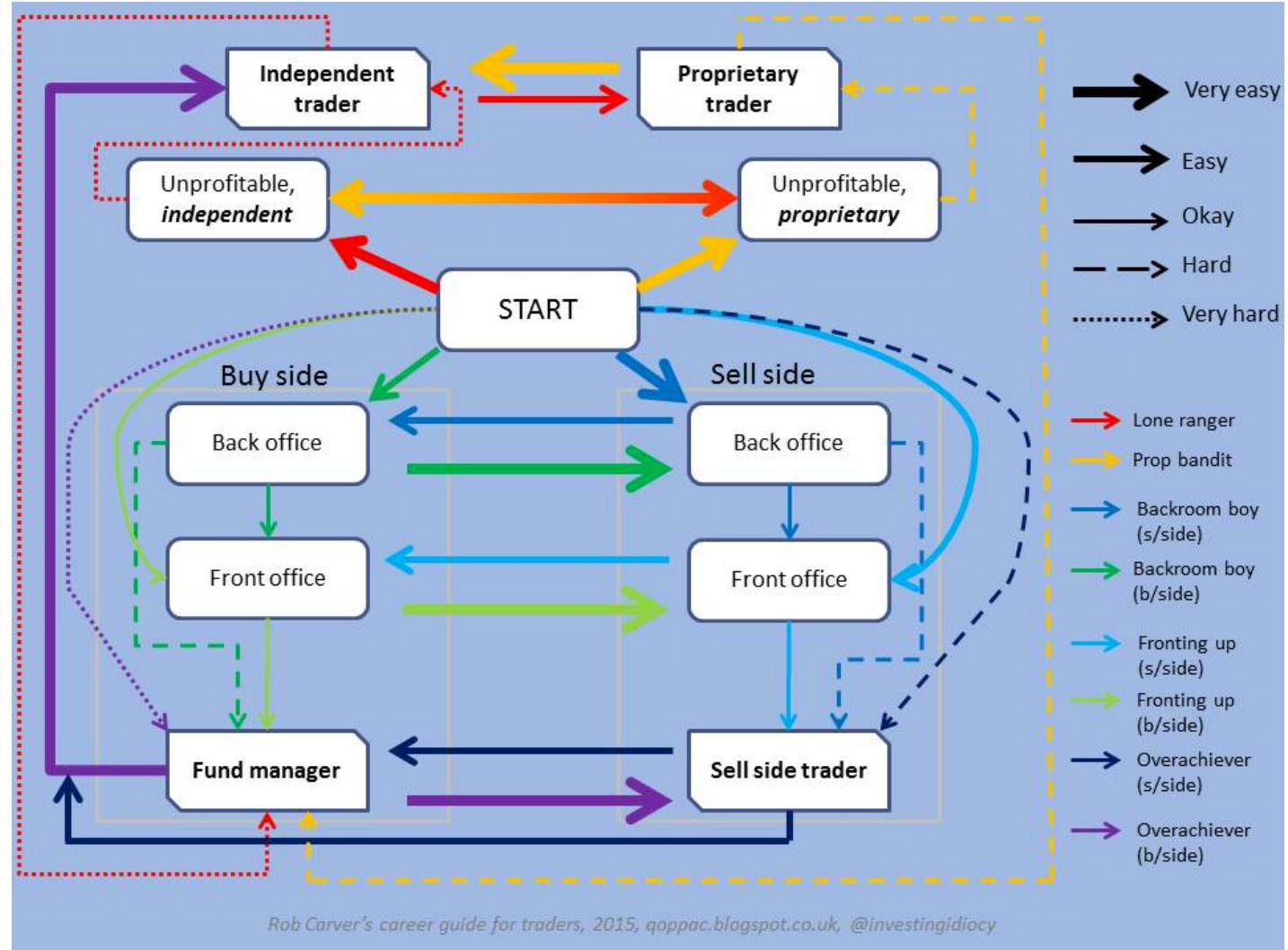


https://en.wikipedia.org/wiki/James_Harris_Simons

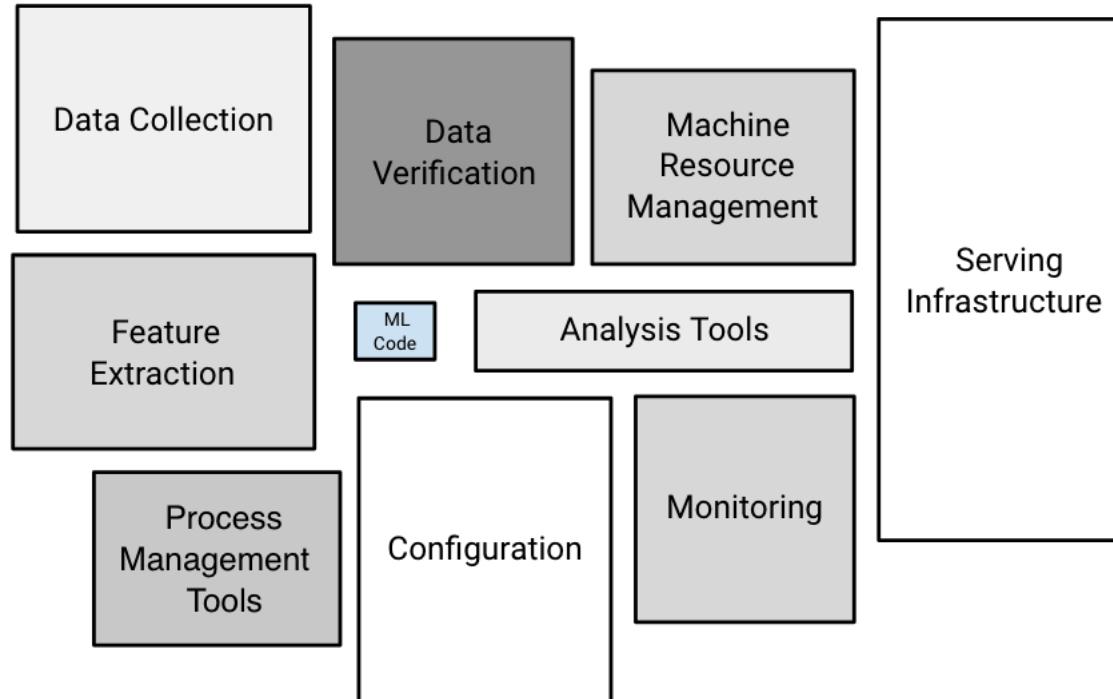
Next Steps and Lessons Learned

A Visual Guide

- » Get started trading!
- » Proof is in the pudding
- » High Sharpe Ratio
- » Quantitative and programming skills



ML/DL is Only a Small Fraction of the Work



<https://developers.google.com/machine-learning/crash-course>

Data Engineering

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Obtaining Data



Mechanical Turk: Build an API for humans to generate you labels

- Better and data will give you better models

Google Trends

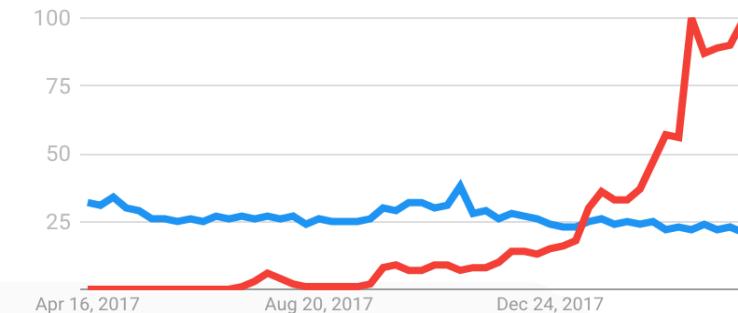
- League of Legends
Online game

- Fortnite
Survival game

+ ADD COMPARISON

Worldwide, Past 12 months

Interest over time



Online Resources: Trading

- » Golden Standard
 - <http://www.quantstart.com>
- » Suggested intro trading platform / broker
 - www.interactivebrokers.com
- » Data:
 - Yahoo Finance, Google Finance, Quandl
- » Other:
 - <https://qoppac.blogspot.com/>
 - <http://epchan.blogspot.com/>

Online Resources: Data Science

- » Golden Standard - Andrew NG (Stanford)
 - <https://www.coursera.org/learn/machine-learning>
 - <https://www.coursera.org/specializations/deep-learning>
- » Father of Deep Learning
 - <https://www.coursera.org/learn/neural-networks> (hardest)
- » Google
 - <https://developers.google.com/machine-learning/crash-course/> (easiest)
 - <https://www.udacity.com/course/deep-learning--ud730>
- » Quantstart
 - <https://www.quantstart.com/>
- » Wikipedia
 - https://en.wikipedia.org/wiki/Deep_learning



<https://fineartamerica.com/featured/playful-spring-colorful-happy-abstract-art-painting-modern-art-prints.html>

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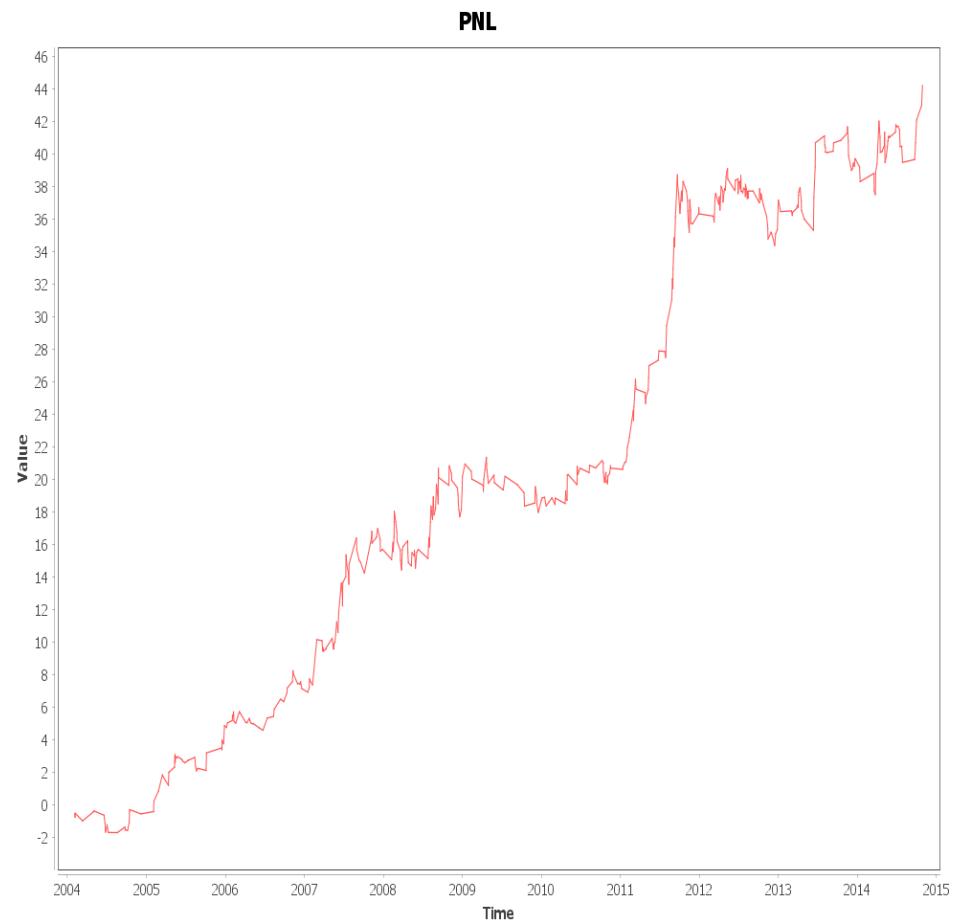
Personal Learnings

Backtesting a Strategy/Risk

- » Provide evidence of profitability
 - Curve fitting/ optimization bias
 - In-sample vs out-of-sample
 - Forward looking bias
- » Risk tolerance

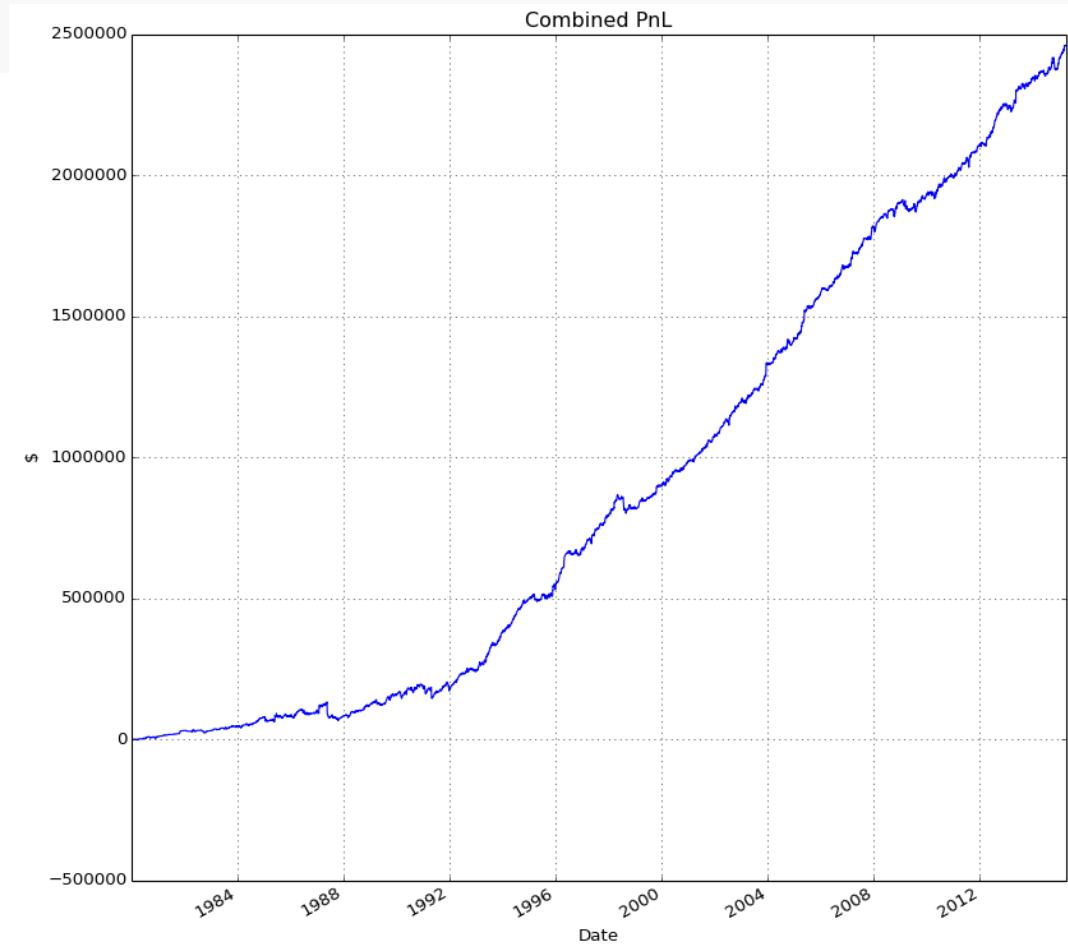
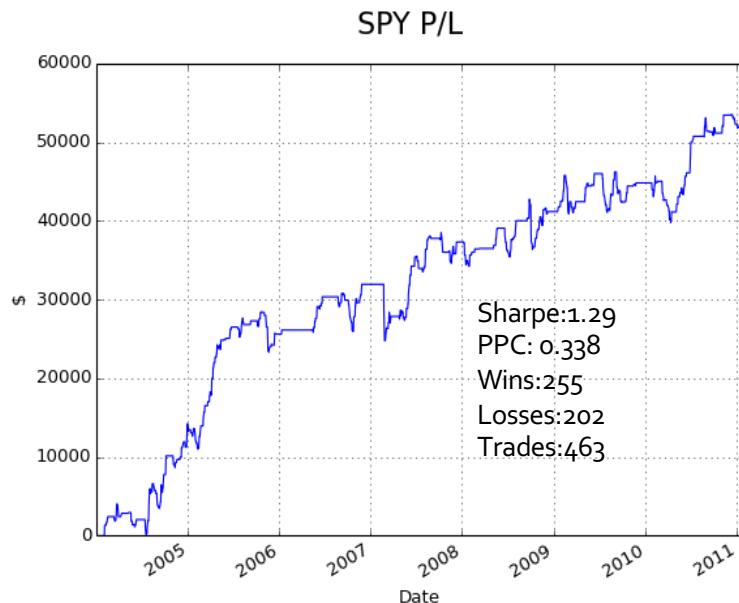
Key Statistics

Average wins	:: 0.637 USD
Average loss	:: -0.438 USD
# Wins	:: 214
# Losses	:: 210
# Neutrals	:: 3
Win Rate	:: 0.501
PPC	:: 0.104USD
# Traded	:: 427.0
Ann. Sharpe	:: 2.335



Backtesting: Correlation and Sample Set

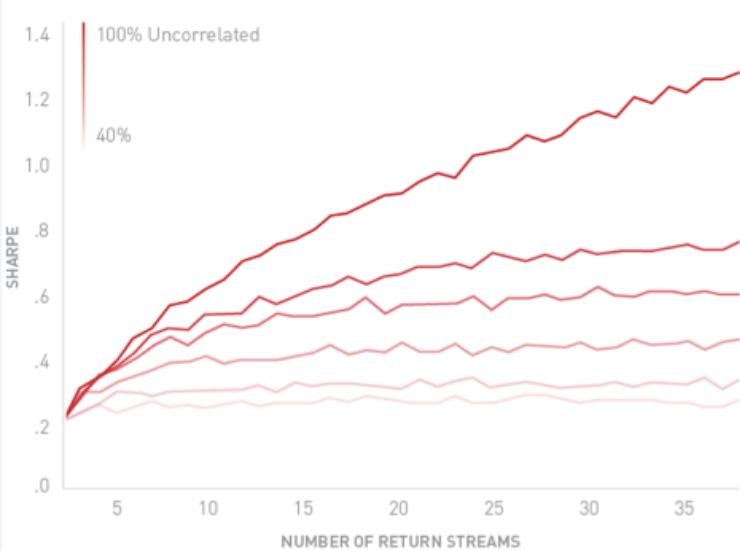
- » Does the strategy work across many assets?
- » How many years does it work for?
- » Does it escape the bid-ask bounce?
- » Risk Tolerance?
 - Maximum Drawdown?
- » Fees? Trading frequency?



In Sample: SPY 2004-2010
Out of Sample: Assets Randomly Selected:
ADBE XLNX BBBY CFN EMC ADP AFL DET SPLS DG ADS ALL MET CL PX WYN

Correlation and Risk

Achieving High Portfolio Sharpe Ratio from holding Low Sharpe Ratio, but uncorrelated, individual algos



Quantopian

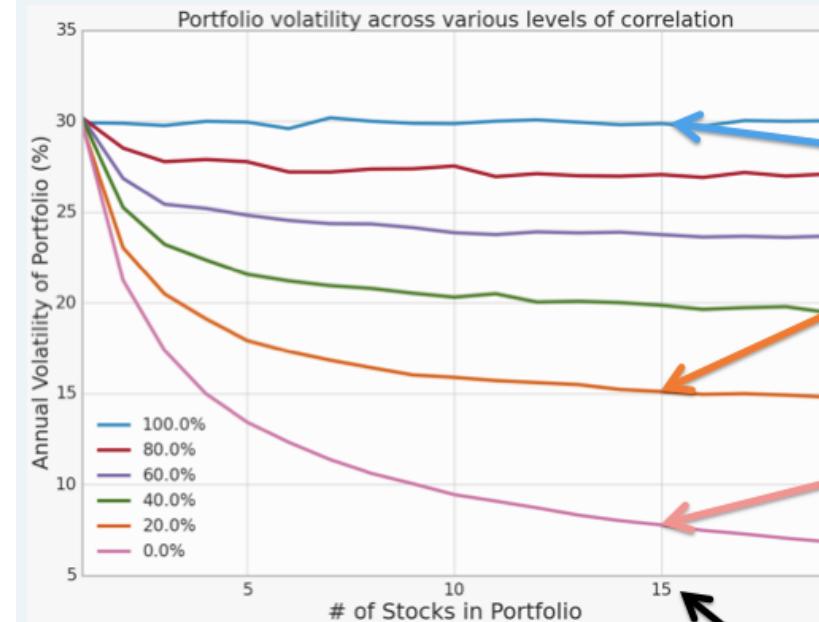
Simulation Setup:

- Each algorithm individually has a Sharpe Ratio of only 0.2
- Hold X strategies across varying correlation assumptions

Results

Sharpe Ratio increases dramatically as you add more uncorrelated algorithms to your portfolio

Investing in uncorrelated algorithms can reduce overall portfolio risk by 50% - 75%



Only need to hold 15 algos in the portfolio

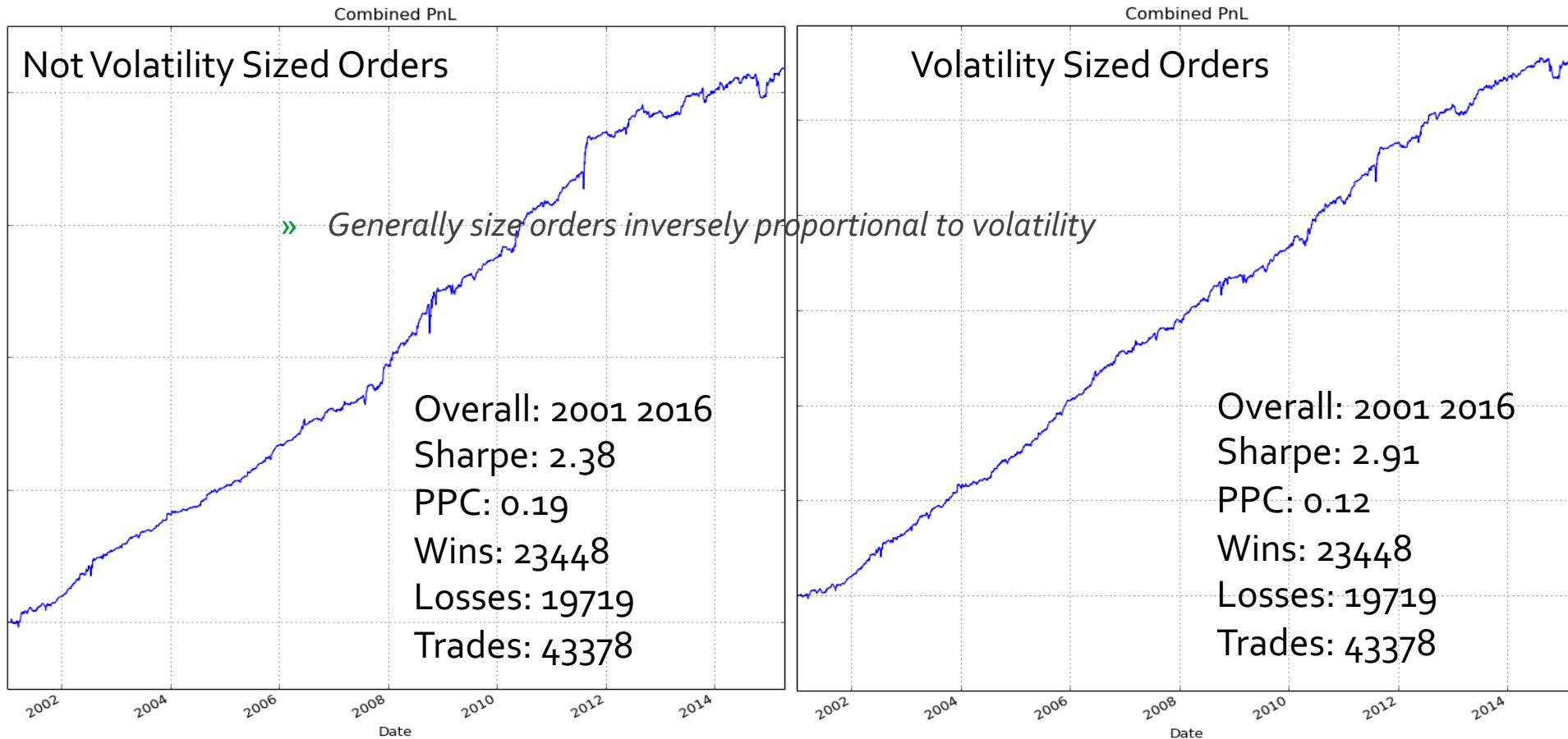
Assume each algo in a portfolio has 30% volatility

If they are 100% correlated, then entire portfolio also has 30% volatility...

...But, if they are only 20% correlated, overall portfolio volatility is reduced by half to 15%

...And...perfect uncorrelation reduces annual volatility to only 8% !

Order Sizing



General Tips

- » Be creative and develop your own way of trading
 - » Develop a thesis and test it
 - » Deep understanding of what you are doing and why
 - » This is not a get rich quick scheme
 - Finding alpha is difficult
 - » At scale this is like any other business
 - » Build your own backtester/execution environment
 - » Data In -> Data Out
-
- » Performance
 - Out of sample performance is generally $\frac{1}{2}$ of in sample performance
 - Live trading performance is generally $\frac{1}{4}$ of in sample performance
 - Due to curve fitting, unexpected slippage, etc.
 - » Make sure you account for ***transaction fees*** and ***slippage*** and ***order sizes***
 - » Visualize

Appendix

And material from older
lectures



<https://unsplash.com/search/photos/milky-way>

Statistical Testing

» Mean Reversion

- A process that refers to a time series that displays a tendency to revert to its historical mean
- More specifically: if the prices within the series move away from their initial value faster than that of Geometric Brownian Motion
- Ornstein-Uhlenbeck process (a random walk has no memory)

» Momentum

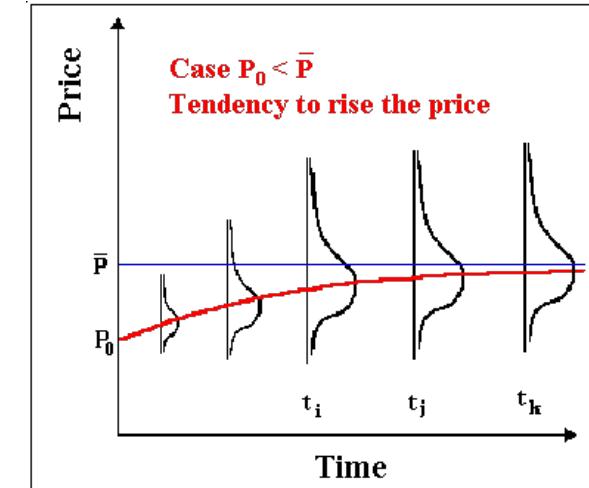
- The exact opposite of mean reversion
- Movement away from the initial value faster than that of random walk

» Mean reversion and momentum go hand in hand, in identifying one you may identify the other

» Will cover two methods: Augmented Dickey-Fuller test, and the Hurst Exponent

Pictures From:

<http://marcoagd.usuarios.rdc.puc-rio.br/revers.html>
<http://www.stockcharts.com>



Statistical Testing: Terms

- » Orenstein-Uhlenbeck SDE
- » Change in price series in next time period is proportional to the difference between the mean price and the current price with Gaussian noise
- » Motivates Augmented Dickey-Fuller (ADF) Test

$$dx_t = \theta(\mu - x_t)dt + \sigma dW_t$$

θ = rate of reversion to mean

μ = mean value of process

σ = variance of the process

W_t = Wiener Process or
Brownian Motion

Augmented Dickey-Fuller (ADF) Test

- » Identify presence of a unit root in autoregressive time series
- » Relies on the fact that if a price series has a mean reversion then the next price will be proportional to the current price
- » Linear Model of Order p

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \cdots + \delta_{p-1} \Delta y_{t-p+1} + \epsilon_t$$

$\alpha = \text{constant}$

$\beta = \text{coefficient of time trend (long term drift)}$

$$\Delta y_t = y(t) - y(t-1)$$

- » Testing null hypothesis: $\gamma = 0$
 - Indicates that process is a random walk ($\alpha = \beta = 0$)

Augmented Dickey-Fuller (ADF) Test

- » Test statistic: sample proportionality / standard error of sample proportionality

$$DF_{\tau} = \frac{\hat{\gamma}}{SE(\hat{\gamma})}$$

- » Negative number, and must be less than critical values to be significant
- » Code `adf_test.py`

Calculated Test Statistic: -2.1900105031287529

P-Value: 0.2098910250427564

Datapoints: 2106

10%: -2.5675011176676956

5%: -2.8629133710702983

1%: -3.4334588739173006

Cannot reject null hypothesis, and
unlikely to have found a mean reverting
time series

Hurst Exponent

- » A stochastic process is strongly stationary if its joint probability distribution is invariant under translations in time or space
 - Mean and variance of process do not change over time and do not follow a trend
- » Hurst Exponent helps to characterize the stationarity of a time series
 - Reverting, trending, or neither
- » Variance of a log price series to identify rate of diffusive behavior
$$Var(\tau) = \langle |\log(t + \tau) - \log(t)|^2 \rangle$$
- » Since large τ , variance is proportional to τ for Geometric Brownian Motion
$$\tau \sim \langle |\log(t + \tau) - \log(t)|^2 \rangle$$
- » If autocorrelations exist the relationship is invalid, but can be modified to include $2H$ with the Hurst Exponent value H
$$\tau^{2H} \sim \langle |\log(t + \tau) - \log(t)|^2 \rangle$$

Hurst Exponent: Meaning

$H < 0.5$ mean reverting process

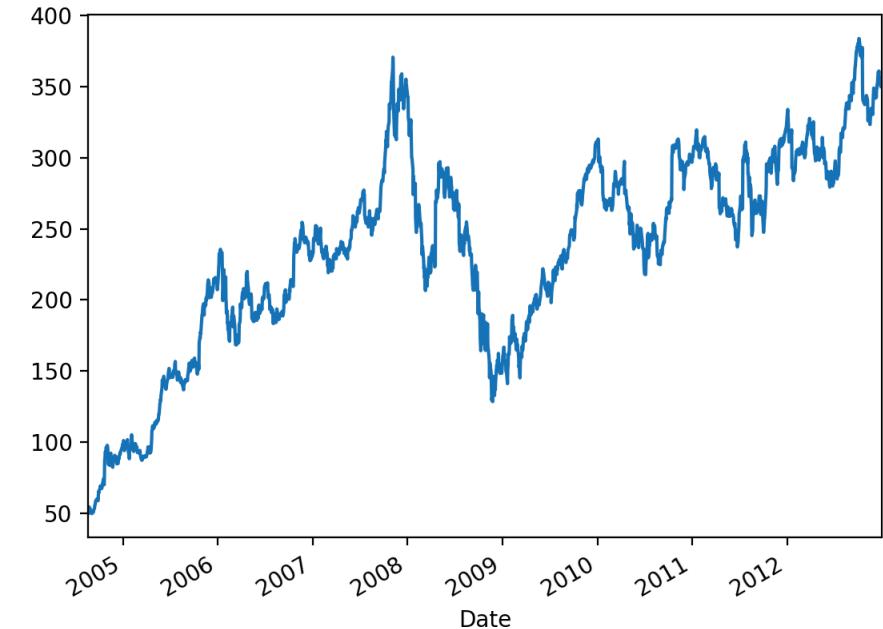
$H == 0.5$ GBM

$H > 0.5$ trending process

» Characterizes extent

- Closer to 0 more mean reverting
- Closer to 1 more trending

» Try different time periods, different stocks



Hurst(GBM): 0.498349157279

Hurst(MR): -6.26637088795e-05

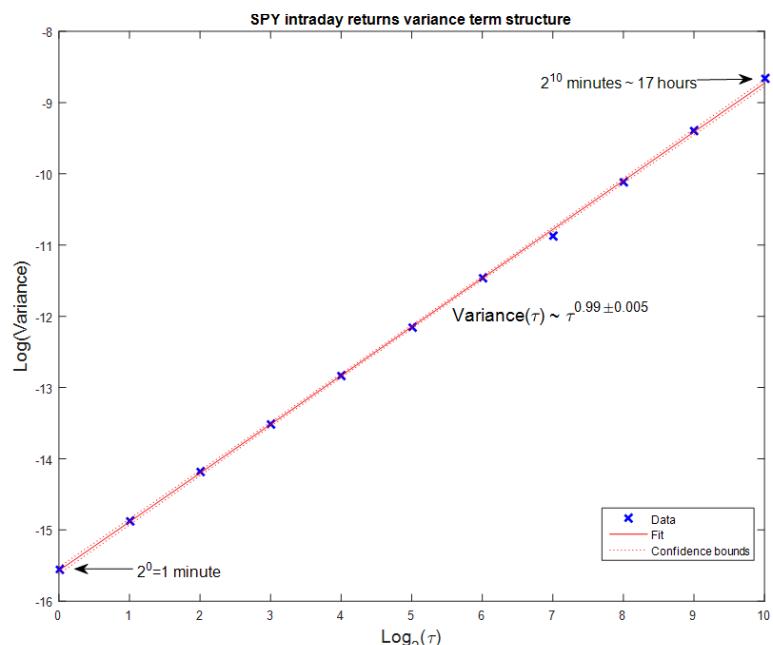
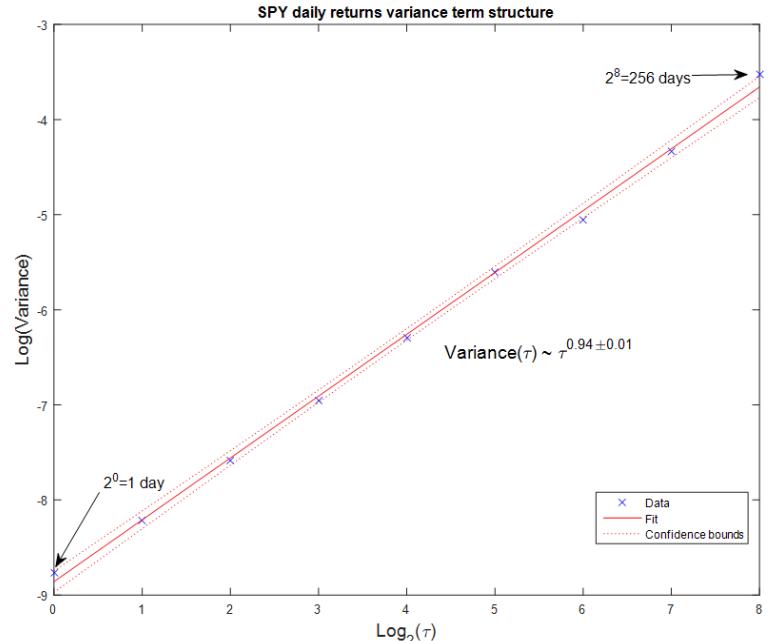
Hurst(TR): 0.95964231812

Hurst(GOOG): 0.50788012279

Variance and Term Structure

- » Plot of $\log(Var(\tau))$ vs $\log(\tau)$ for SPY
 - Slope/2 is the Hurst exponent
 - Intraday
 - Returns of mid-prices from 1 minute to 2^{10} minutes
 - $H = 0.494 \pm 0.003$; slightly mean reverting
 - Daily
 - Returns from 1 day to 2^8 days
 - $H = 0.469 \pm 0.007$; strongly mean reverting
- » Mean reversion strategies should work better than intraday strategies on SPY

<http://epchan.blogspot.com/2016/04/mean-reversion-momentum-and-volatility.html>



Variance and Term Structure: Gold

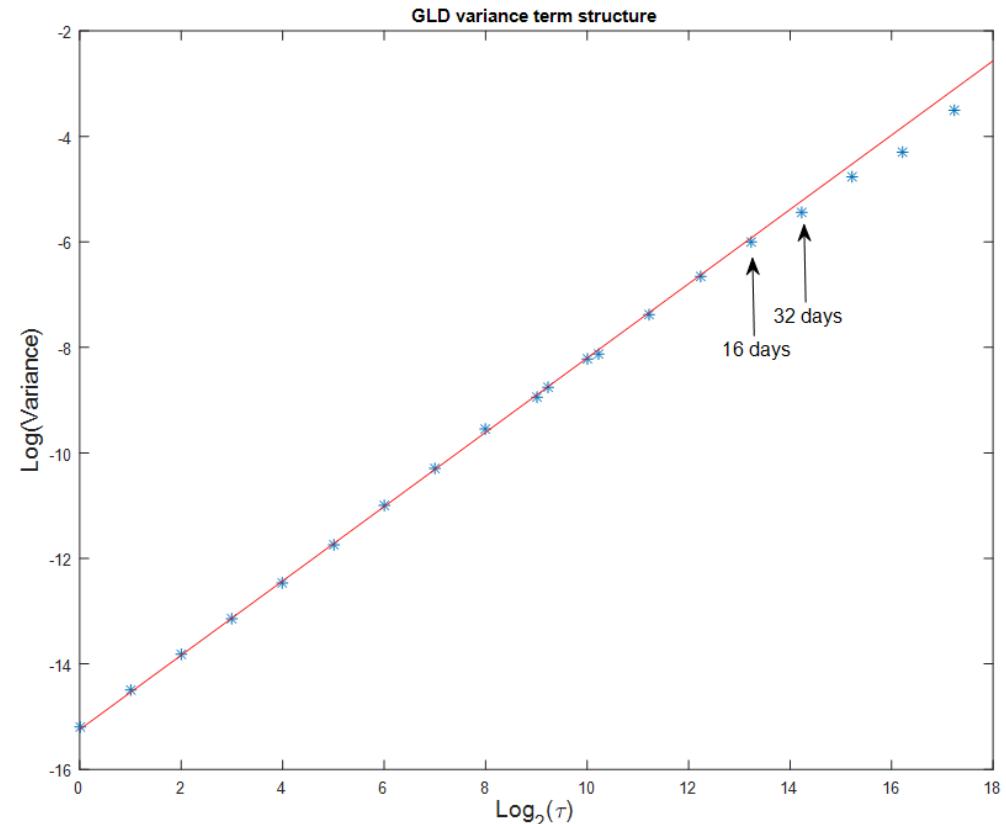
- » Intraday: $H = 0.505 \pm 0.002$
- » Daily: $H = 0.469 \pm 0.007$
- » 16-32 days volatilities drift from the regression
 - *This is where we should switch from momentum to mean reversion strategies*

A Trending Example: USO

Intraday $H = 0.515 \pm 0.001$

Daily $H = 0.560 \pm 0.020$

Momentum strategies should work well here



<http://epchan.blogspot.com/2016/04/mean-reversion-momentum-and-volatility.html>



General Information and Terminology

Appendix: Sharpe Ratio

$$\text{Sharpe} = \frac{r_p - r_f}{\sigma_p}$$

r_p = portfolio return

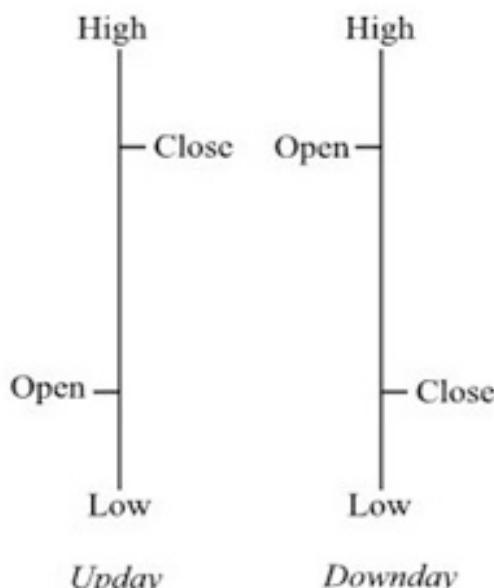
r_f = risk free rate

σ_p = standard deviation of return

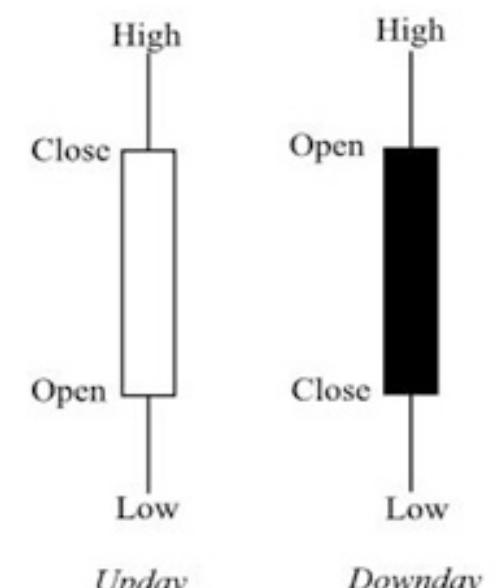
- » Measures risk adjusted performance
 - Risk vs. Reward
- » Higher is usually better
- » Risk free rate sometimes assumed to be 0
- » Usually annualized and volatility taken as standard deviation
 - Monthly: Volatility sampled monthly * sqrt(12)
 - Daily: Volatility sampled daily * sqrt(252)
 - Minutely: Volatility sampled minutely * sqrt(390*252)

Appendix: Candlestick/Bar Data

- » Open – price at start of bar
- » High – highest price
- » Low – lowest price
- » Close – price at end of bar
- » Volume – number traded during bar
- » Can be on any timescale: seconds to monthly



Bar Chart



Candlestick Chart

<http://www.financial-spread-betting.com/course/candle-stick-charting.html>

Appendix: Order Sizing

- » Average True Range Scaling
- » Reduces trade size during times of volatility, Increase during low volatility
- » Increases Sharpe Ratio
- » Can adjust to size of contract, and/or contract price

Initial Capital = \$1,000

Initial Capital

$$\text{Trade Size} = \text{Initial Capital} \frac{\text{Initial Capital}}{\text{ATR}(10) * \text{Min Tick Size}(\$)}$$

$$\text{True Range} = \max[(\text{high} - \text{low}), \text{abs}(\text{high} - \text{close}_{\text{prev}}), \text{abs}(\text{low} - \text{close}_{\text{prev}})]$$

$$\text{ATR}_t = \frac{\text{ATR}_{t-1}(n-1) + \text{True Range}_t}{n}$$

Appendix: Profit Per Contract (PPC)

$$\frac{r_a}{c * t_s}$$

r_a = average return

c = number of contracts traded

t_s = tick size

- » A measure of profitability, measured in ticks
- » A highly liquid stock usually has a tick size of a penny
- » If your strategy has more than 2 ticks, it is considered profitable (can escape the bid/ask bounce), if testing on bar data without limit order execution on bar closes
 - You can submit market orders and still make money
 - Assumes liquidity!!!!

Appendix: Capital Asset Pricing Model

$$r_a = r_f + B_a(r_m - r_f)$$

r_f = Risk Free Rate

B_a = Beta of Security

r_m = Expected Market Return

r_a = Asset Return

- » Describes the relationship between risk and the expected return
- » Investors need to be compensated for time (risk free rate) and risk (beta)

Appendix: Drawdown

- » The measure of the largest drop from peak to bottom (in percentage)

- It is a pain index measure

- » Extremely important to measure the duration of the drawdown

- Do you want to be losing money for years?

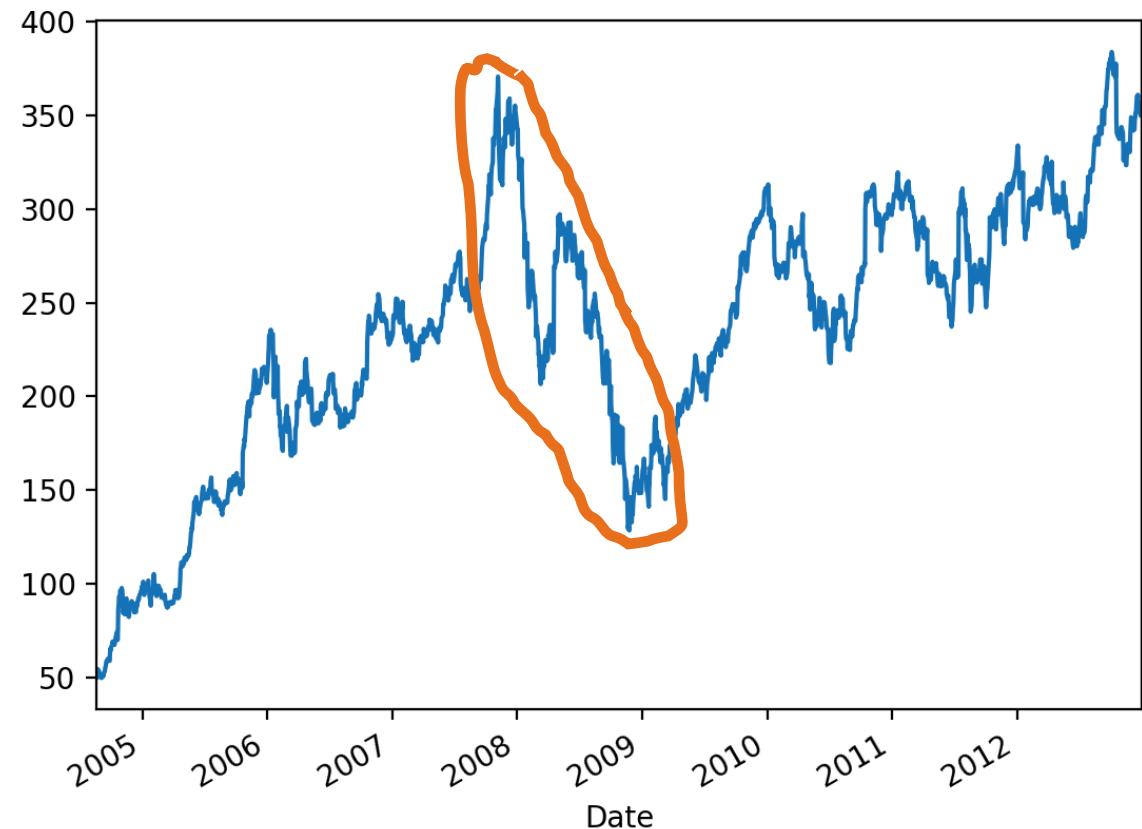
$$D(T) = \max_{t \in (0, T)} \{X(t) - X(T)\}$$

$$\text{MDD}(T) = \max_{t \in (0, T)} [\max_{\tau \in (0, t)} \{X(t) - X(\tau)\}]$$

- » Where $X = (X(t), t \geq 0)$ is a random process

- » Simply put maximum drawdown is:

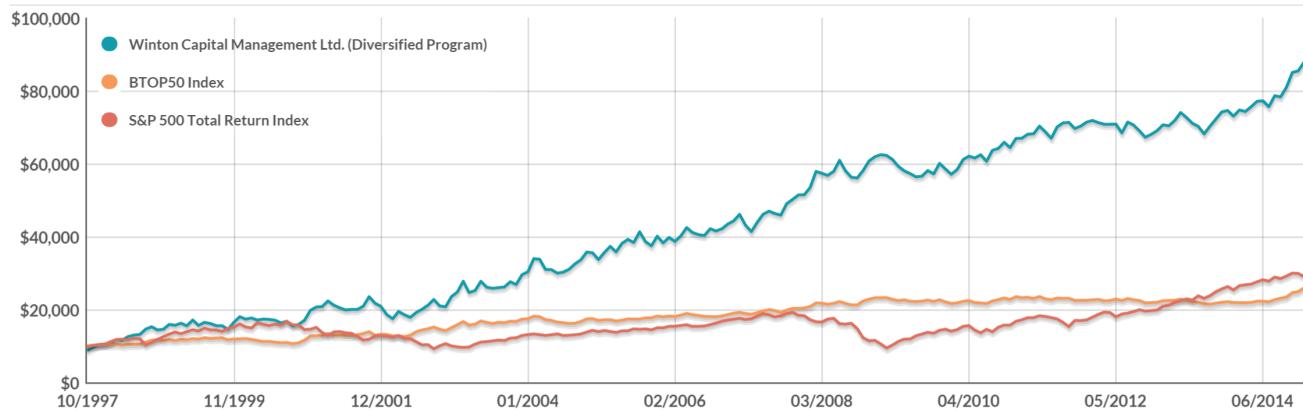
- (Peak value before largest drop – lowest value before new high) / Peak value before drop



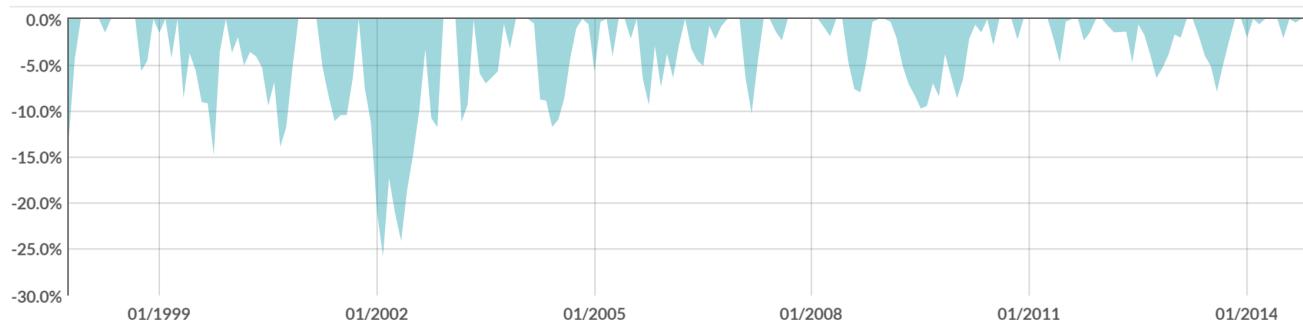
Appendix: Underwater Curve

- » Good way to visualize how much of the time you are in a drawdown
- » Lets you evaluate how much pain you should be able to handle

Performance comparison: Growth of \$10,000 invested since inception – Oct 1997 to Mar 2015



Underwater curve – Oct 1997 to Mar 2015

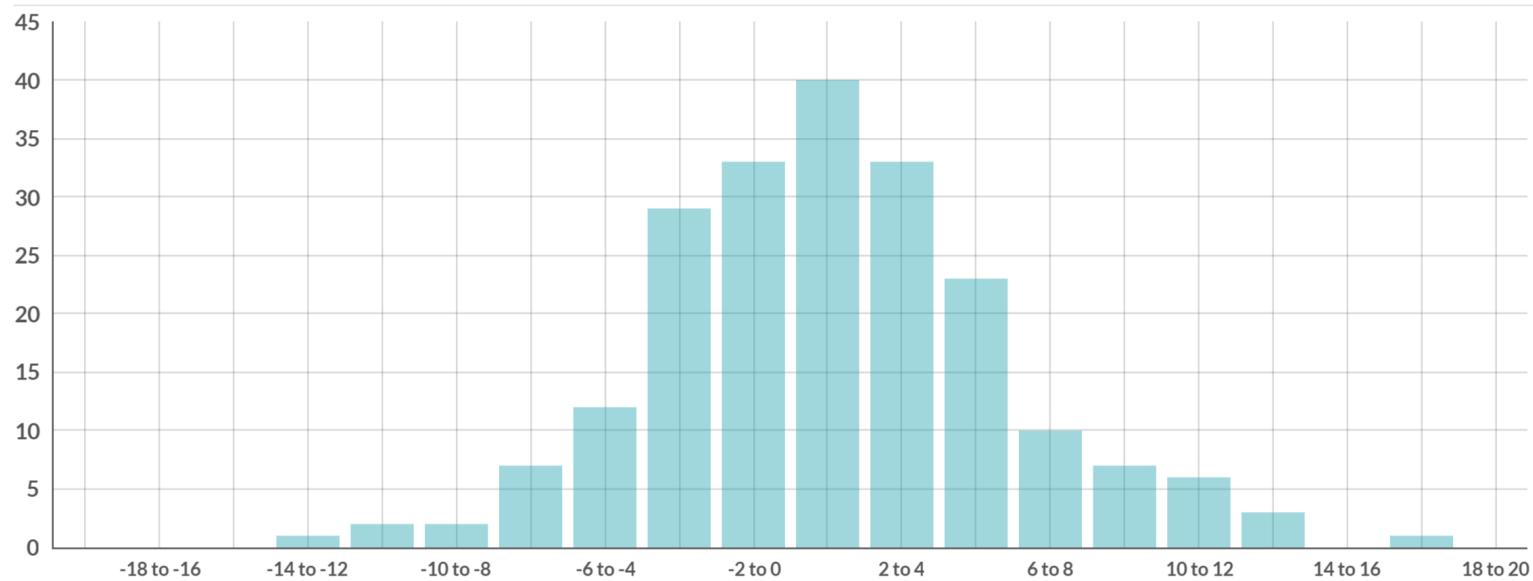


<http://ctaperformance.com/wntn>

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Appendix: Distribution of Returns

Distribution of monthly returns – Oct 1997 to Mar 2015



- » Generally a histogram of returns
- » Look at center, shape, distribution, spread
 - Want positive center, and no major outliers

<http://ctaperformance.com/wntn>

Appendix: Tradeable AUM

- » Not all strategies are created equal
- » Strategy A might be able to trade \$1,000,000 without incurring large slippage but trading \$100,000,000 it might incur much more slippage and kill the strategy
 - Market making – your ability to capture the inside bid offer decreases with size
 - High frequency strategies
 - Some momentum strategies
- » Sharpe ratios and AUM tradable are usually inversely correlated
 - There are some exceptions
- » Note that these numbers are artificial

Thank you Aaron Rosen for your feedback