BY: AVI THAKER

Algorithmic Trading: An Introduction

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Lets Play a Game: Trading

Objective: Make as much money as possible

Reward: $5 Amazon Gift Card per team member

Team Size 3-4

- 1 Trader – trades on the floor with other traders
- 1 Runner – Runes the orders made by the trader
- 1+ Backend ”Prime Broker” – Clear the trades made with the teams

Trading a geometric random walk; 6 rounds 45 seconds each

Must quote a spread (unit values), e.g. 30-32

Must accept trade if someone ***hits*** (accepts your bid) or ***takes*** (accepts your ask)

Trades must be cleared (the backend and runners verify trade with other backend) to count

Will fill all unfilled orders at the end with 2 units penalty cost

Lets Play a Game: The Ticket

TEAM ID: 0001
TRADE PRICE: 32
TRADE SIZE: 10
TRADE DIRECTION: BUY

TRADED WITH: 0003
INITIAL: TS

TEAM ID: 0003
TRADE PRICE: 32
TRADE SIZE: 10
TRADE DIRECTION: SELL

TRADED WITH: 0001
INITIAL: MK

Global Workbook (Google Sheet)

A	B	C	D	E
Team BUYING	Team SELLING	Trade Price	Trade Size	Trade Round
1	3	32	10	1

Personal Workbook

A	B	C	D	E
Trade	Size	PNL	Round	With Team
32	10		1	3
34	-10	20	1	3

ETF Creation/Redemption

Authorized participant (market maker, intuitional 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 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?

HFT and Flow

Pure Arbitrage
- Fastest always wins

Deal Flow
- Orders executed on behalf of another client
- E*TRADE – guaranteed 2 second execution market order
- Smart Orders

Example Companies
- Citadel, market makers, Goldman, JP Morgan, etc.

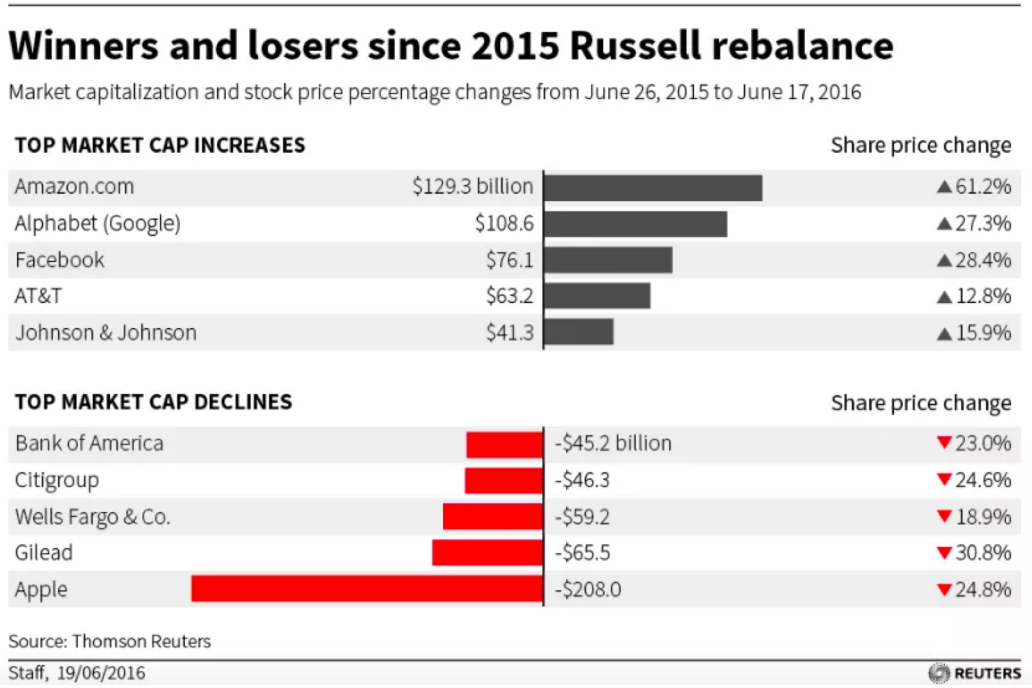
Deal Flow: The Russell Rebalance

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!



Deal Flow: Market Microstructure

Capture the Spread

Increase Liquidity

On both sides of the market

Risky during times of volatility

Must be fast and have excellent queue position

Math is generally more complicated

Manipulate market when incoming market order to get better price

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	

Lots of machine learning: think Bayesian and neural networks, ML

Statistical Testing

Mean Reversion

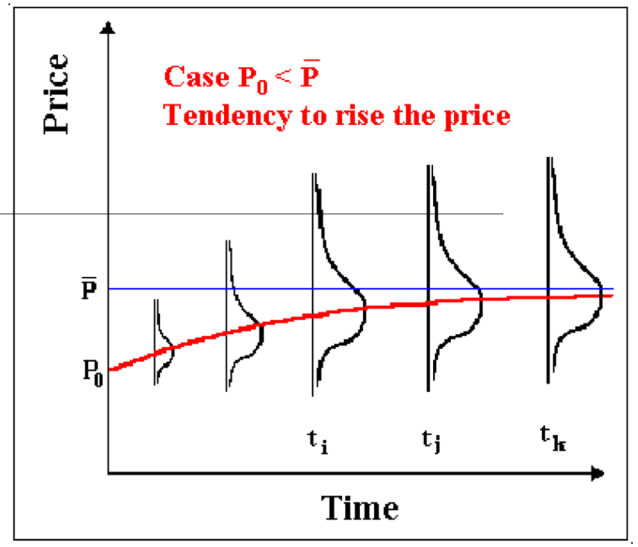
- A process that refers to a time series that displays a tendency to revert to its historical mean
- More specifically: if the prices within the series move away from their initial value faster than that of Geometric Brownian Motion
- Ornstein-Uhlenbeck process (a random walk has no memory)

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

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

$$\theta = rate\ of\ reversion\ to\ mean$$

$$\mu = mean\ value\ of\ process$$

$$\sigma = variance\ of\ the\ process$$

$$W_t = Wiener\ Process\ or\ Brownian\ Motion$$

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*

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

$$\alpha = constant$$

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

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

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: -2.190010503128752 9
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 join 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 not valid, 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

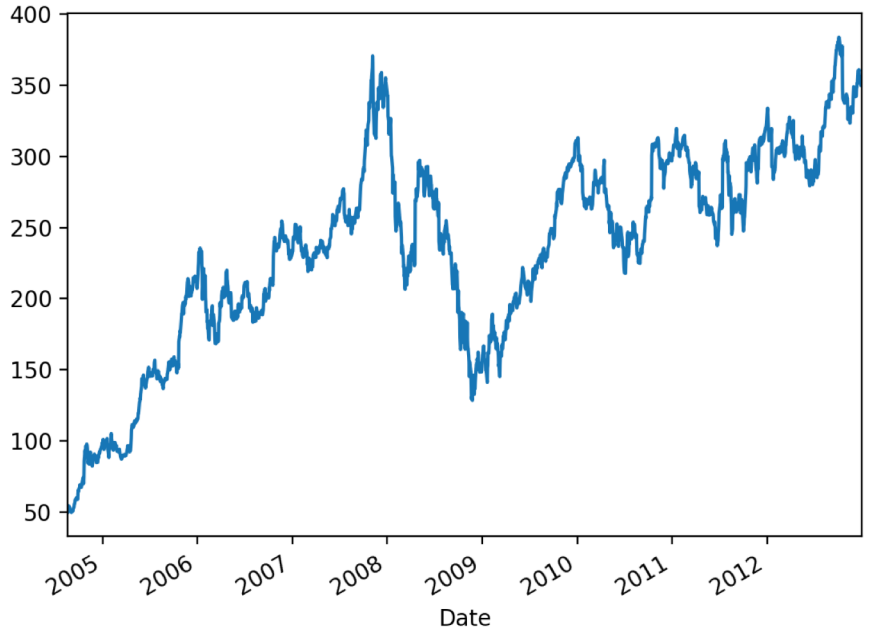
$H == 0.5$ GBM

$H > 0.5$ 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

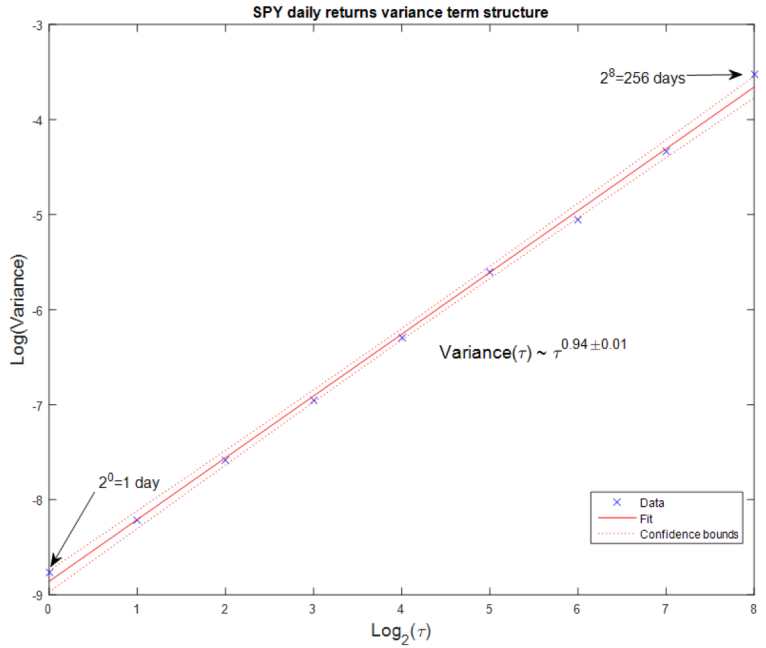
Variance and Term Structure

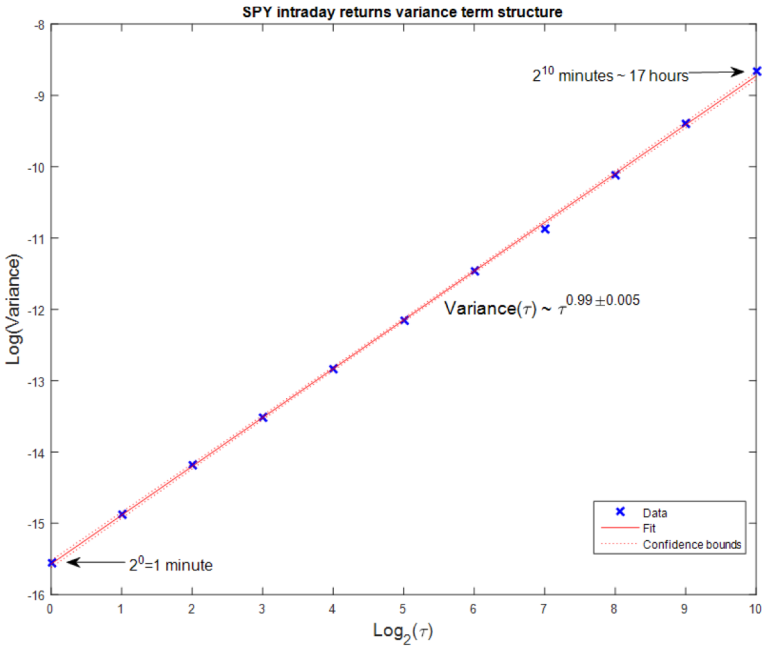
Not included in code

Plot of $\log\left(Var(\tau)\right) vs \log(\tau)$ for SPY

- Slope/2 is the Hurst exponent
- Intraday
  - Returns of mid-prices from 1 minute to 2^10 minutes
  - $\mathrm{H} = 0.494 \pm 0.003$; slightly mean reverting
- Daily
  - Returns from 1 day to 2^8 days
  - $\mathrm{H} = 0.469 \pm 0.007$; 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

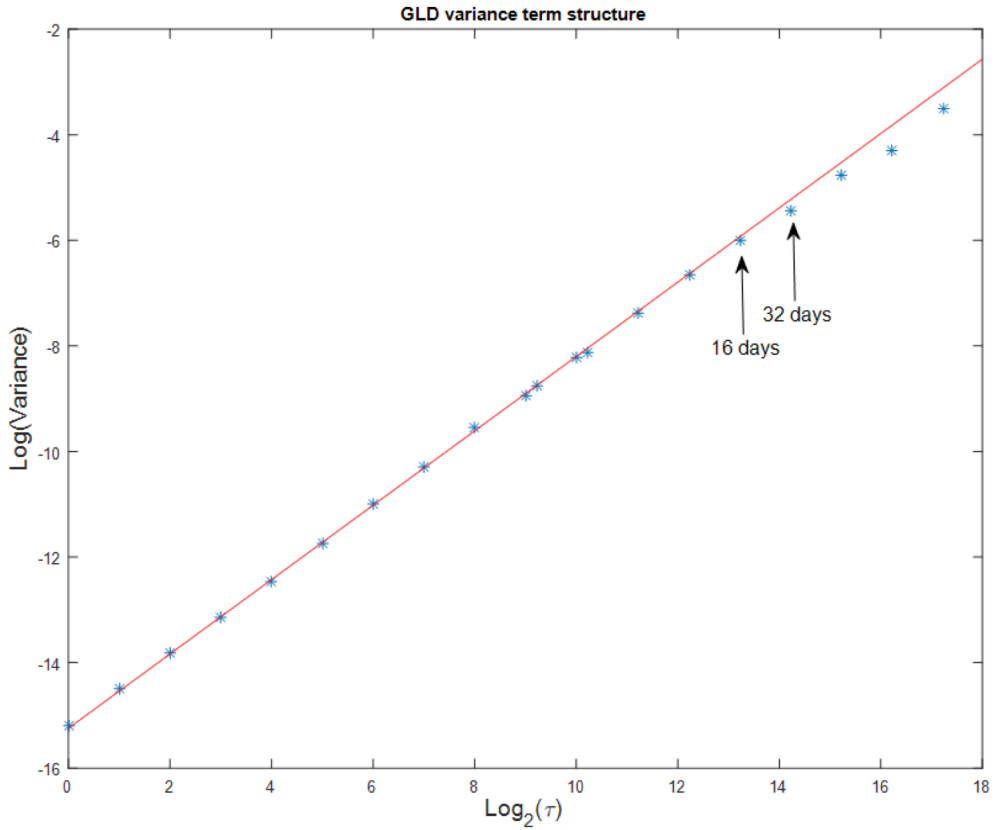
Variance and Term Structure: Gold

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***



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

A Trending Example: USO

Intraday $H = 0.515 \pm 0.001$

Daily $H = 0.560 \pm 0.020$

Momentum strategies should work well here

Example Strategies

Momentum

- Exponential moving averages (MACD
- Breakouts
- Volatility Surges
- News driven
- Tend to have low win rates but high profitability

Reversion

- Bollinger bands
- Statistical pairs trading and index trading
- Tend to have high win rates and low profitability

Strategy Detail: Exponential Moving Average: EMA

Infinite impulse response filter

Less lag than SMA

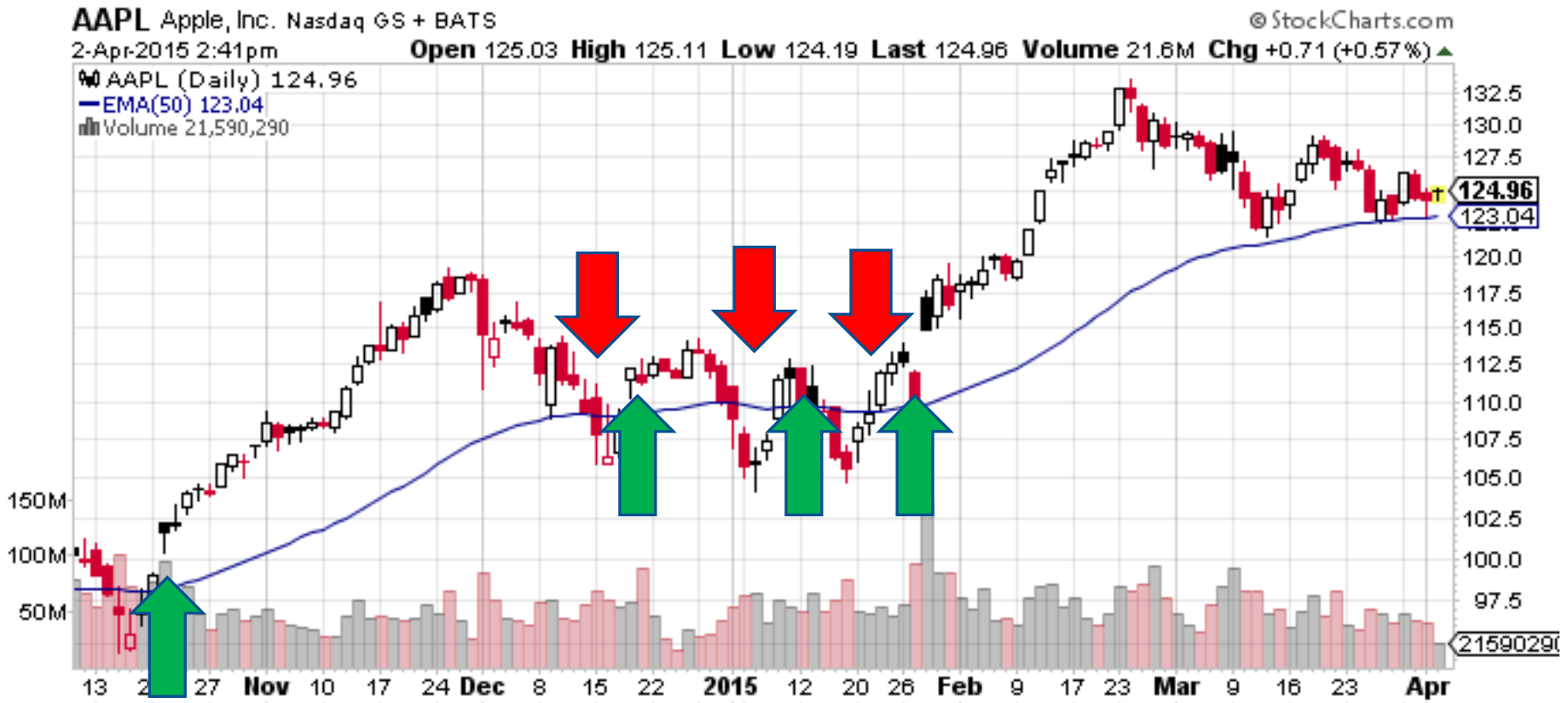
Commonly used signal

$$\alpha = \frac{2}{n+1}$$

$$EMA_{current} = \frac{p_1 + (1-\alpha)p_2 + (1-\alpha)^2 + \cdots}{1 + (1-\alpha) + (1-\alpha)^2 + \ \ldots}$$

$$= EMA_{previous} + \alpha\left(p_{current} - EMA_{previous}\right),$$

Trading The EMA



Enter Long: Close > EMA & Prev_Close > EMA_Prev

Enter Short: Close < EMA & Prev_Close < EMA_Prev

Strategy Detail: Common Signals Bollinger Bands

Volatility Bands

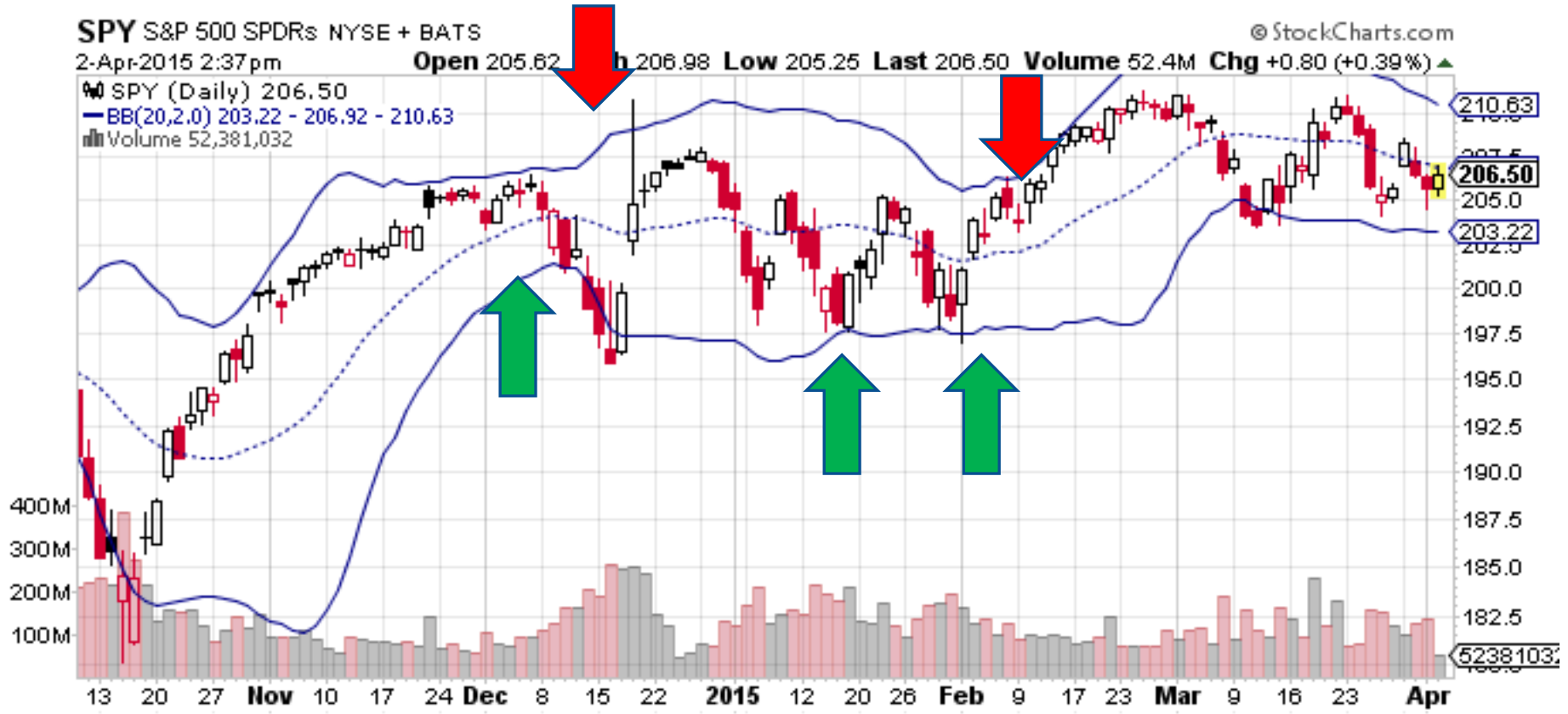
- Based upon standard deviation
- Identifies points of reversion

Middle Band = 50-Day SMA

Upper Band = 50-Day SMA + 50-Day SD of Price

Lower Band = 50-Day SMA - 50-Day SD of Price

Example: Trading the Bollinger Bands



Neural Networks

The below link contains a tutorial in which a neural network is used to predict time series stock data using Microsoft's deep learning platform CNTK published in conjunction with MSR

https://github.com/Microsoft/CNTK/blob/master/Tutorials/CNTK_104_Finance_Timeseries_Basic_with_Pandas_Numpy.ipynb

Personal Learnings

LESSONS FROM FAILURE, SUCCESS, AND PURE DUMB LUCK

Technical Indicators

Technical indicators are mostly **useless** on their own

Must identify something that happens in the market, and use the indicators (or come up with your own) to represent that something

Data visualization is crucial

Simplicity is usually better

RSI Relative Strength Index

Parabolic SAR – Parabolic Stop and Reverse

Price Channels

VWAP – Volume Weighted Average Price

ZigZag

MACD – Moving Average Convergence Divergence

PPO – Percentage Price Oscillator

KST - Know Sure Thing

Ultimate Oscillator

Vortex Indicator

… The list goes on forever

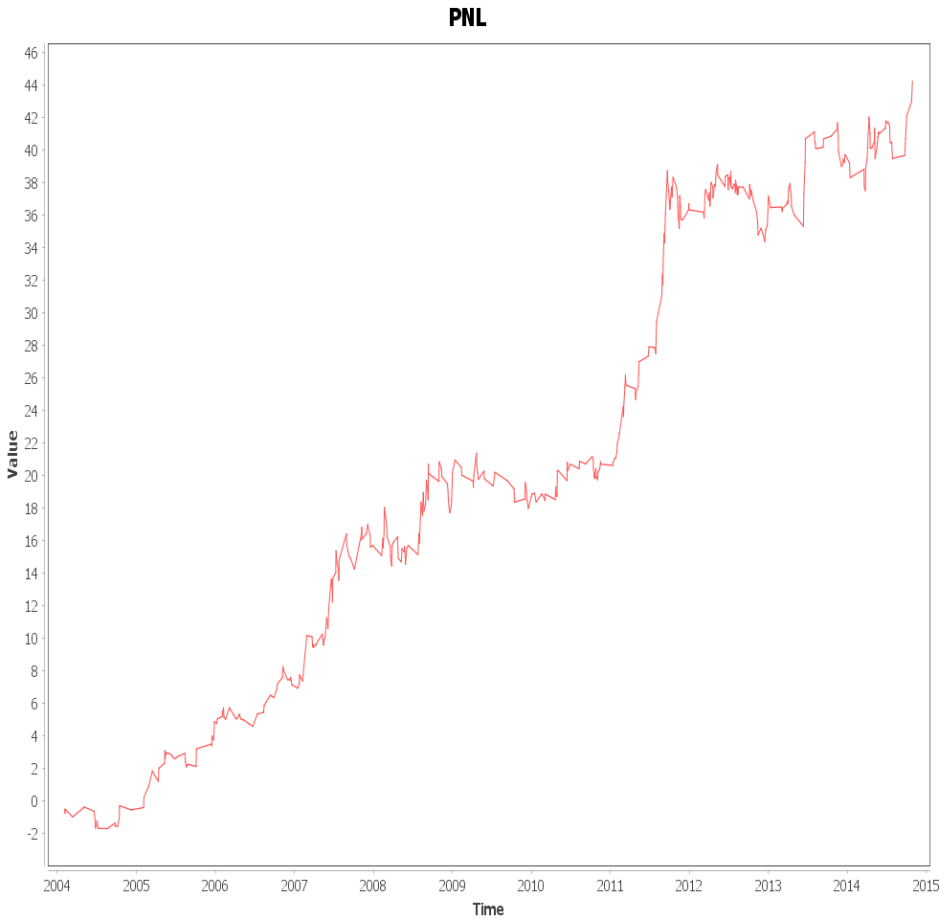
Backtesting a Strategy/Risk

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 a Strategy

Does the strategy work across many assets?

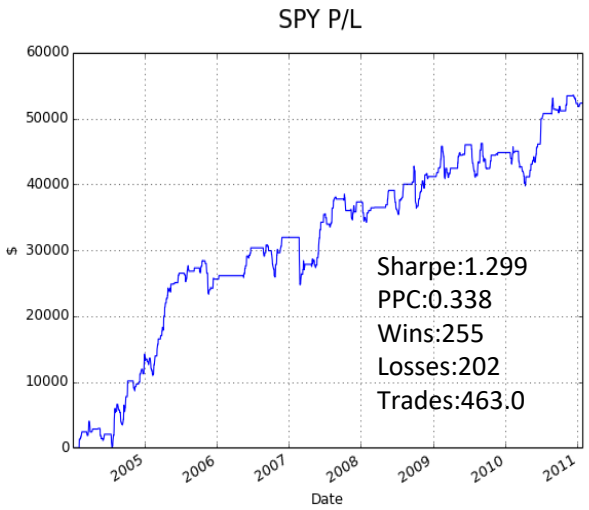
How many years does it work for?

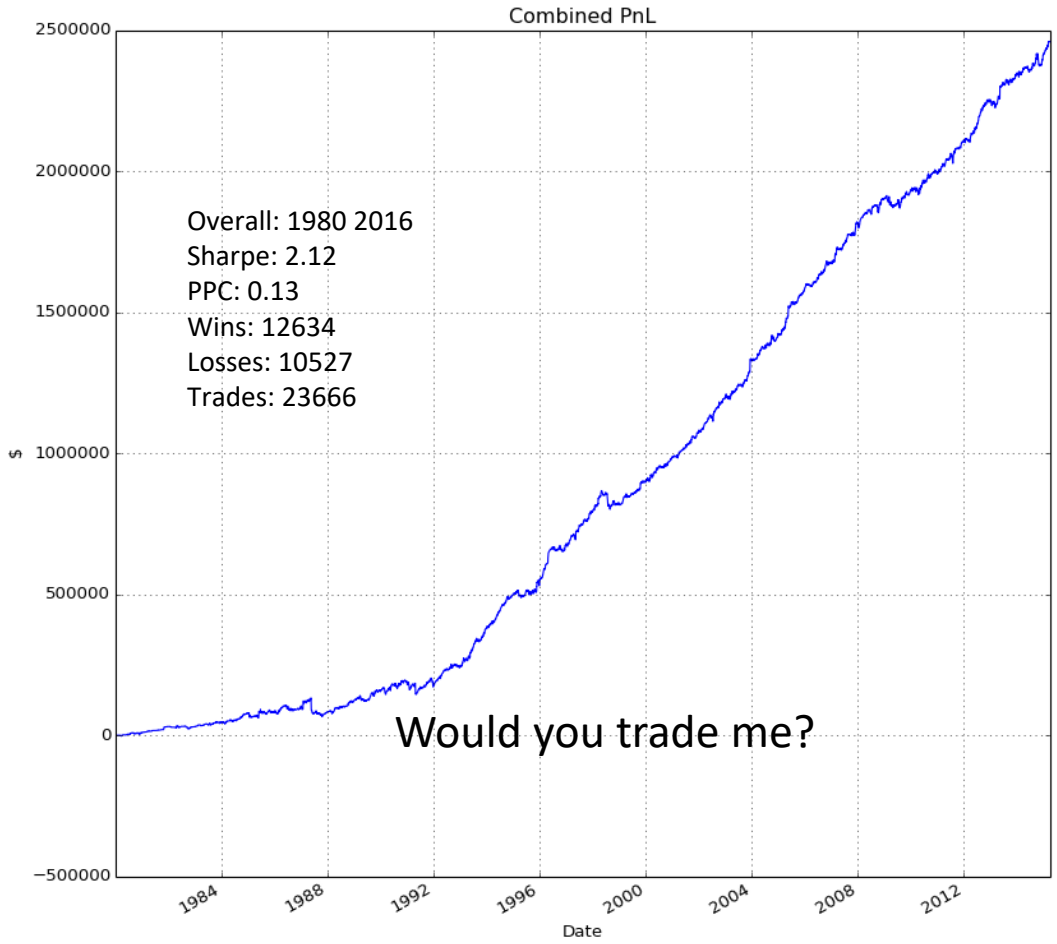
Does it escape the bid-ask bounce?

Risk Tolerance?

- Maximum Drawdown?

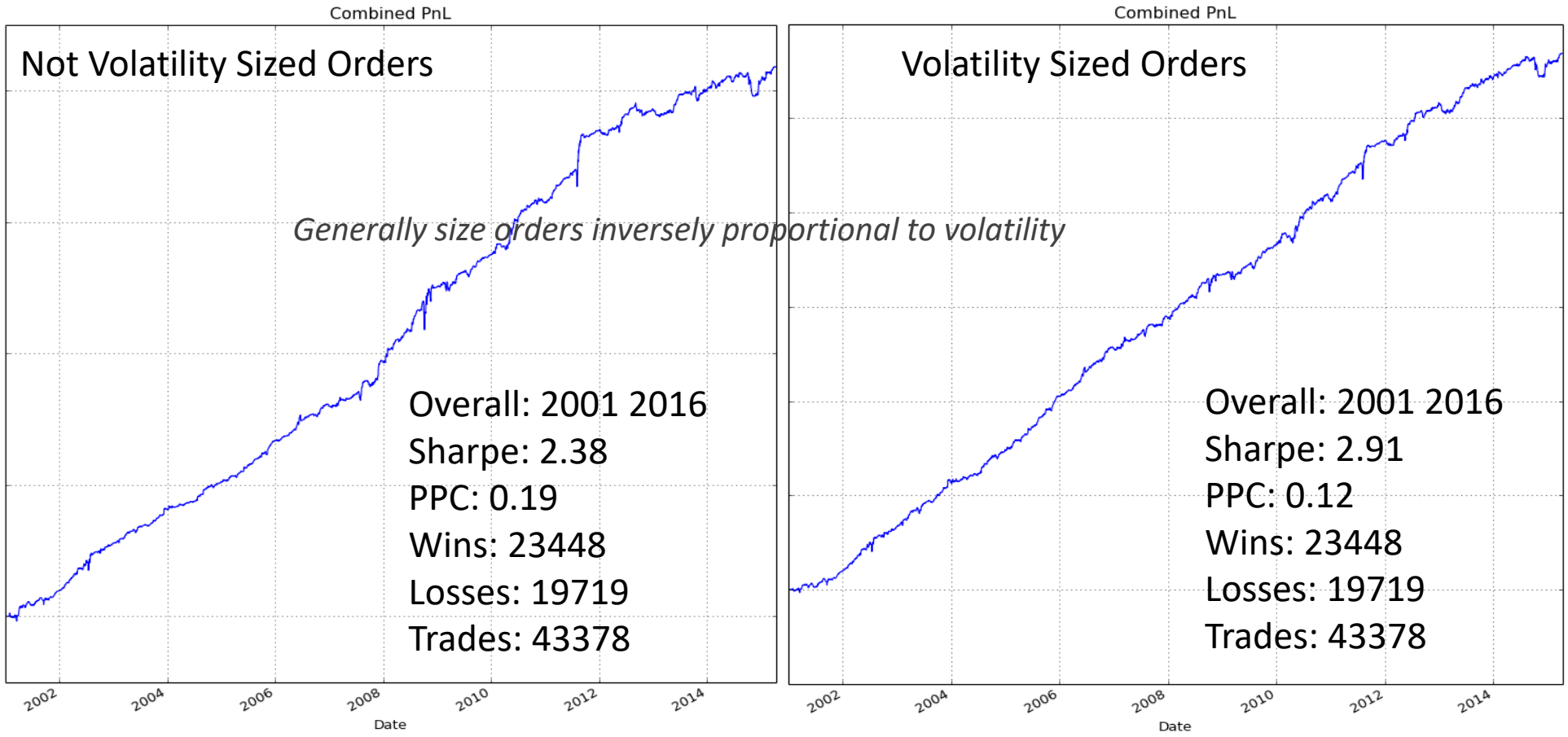
Fees? Trading frequency?





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

Order Sizing



Generally size orders inversely proportional to volatility

Biases and Pitfalls

These can be done unintentionally

Curve Fitting Bias

- Adjusting/adding parameters until the strategy looks attractive in backtest

Forward looking bias

- Program looks at future due to bug in code
- Calculating optimal parameters, optimizations
- Looking at the data!

Survivorship Bias

- Not including full universe (pre 2008 crash, 2007 algo trading blow up)

Psychological Bias

- Can you tolerate a 5 month drawdown? Lose half your portfolio
- Your backtests will suggest possible severity

General Tips

This is not a get rich quick scheme

Finding alpha is hard, do not get discouraged

Drawdown are painful, be careful with leverage

Trust your alpha (if you have some), strategies are usually simple

Performance
- Out of sample performance is generally ½ of in sample performance
- Live trading performance is generally ¼ of in sample performance
- Due to curve fitting, unexpected slippage, etc.

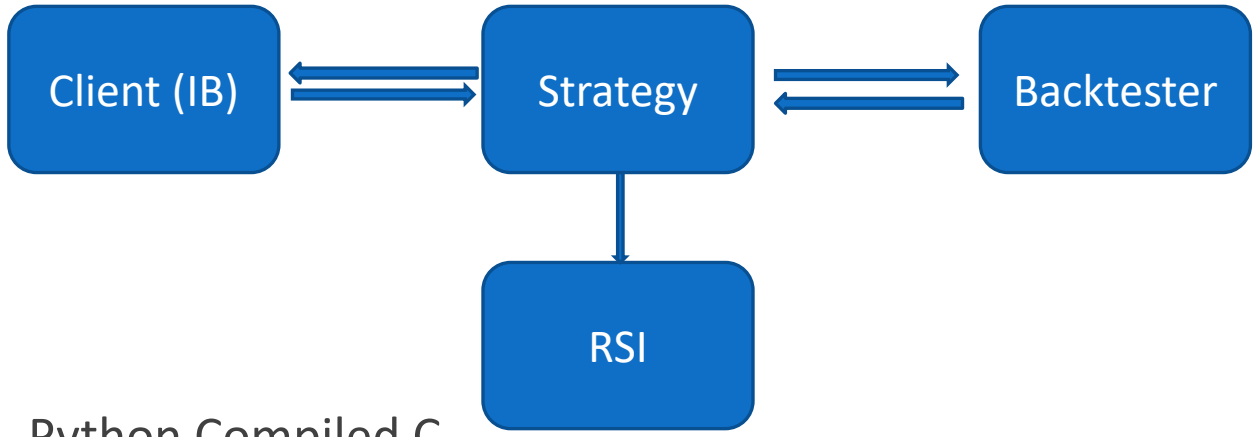
Make sure you account for ***transaction fees*** and ***slippage*** and ***order sizes***

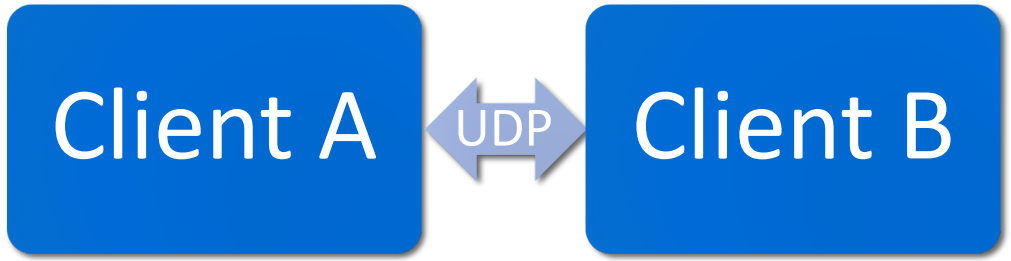
Fun and exciting way to learn not only the markets but also computer science and math

Data is your friend

Build your own backtester/execution environment

System Architecture Overview





Python Compiled C

Multi-Threaded
- Can instantiate multiple strategies

Event Driven Backtester
- Eliminates errors

Can use the same strategy for trading and backtesting

- Redundant instances
  - Multiple instances communicate over UDP to check state
  - Master slave/slaves architecture
  - Can extend to N instances
- AWS and Personal Server

Limit Order Execution – Place Order

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

Limit Order Execution – Book Movement

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~~

Limit Order Execution – Order Fill

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

Backtesting a Strategy

Backtesting with Limit order Execution

- Simulate by placing limit orders
- Need to check for fills
- Complex and requires time
- Does not perfectly model slippage

Backtesting with Close execution

- Orders filled on close of bar
- Subject to bid/ask bounce
  - Must subtract slippage numbers
  - More than 2 ticks?

Event Driven

Appendix

DETAILS THAT MIGHT BE INTERESTING TO READ

Appendix: Further Readings

Best guide to starting algo trading (intro/backtester taken from here)
- http://www.quantstart.com/

Execution Environment/Backtester/Community
- https://www.quantopian.com/

Cheap trading platform with API
- https://www.interactivebrokers.com/ind/en/main.php
  - Stellar documentation on how to do execution

Technical Analysis Library TA-Lib
- http://ta-lib.org/
- https://pypi.python.org/pypi/TA-Lib

Data:
- Free: Yahoo Finance, Google Finance – error prone
- Cheap: Pi Trading, Kibot, Tickwrite

Appendix: Sharpe Ratio

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

$$r_p = portfolio\ return$$

$$r_f = risk\ free\ rate$$

$$\sigma_p = standard\ deviation\ of\ return$$

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

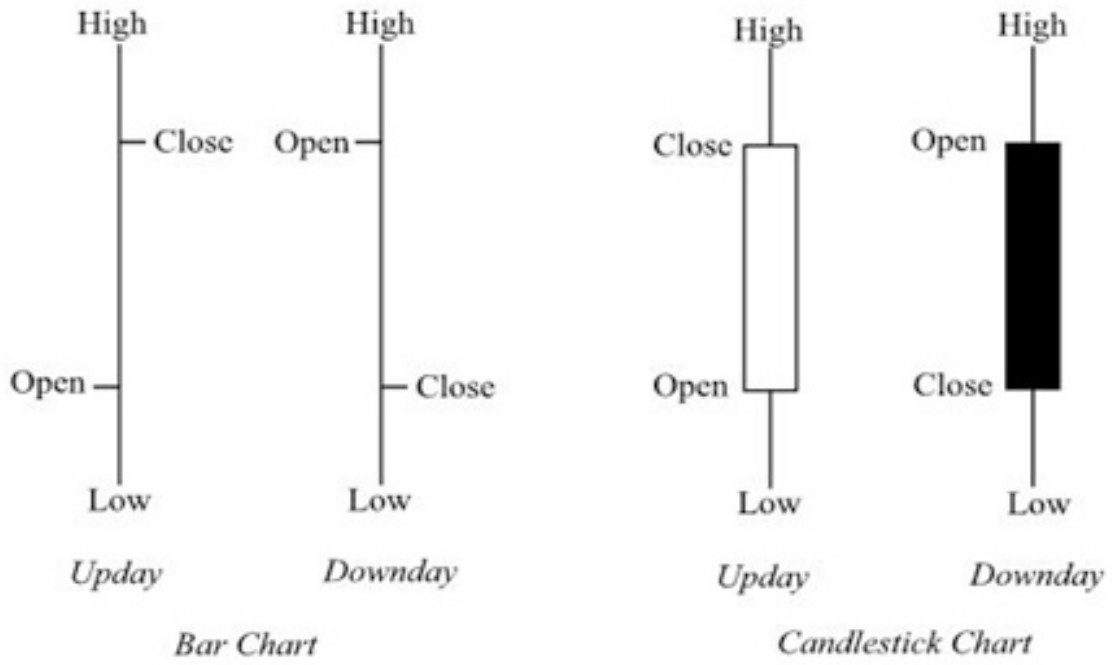
High – highest price

Low – lowest price

Close – price at end of bar

Volume – number traded during bar

Can be on any timescale: seconds to monthly



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

$$Initial\ Capital = \$1{,}000$$

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

$$True\ Range = \max\left[(high\ - low), abs\left(high - close_{prev}\right), abs\left(low - close_{prev}\right)\right]$$

$$ATR_t = \frac{ATR_{t-1}(n-1) + True\ Range_t}{n}$$

Appendix: PPC
Profit Per Contract

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

$$r_a = average\ return$$

$$c = number\ of\ contracts\ traded$$

$$t_s = tick\ size$$

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: CAPM
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?

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

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

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

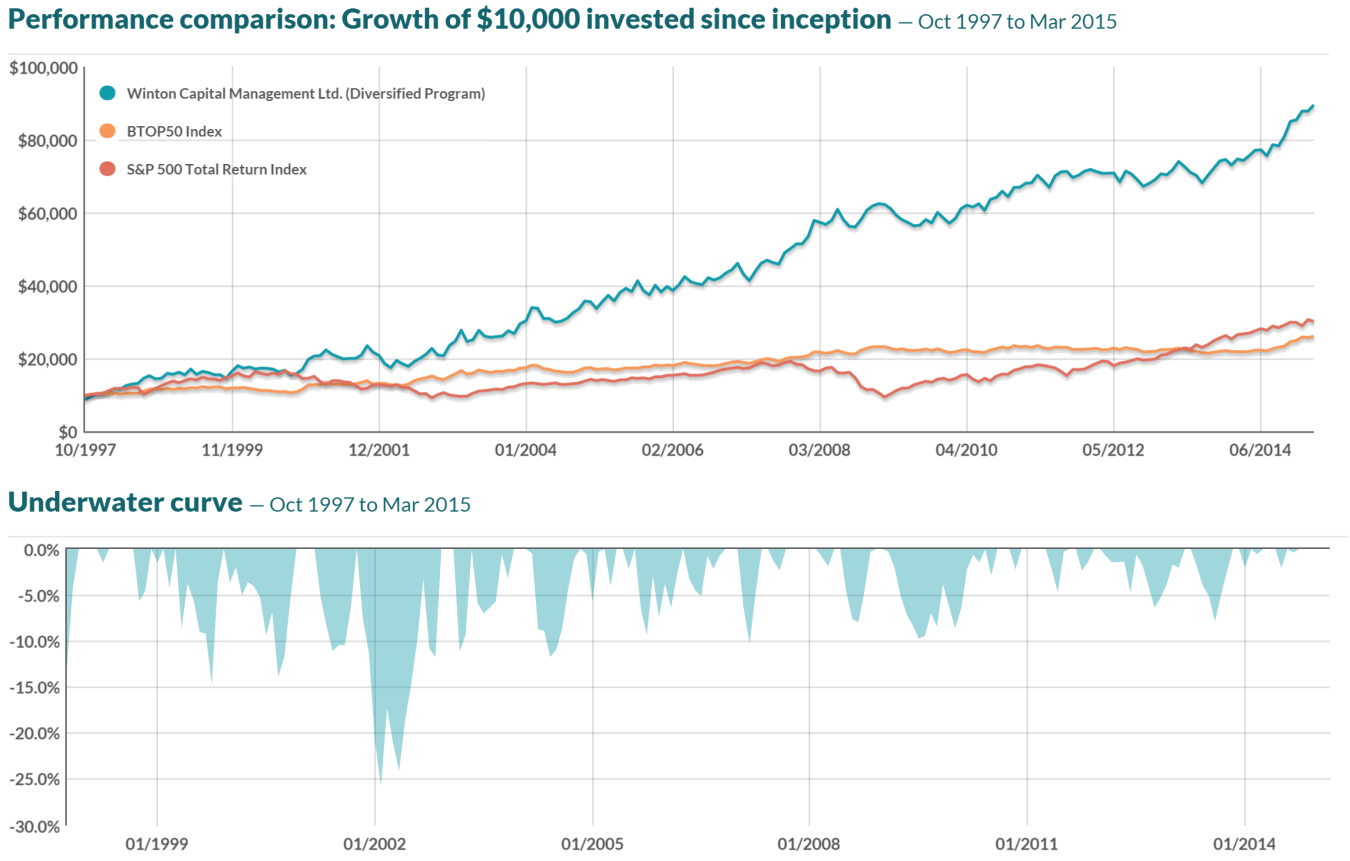
Simply put maximum drawdown is:

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

Appendix: Underwater Curve

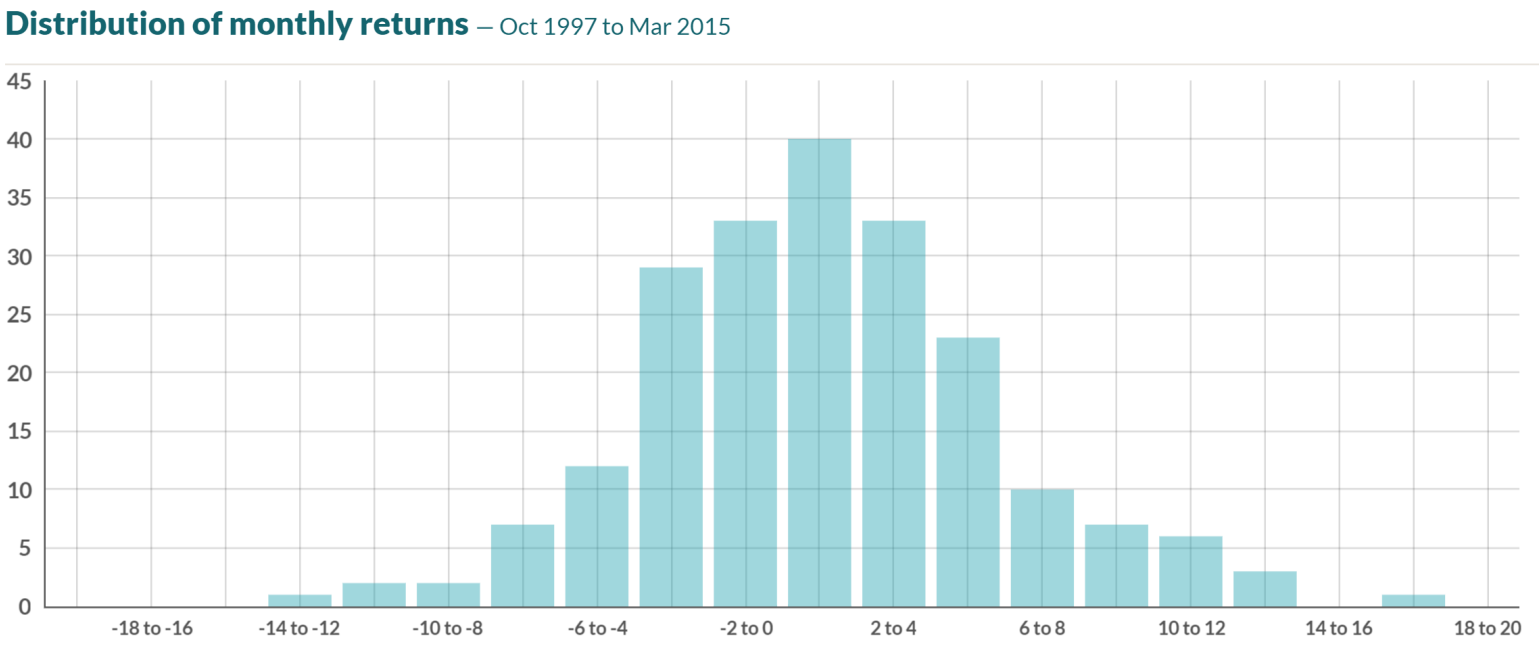
Good way to visualize how much of the time you are in a drawdown

Lets you evaluate how much pain you should be able to handle



http://ctaperformance.com/wntn

Appendix: Distribution of Returns



http://ctaperformance.com/wntn

Generally a histogram of returns

Look at center, shape, distribution, spread

- Want positive center, and no major outliers

Appendix: Strategy Correlation

Generally you want to make sure that your strategies are not correlated to each other (look at daily returns)

- You do not want everything to have a bad day at the same time
- Balanced returns are good

Uncorrelated strategies tend to yield higher Sharpe ratios when mixed

Correlated strategies tend to reflect the same alpha

- These strategies tend to compete with each other

Negatively correlated strategies can be good

- Highly negatively correlated strategies can indicate problems with your alpha

Thank you Aaron Rosen for your feedback

Appendix: Tradable 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