Algorithmic Trading

By: Avi Thaker

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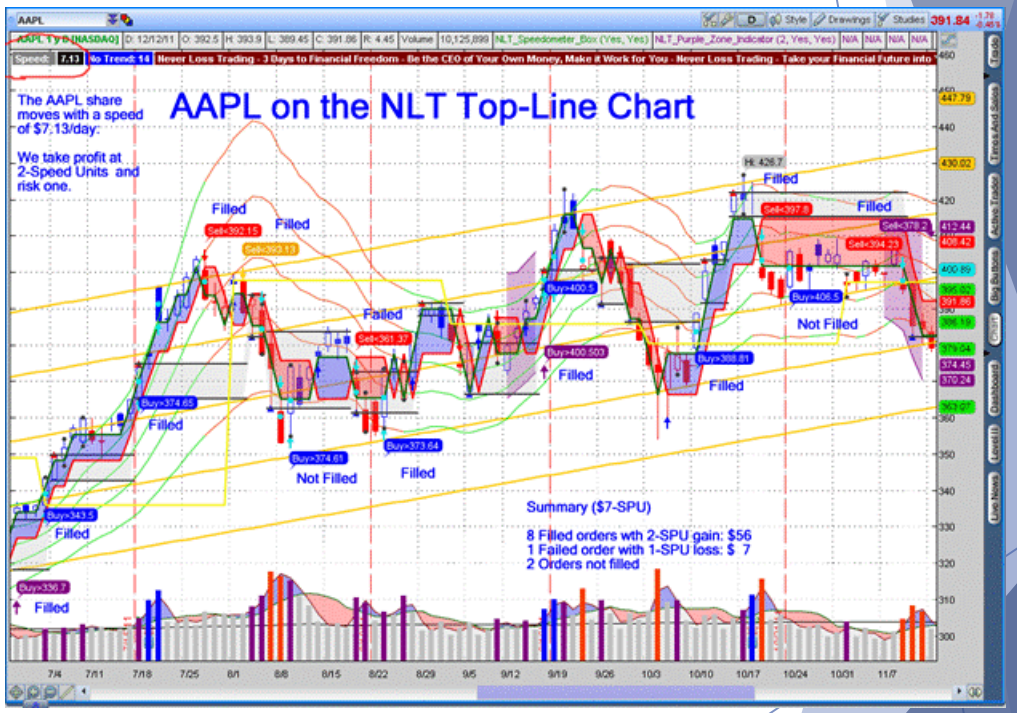
What is Algorithmic Trading

- The use of electronic platforms for entering trading orders with an algorithm which executes pre-programmed trading instructions whose variables may include timing, price, or quantity of the order.



http://neverlosstrading.com/Algorithmic%20Trading.html

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Motivation

- Computers can process larger amounts of data than humans and make decisions faster than humans
- Algorithms do what they are told, takes the human emotion out of trading
- ***Trillions*** of **$$$** traded daily - highly paid employees
- Bleeding edge of sciences; math, engineering, computer science, etc.

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Introduction:
The Efficient Market Hypothesis

- Impossible to “beat the market”
  - Market efficiency causes prices to incorporate and reflect all relevant information
    - Prices adjust quickly to new information
    - Prices should reflect all available information
  - Securities always trade at their fair value
  - The only way to obtain higher returns is to purchase riskier investments
  - Cannot predict trends, history does not indicate future
- Warren Buffett? Citadel? Two Sigma?
  - Are they lucky
- The market is becoming increasingly more efficient

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Index

- DataCollection.jar
- Python Pandas
- Hello World – Algo Trading
- Kinds of Trading Strategies
- Backtesting
- System Architecture
- Appendix

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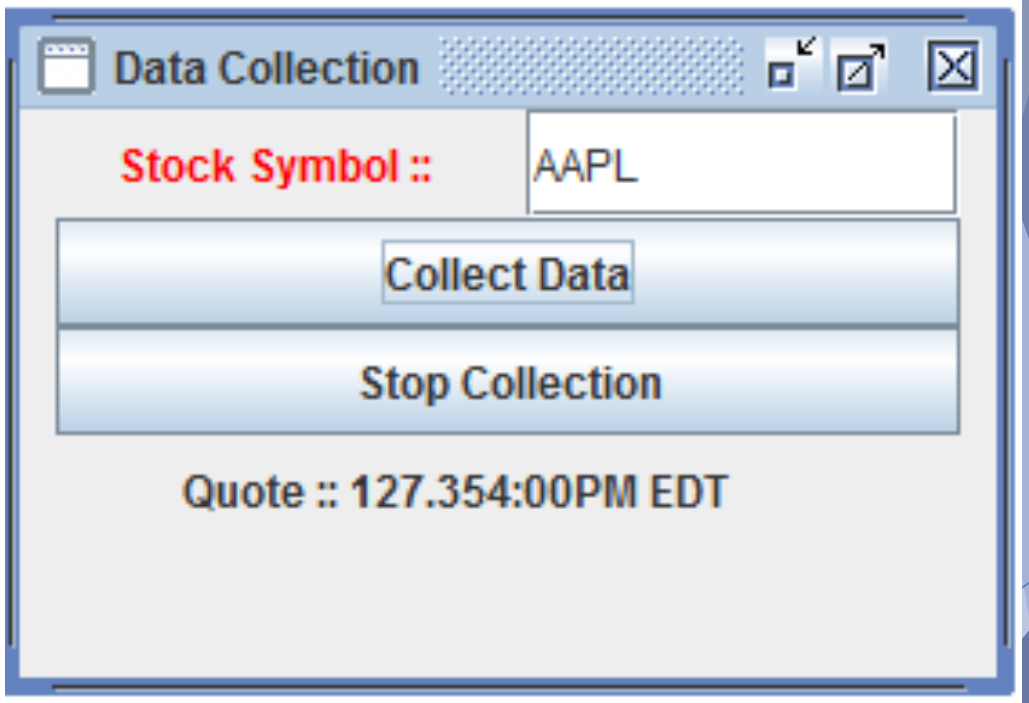
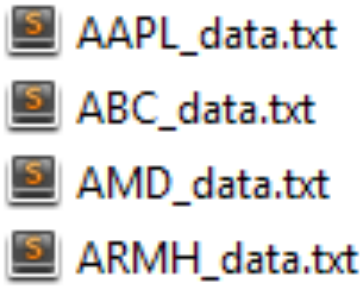
DataCollection.jar

- Collects intra-day data from Google Finance
  - Writes data to current directory
  - Snapshots
- Can collect multiple stocks
  - Type in ticker, hit collect data
- Works on Macs and PC's with Java
- Example Output (tab delimited)
  - 127.35 4:00PM EDT



Run me please? See how I work.



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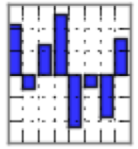
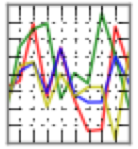
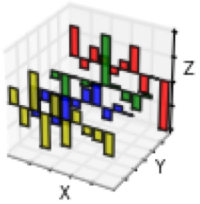
pandas

$$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$$







A programming introduction

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Python Pandas

- Developed for data manipulation and analysis by Wes Mckinney at AQR
- Extremely fast vector driven manipulation
  - Dataframe manipulation, integrated indexing
  - Data alignment and integrated handling of missing data
- Time series-functionality
  - Date range generation
  - Frequency conversion
  - Regressions, moving window statistics
- And so much more!

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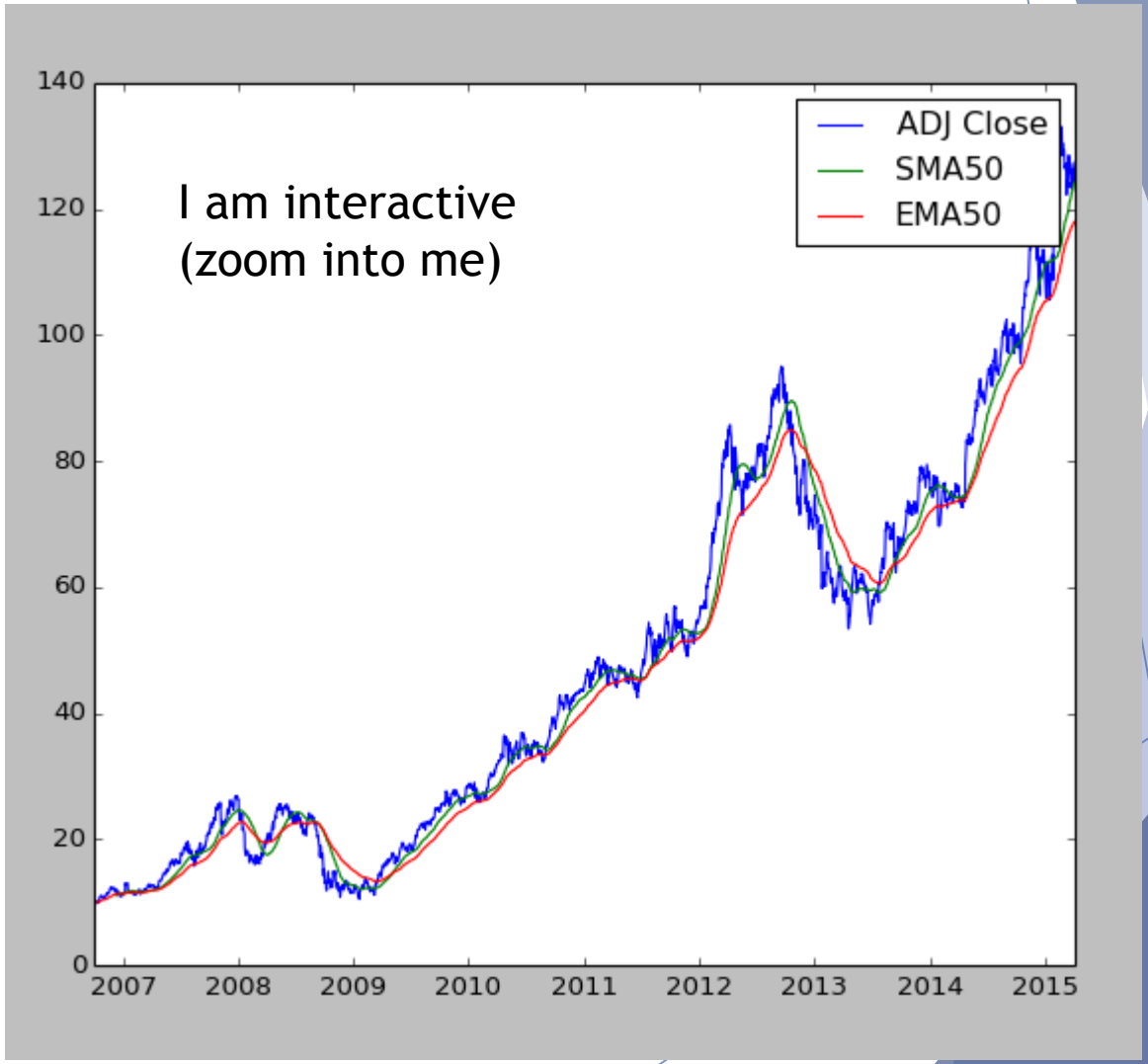
Pandas Example: Getting Historical Data

#pandas_example.py

```
# Imports
import datetime
import pandas as pd
import pandas.io.data
from pandas import Series, DataFrame
import matplotlib.pyplot as plt
import matplotlib as mpl
mpl.rc('figure', figsize=(8, 7))

# Get Data
aapl = pd.io.data.get_data_yahoo('AAPL',
      start=datetime.datetime(2006, 10, 1),
      end=datetime.datetime(2015, 4, 7) )
aapl.head()
# Do some time series manipulation
aapl['SMA50'] = pd.rolling_mean(aapl['Adj Close'],50)
aapl['EMA50'] = pd.ewma(aapl['Adj Close'], 50)

# Plot
plt.figure()
plot(aapl.index, aapl['Adj Close'])
plot(aapl.index, aapl['SMA50'])
plot(aapl.index, aapl['EMA50'])
plt.legend(('ADJ Close', 'SMA50', 'EMA50'))
```



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Pandas Example: DataFrame

- Data Arranged In columns indexed by date
  - Resembles Excel/R
- Handles NaN data extremely well
- Great for data manipulation
- Common functions
  - Df.head()
  - Df.tail()
  - Df.index()
  - Df.ffill()
    - Align and fill missing data

view the first few elements aapl.head()

	Open	High	Low	Close	Volume	Adj Close	SMA50	EMA50
Date								
10/2/2006	75.1	75.87	74.3	74.86	178159800	10.09	NaN	10.09
10/3/2006	74.45	74.95	73.19	74.08	197677200	9.98	NaN	10.03446
10/4/2006	74.1	75.46	73.16	75.38	207270700	10.16	NaN	10.07714
10/5/2006	74.53	76.16	74.13	74.83	170970800	10.08	NaN	10.07787
10/6/2006	74.42	75.04	73.81	74.22	116739700	10	NaN	10.06168

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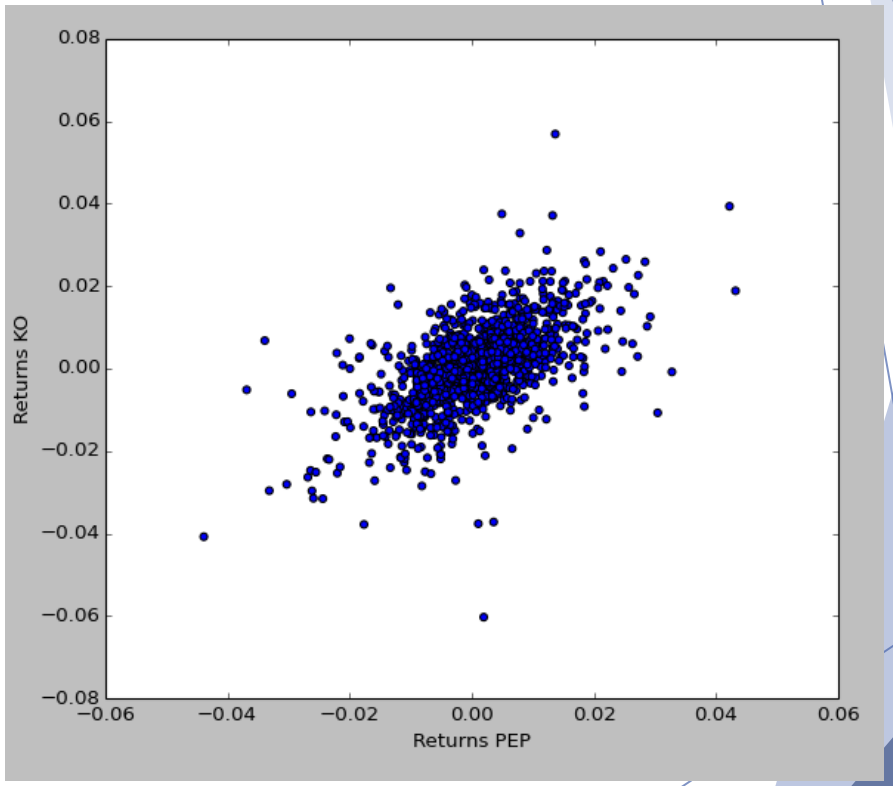
Pandas Example: Data Visualization

```
df = pd.io.data.get_data_yahoo(symbols=['AAPL', 'GE',
'GOOG', 'IBM', 'KO', 'MSFT', 'PEP'])['Adj Close']

rets = df.pct_change()

a = plt.figure()

plt.scatter(rets.PEP, rets.KO)

plt.xlabel('Returns PEP')

plt.ylabel('Returns KO')

pd.scatter_matrix(rets, diagonal='kde', figsize=(10, 10));
```



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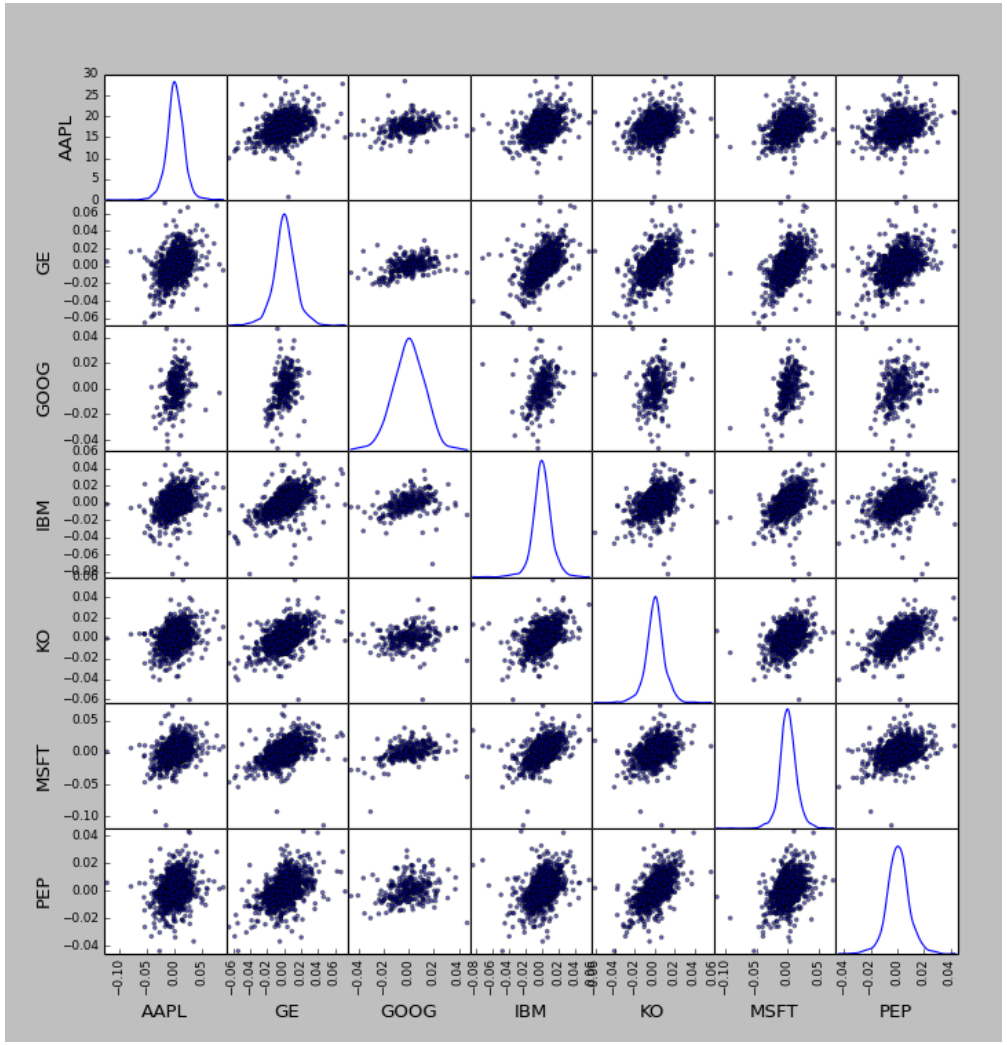
Pandas Example: Data Visualization 2




```
pd.scatter_matrix(rets, diagonal='kde', figsize=(10, 10));
```

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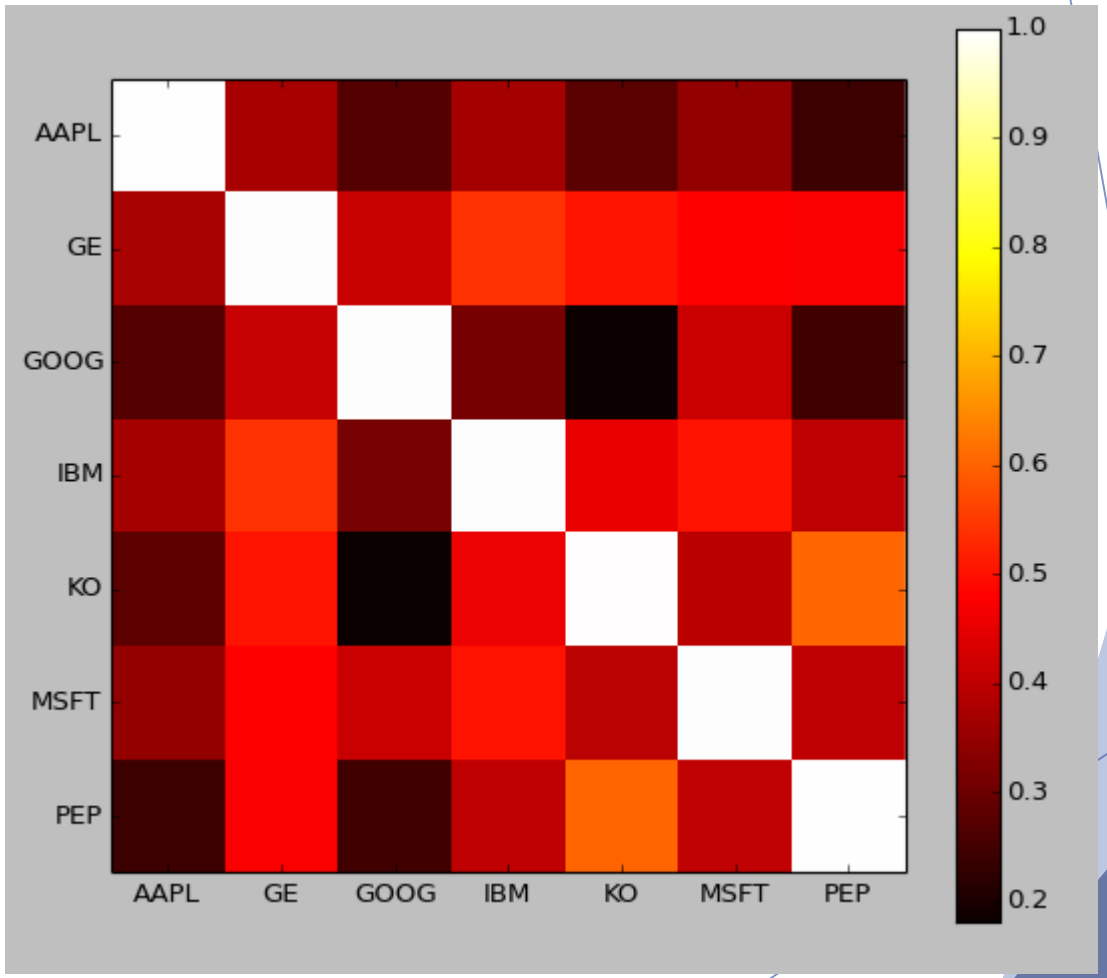
Pandas Example: Data Visualization 3

```
# Display a Correlation of returns

corr = rets.corr()

plt.figure()

plt.imshow(corr, cmap='hot',
interpolation='none')

plt.colorbar()

plt.xticks(range(len(corr)),
corr.columns)

plt.yticks(range(len(corr)),
corr.columns)
```



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Pandas Example: Data Visualization 4

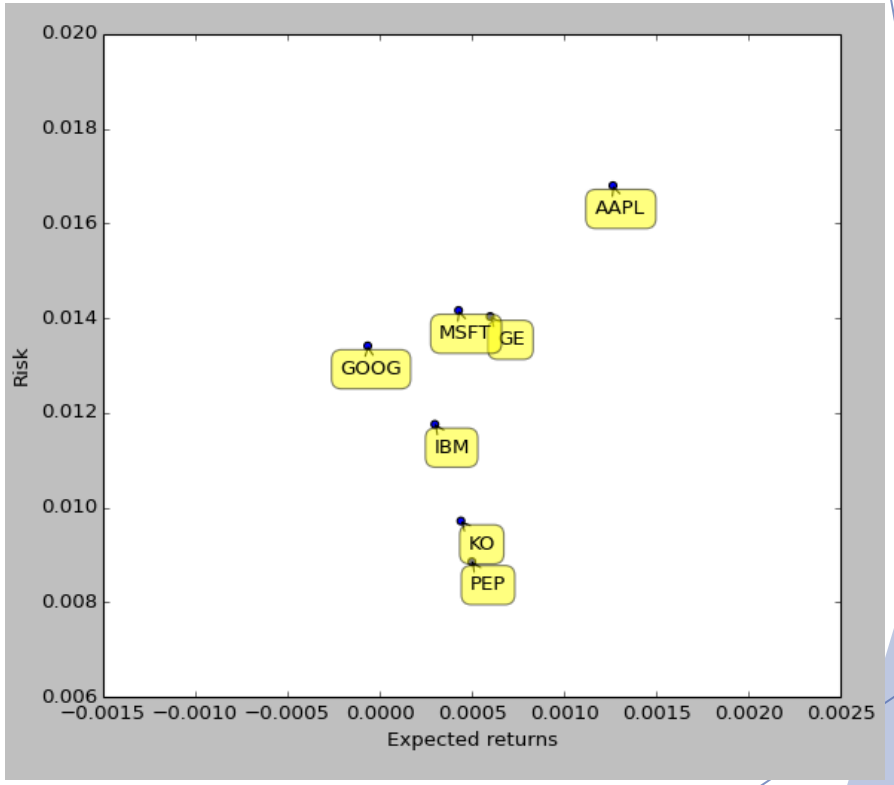
```
plt.scatter(rets.mean(), rets.std())

plt.xlabel('Expected returns')

plt.ylabel('Risk')

for label, x, y in zip(rets.columns,
rets.mean(), rets.std()):

plt.annotate(label, xy = (x, y), xytext =
(20, -20),textcoords = 'offset points', ha =
'right', va = 'bottom', bbox = dict(boxstyle =
'round,pad=0.5', fc = 'yellow', alpha = 0.5),
arrowprops = dict(arrowstyle = '->',
connectionstyle = 'arc3,rad=0'))
```



http://nbviewer.ipython.org/github/twiecki/financial-analysis-python-tutorial/blob/master/1.%20Pandas%20Basics.ipynb

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Hello World – Algorithmic Trading

Backtesting a Moving Average Crossover Strategy

http://www.quantstart.com/articles/Backtesting-a-Moving-Average-Crossover-in-Python-with-pandas, Zipline

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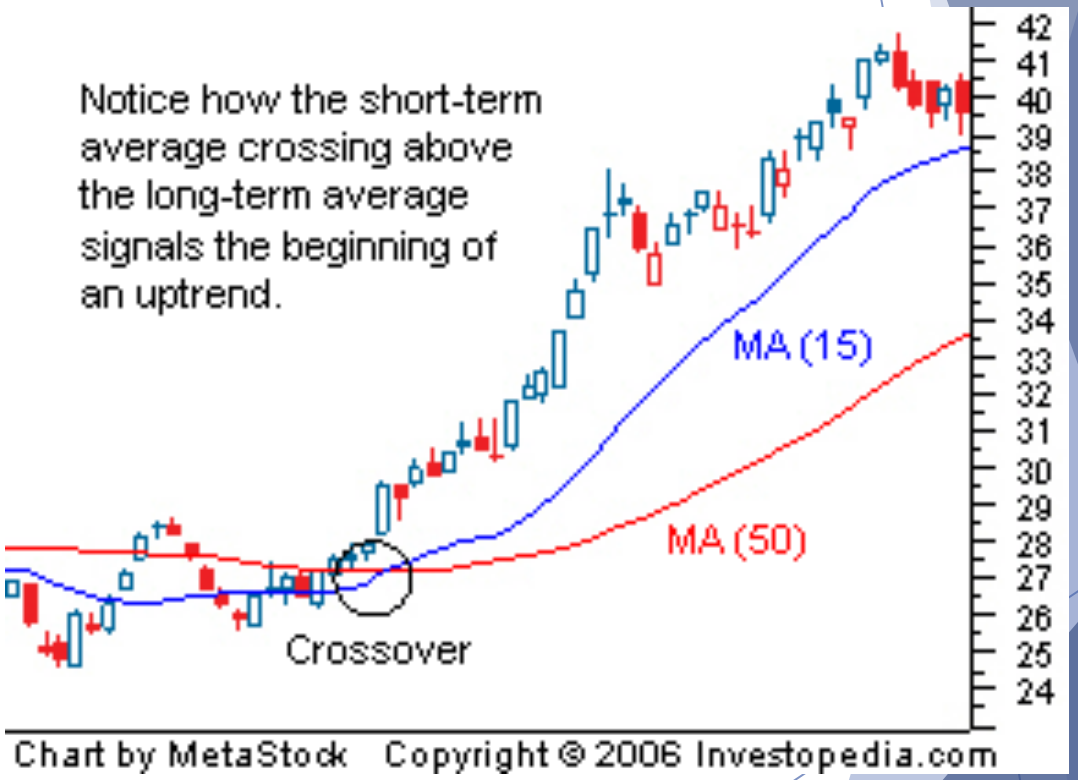
Strategy: Moving Average Crossover

- Momentum Strategy (more later)
- Enter long, when longer MA crosses over the shorter faster MA
- Enter short (or exit), when shorter faster MA crossover longer MA
- Believe that market will strongly move in one direction
- Prone to whiplash
- We will build and backtest this!



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Getting Started

- Prerequisites
  - Python - 2.7+
  - NumPy
  - Pandas
  - Matplotlib
  - I suggest using pythonXY/Spyder – does everything for you
- We will now create this strategy and run it on AAPL
  - Take ma_cross.py and backtest.py and place them into the same directory
  - Run the files
- **Change the Parameters to Short=20, Long=200, on ARMH from 2011-Now**

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Code Details and Questions

- Only trades long, creates two simple moving averages
- *MovingAverageCrossStrategy* is subclassed from *Strategy*
- *MarketOnClosePortfolio* is subclassed from *Portfolio*
- What is misleading with the data we are using?
  - Hint look at AAPL's price.
- How can we improve on this code?
- How do we measure strategy performance?
- How can we tell if a strategy is good?
- What are some other kinds of trading strategies?

Output

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Quantopian

- Extremely Slow, but provides a decent backtester
- Direct Python interface to IB
  - Live and Paper Trading
- Hosts competitions, if you win, will be awarded with $100,000 to trade with
  - All profits go to you
  - https://www.quantopian.com/open
- Open source community
  - https://www.quantopian.com/home
  - https://www.quantopian.com/posts

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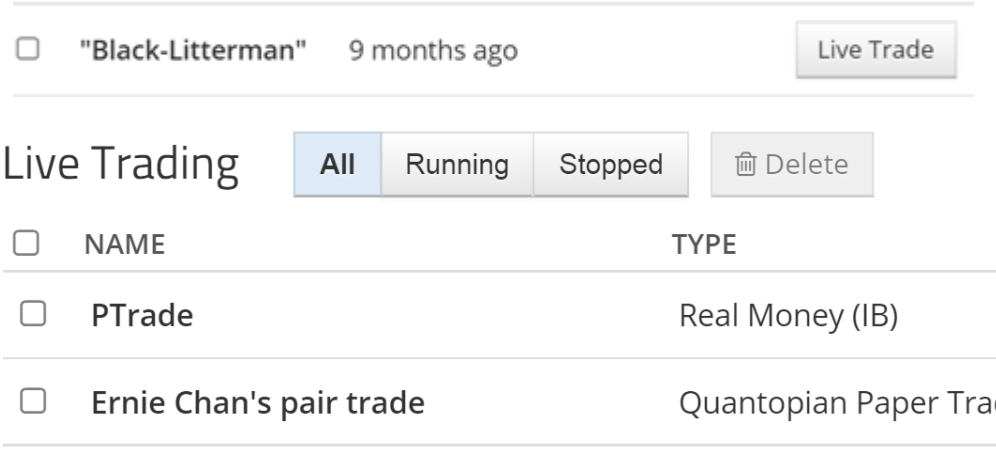
Quantopian

- A sample momentum algorithm from Quantopian.
- Very simple coding interface to use, and push to live trading with IB, or paper trade
  - This system can directly trade with your Interactive Brokers account
  - Must give privileges, have cash, etc.




```python
def initialize(context):
    # Trading AAPL
    context.aapl = sid(24)

    # In these two lines, we set the maximum and minimum we want our algorithm
    # to go long or short our security
    context.max_notional = 1000000.1
    context.min_notional = -1000000.0

def handle_data(context, data):
    #This function runs on each frame of the data, each tick/frame is 1 min

    # 3 day volume weighted price
    vwap = data[context.aapl].vwap(3)
    # We need a variable for the current price of the security
    price = data[context.aapl].price

    # How long or short our position is at this minute.
    notional = context.portfolio.positions[context.aapl].amount * price

    # You can use the record() method to track any custom signal. The record graph
    # will track up to five different variables. Here we record the portfolio cash value
    record(cash = context.portfolio.cash)

    # If the price of the security is .5% less than the 3-day volume weighted average
    # price AND we haven't reached our maximum short, sell 100 shares
    # command and sell 100 shares.
    # If the stock is .5% higher than the 3-day average AND we haven't reached our
    # maximum long, buy 100 shares
    if price < vwap * 0.995 and notional > context.min_notional:
        order(context.aapl,-100)
        log.info("Selling %s" % (context.aapl))
    elif price > vwap * 1.005 and notional < context.max_notional:
        order(context.aapl,+100)
        log.info("Buying %s" % (context.aapl))
```

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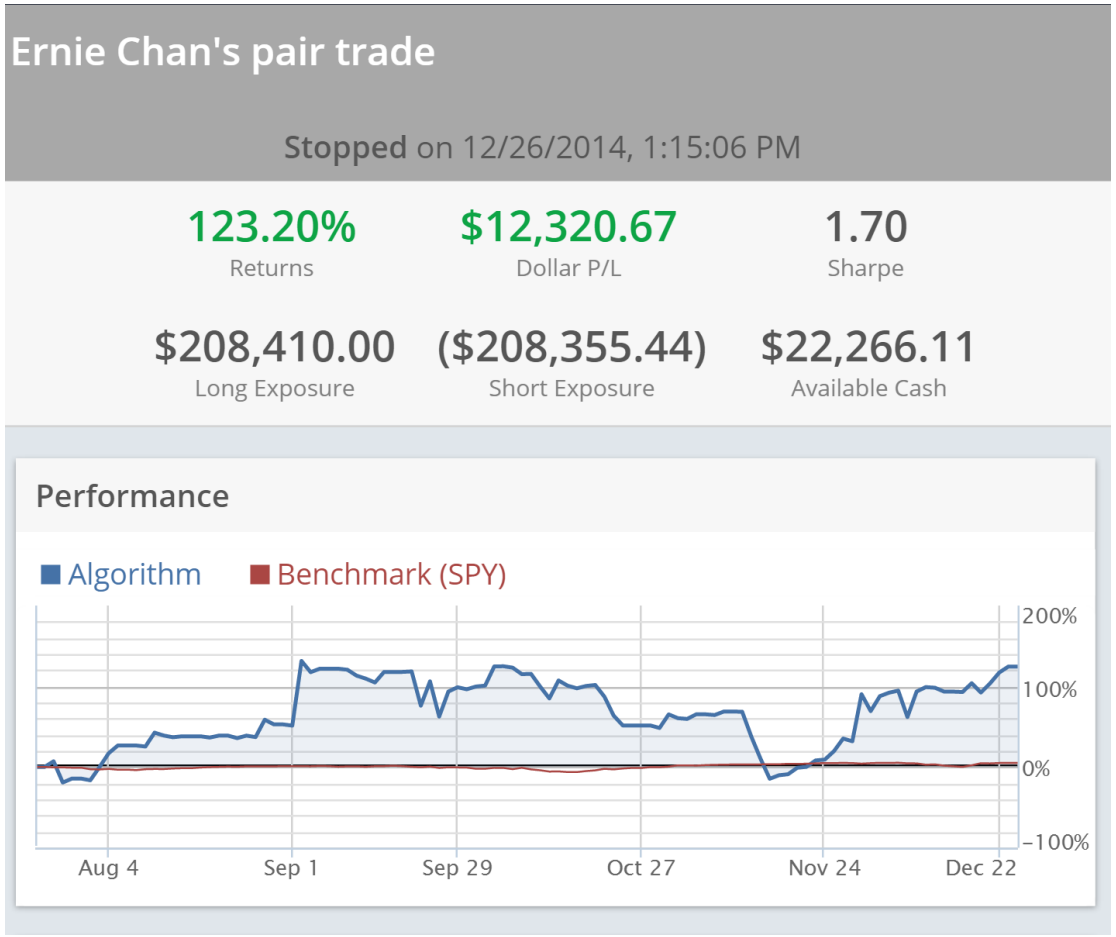
Quantopian



Sample results from a paper trade, with statistics and an equity curve

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Kinds of Strategies

A Brief Introduction

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Terms

- Depth of Market (DOM, Limit Order Book, Level 2)
- Best Bid – price to instantly sell
- Best Ask – price to instantly buy
- Bid Size
- Ask Size
- Alpha
  - The abnormal rate of return in excess of what would be predicted by an equilibrium model like the capital asset pricing model (CAPM).
- Tick Size – Interval between possible prices
- Slippage – Difference between signaled price and trade price

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HFT vs Non HFT

- HFT or High Frequency Trading, relies on quick algorithmic trading to capture small spreads or small alpha (less than 1 minute holds)
  - Difficult for the retail investor to get into
  - Extremely competitive
    - Fastest usually takes all profits
    - Makes up 70%+ of all trading volume
- Non HFT (trades of longer periods)
  - Easier for the retail investor to get into
  - Not as competitive
    - Smarter people make profits
  - This is our focus

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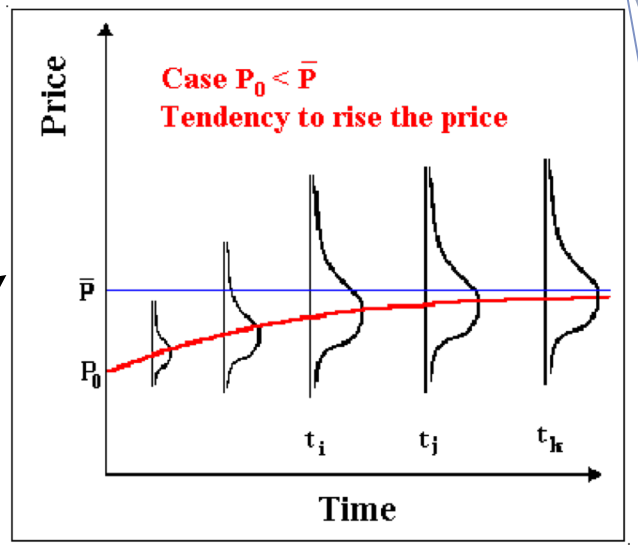
Strategy: Alpha Taking

- Believes the market will move in one direction
- Mean Reverting – price reverts back to a "average" price, Bollinger Bands
  - Stochastic Math
- Trend following / Momentum
  - price will move in one direction
  - We tested/built one of these
  - Impulse response filters



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

Stockcharts.com

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Strategy: Market Making

- Capture the Spread
- Increase Liquidity
- On both sides of the market
- Risky during times of volatility
- Must be fast and have good queue position
- Math is generally more complicated

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 networks, and neural networks
The focus is on market microstructure

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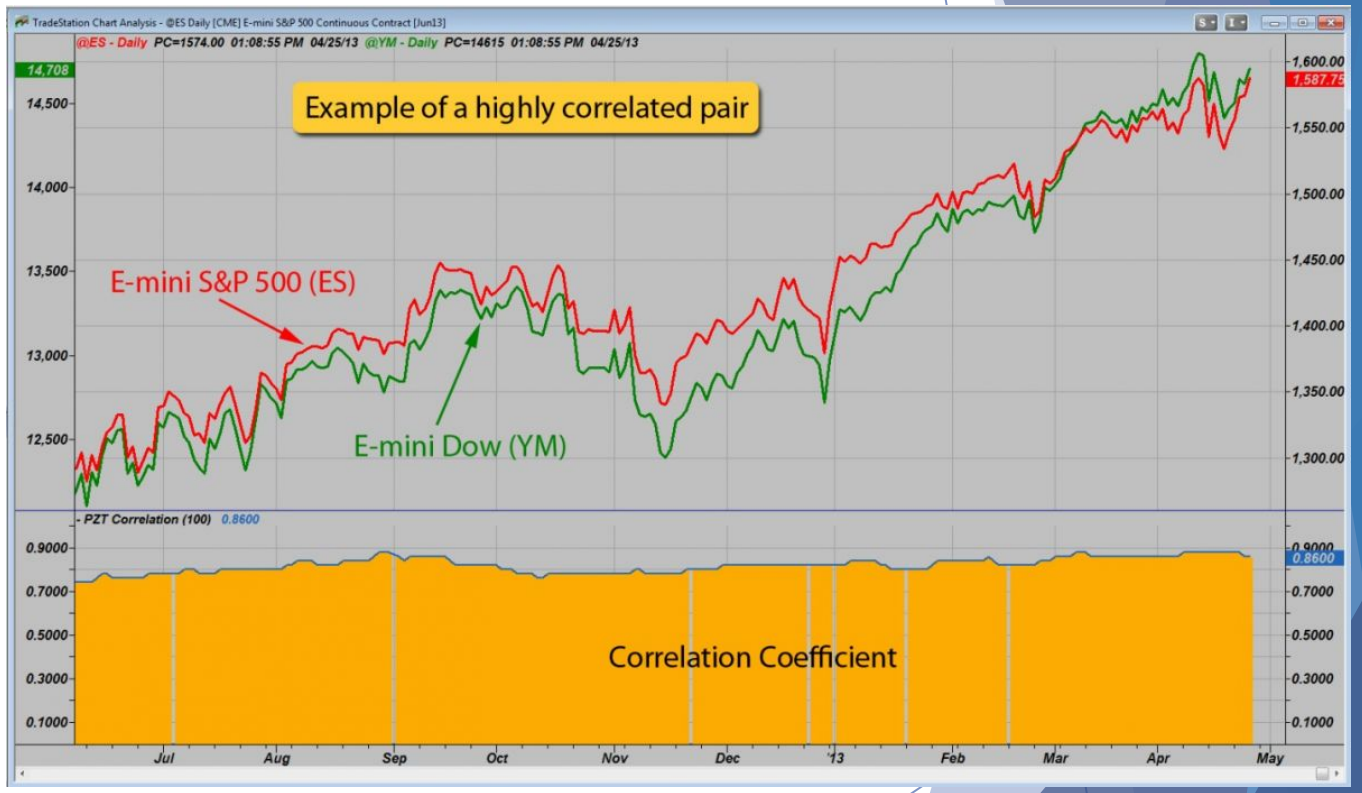
Strategy: Pair Trading

- Assumes two contracts move together
- Revert moves when one moves against the other
- Can be highly risky
  - 2007 Crash?
  - Spreads blow up
- Commonly used by Hedgefunds
- High usage of Kalman Filters, CADF (Co-integrated Augmented Dickey Fuller) tests, autocorrelation, etc.



http://www.investopedia.com/university/guide-pairs-trading/pairs-trade-example.asp

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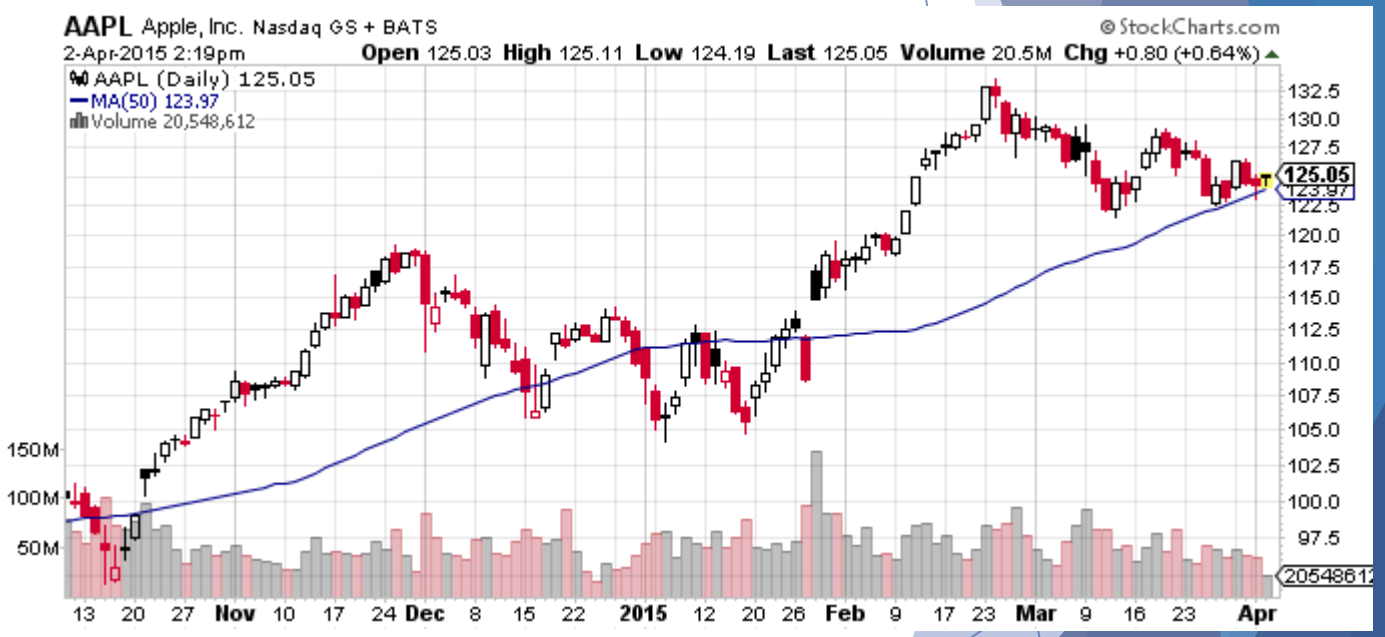
Strategy Detail: Common Signals
Simple Moving Average: SMA

- Mean of previous n periods
- Smooths data, easier to identify trends
- Common signal

$$SMA = \frac{p_M + p_{M-1} + \ \ldots + p_{M-(n-1)}}{n}$$

$$SMA_{current} = SMA_{previous} - \frac{p_{M-n}}{n} + \frac{p_M}{n}$$

$$p_i = price\ at\ given\ time$$



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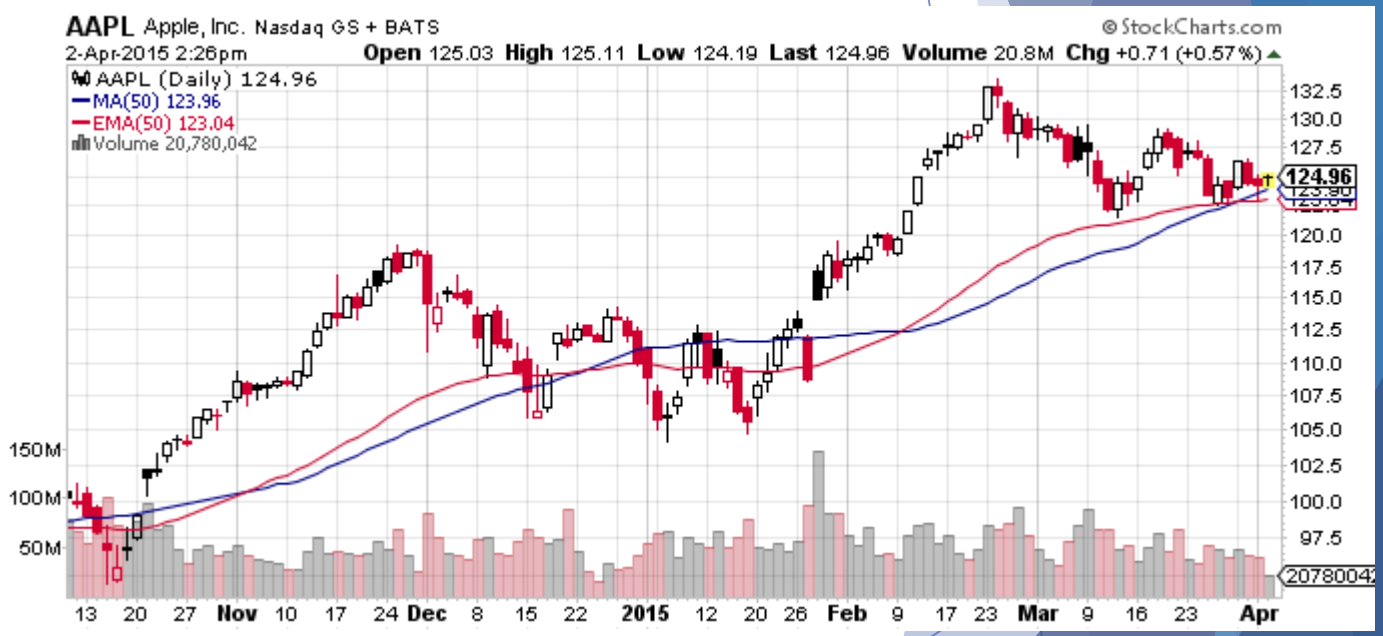
Strategy Detail: Common Signals
Exponential Moving Average: EMA

- Infinite impulse response filter
- Less lag than SMA
- Commonly used signal

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

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

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



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Trading The EMA

Enter Long: Close > EMA & Prev_Close > EMA_Prev
Enter Short: Close < EMA & Prev_Close < EMA_Prev

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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

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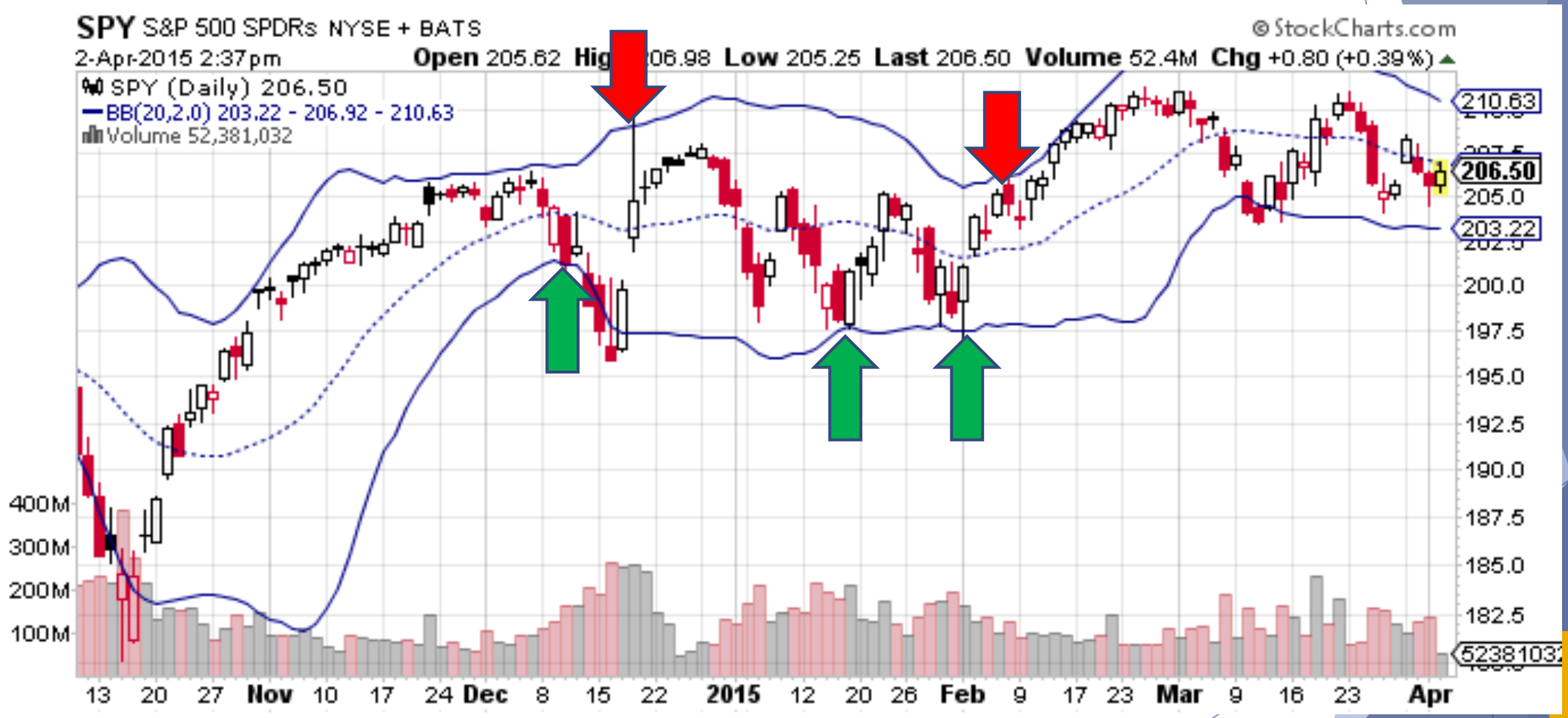
Example: Trading the Bollinger Bands



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More Examples / 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

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Backtesting

Really again? How much is there to backtesting?

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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

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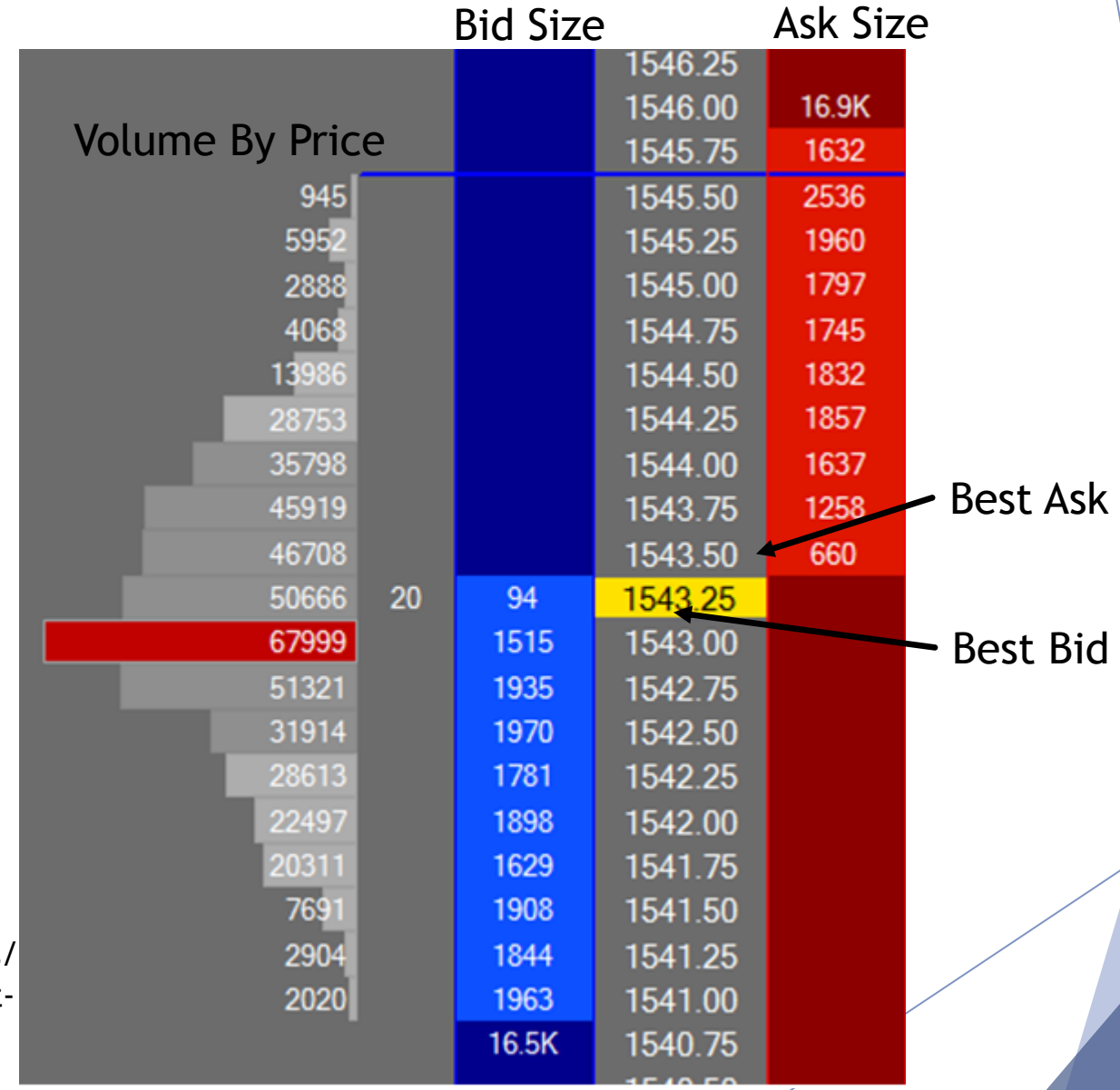
Limit Order Book



http://www.trade2win.com/articles/1750-understanding-liquidity-market-pullbacks

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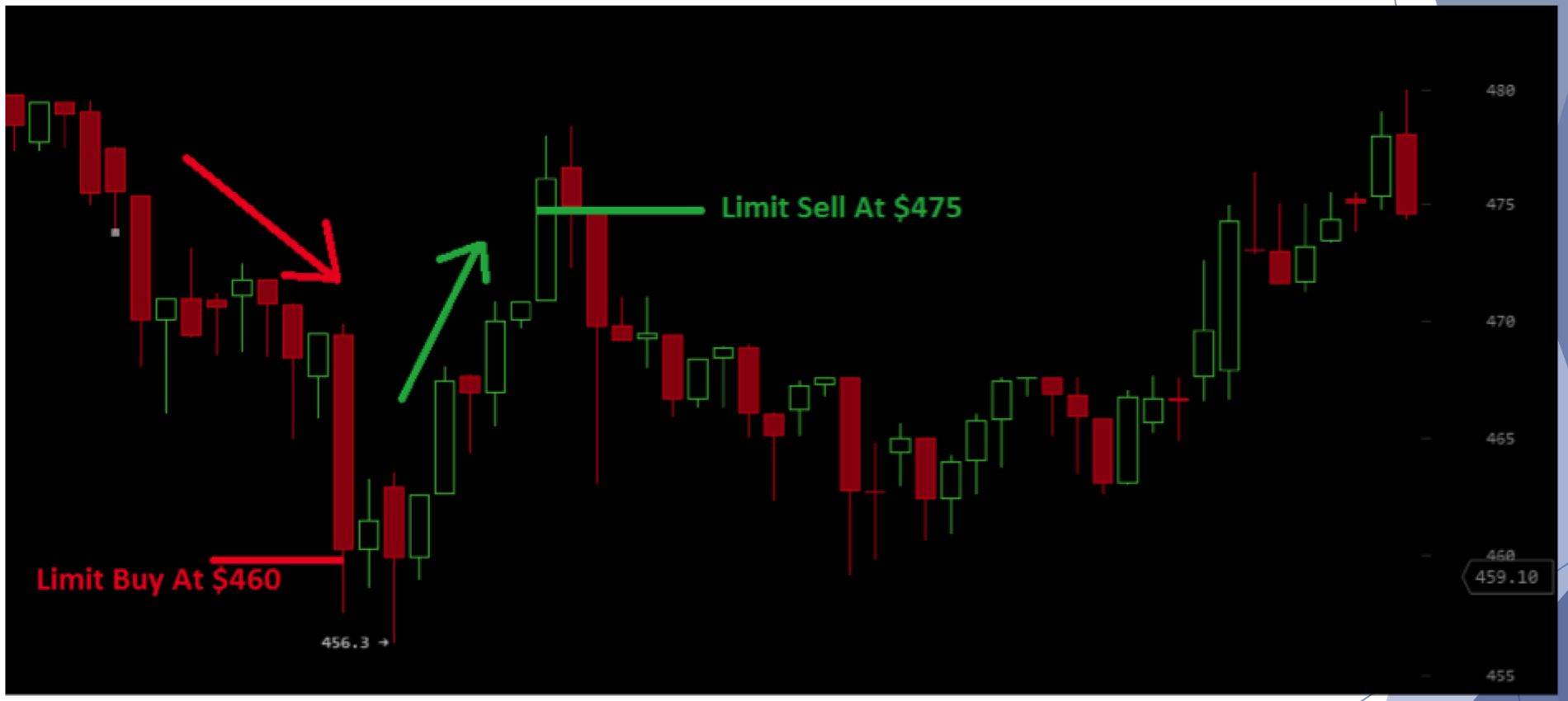
Limit Order Execution



For an order to be executed, a trade must cross below your buy, or a trade happens at your price, when you have been filled in the queue

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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

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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~~

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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

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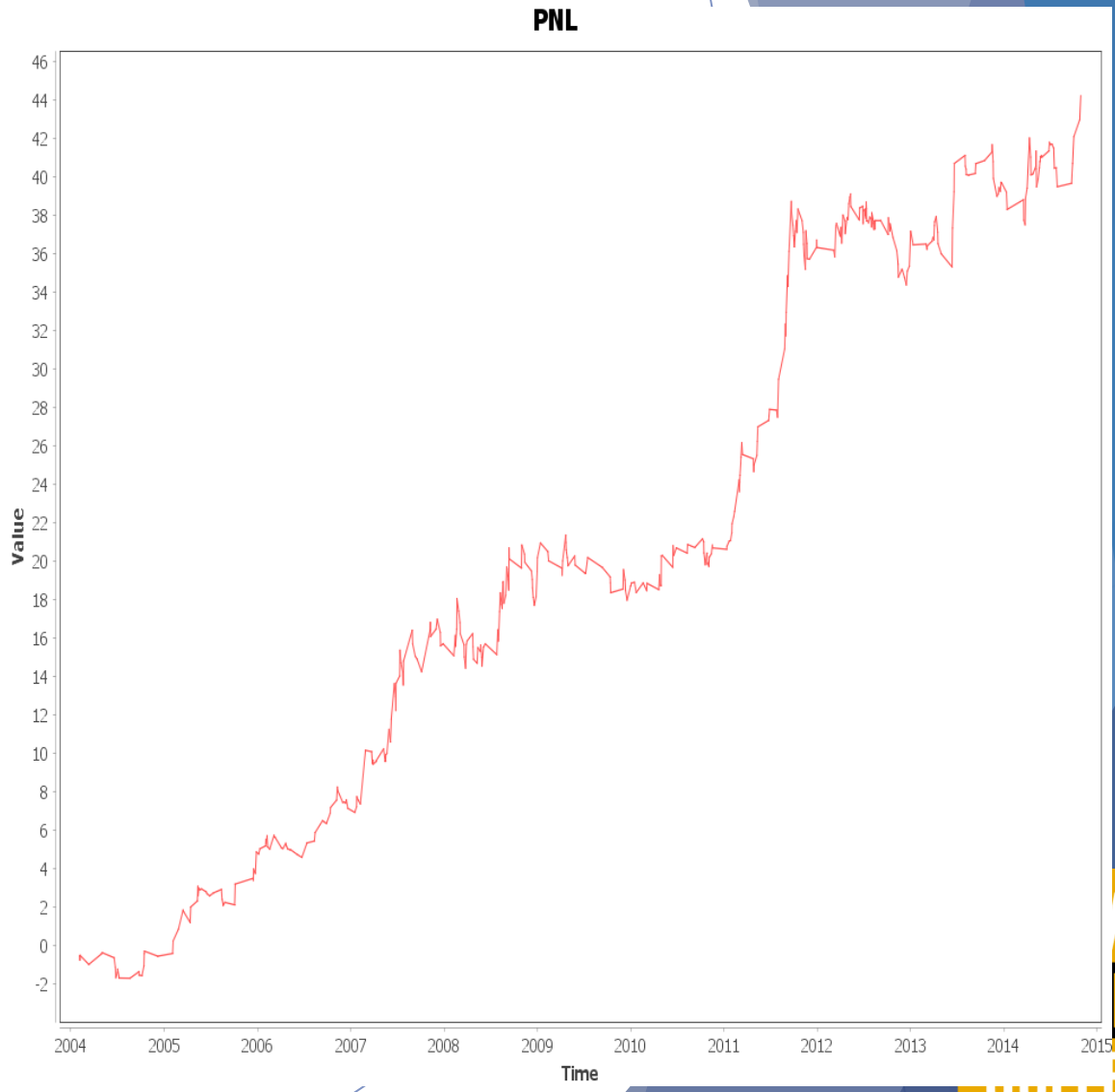
Backtesting a Strategy/Risk

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

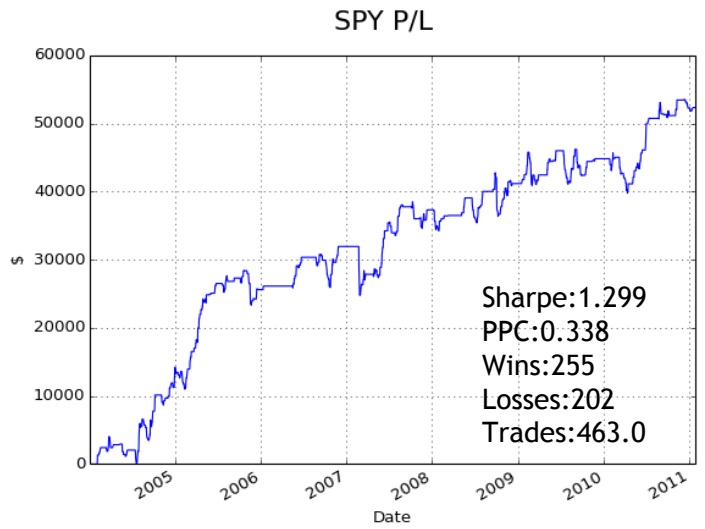
Key Statistics

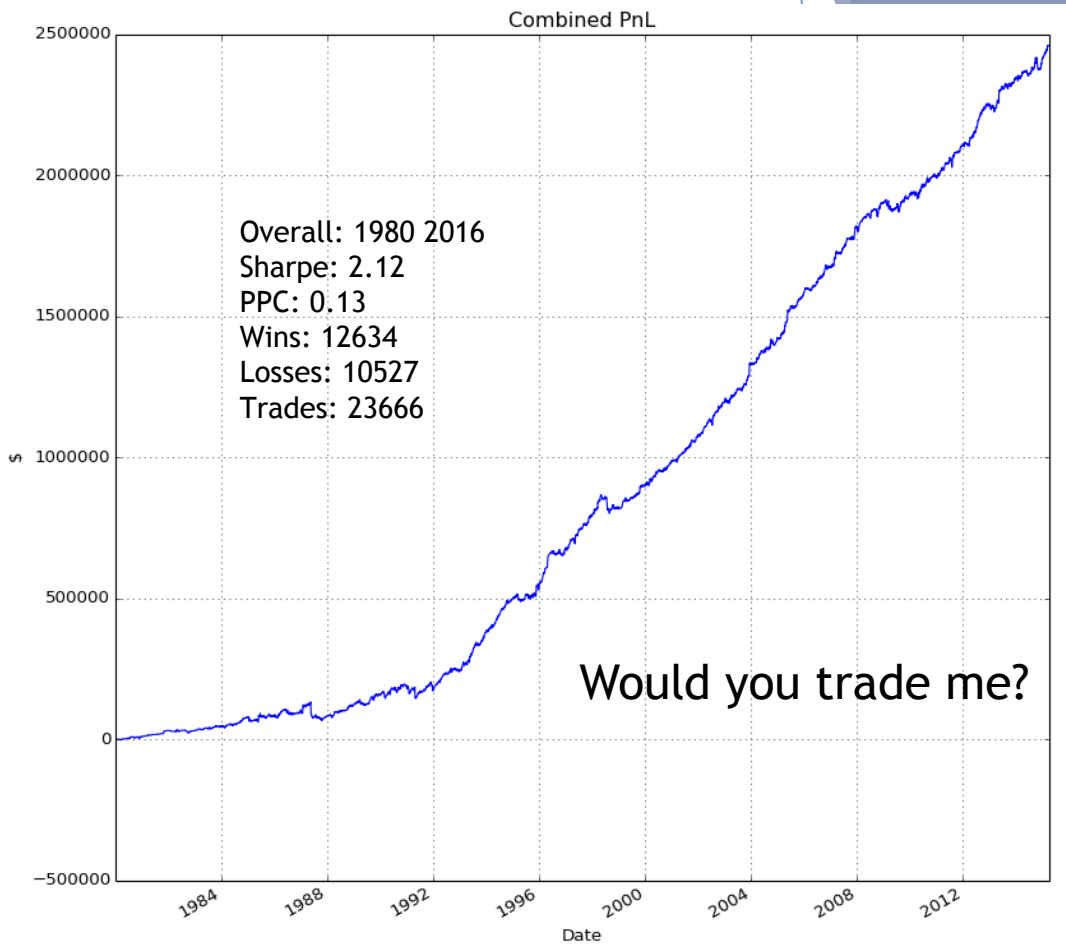
Average wins	:: 0.637 USD
Average loss	:: -0.438 USD
# Wins	:: 214
# Losses	:: 210
# Neutrals	:: 3
Win Rate	:: 0.501
PPC	:: 0.104USD
# Traded	:: 427.0
Ann. Sharpe	:: 2.335



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

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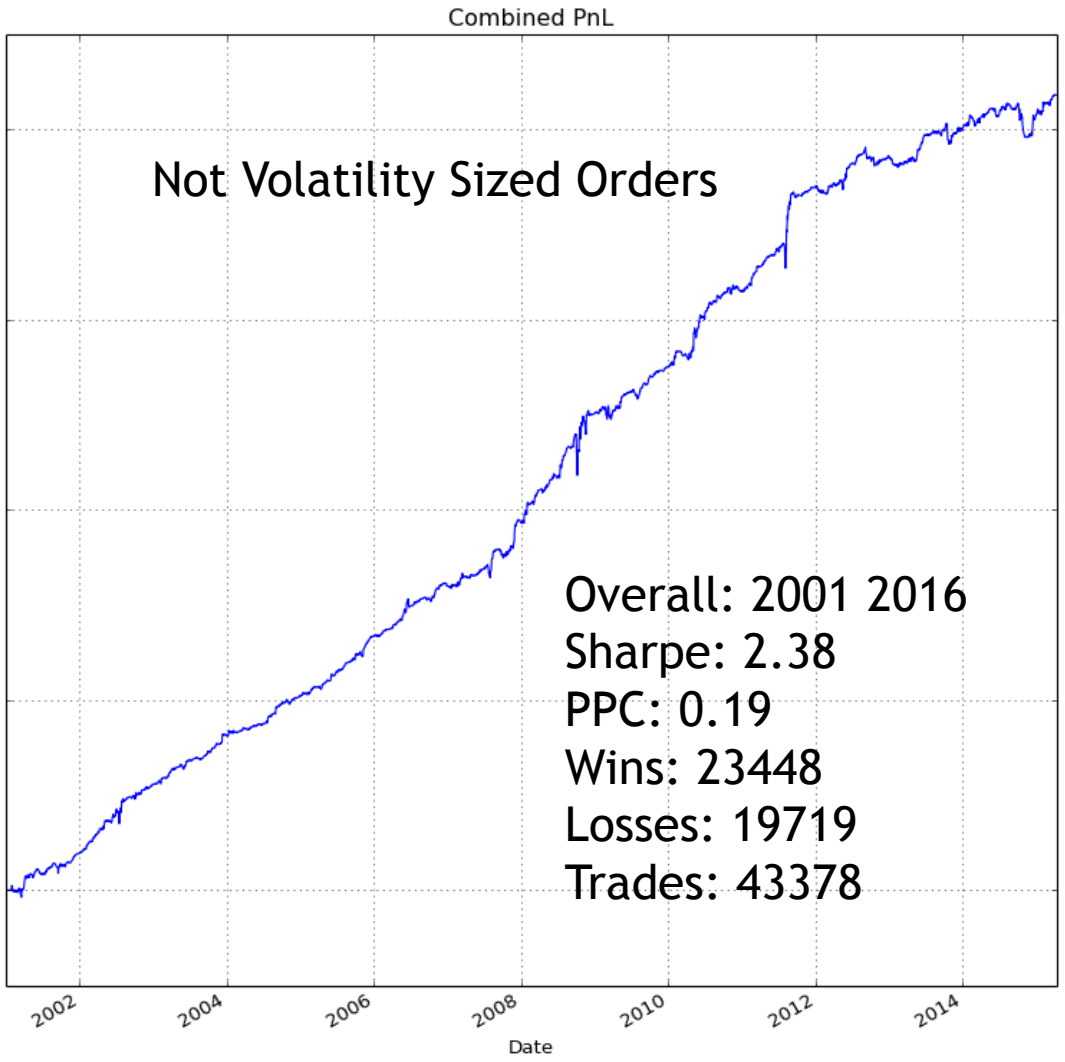
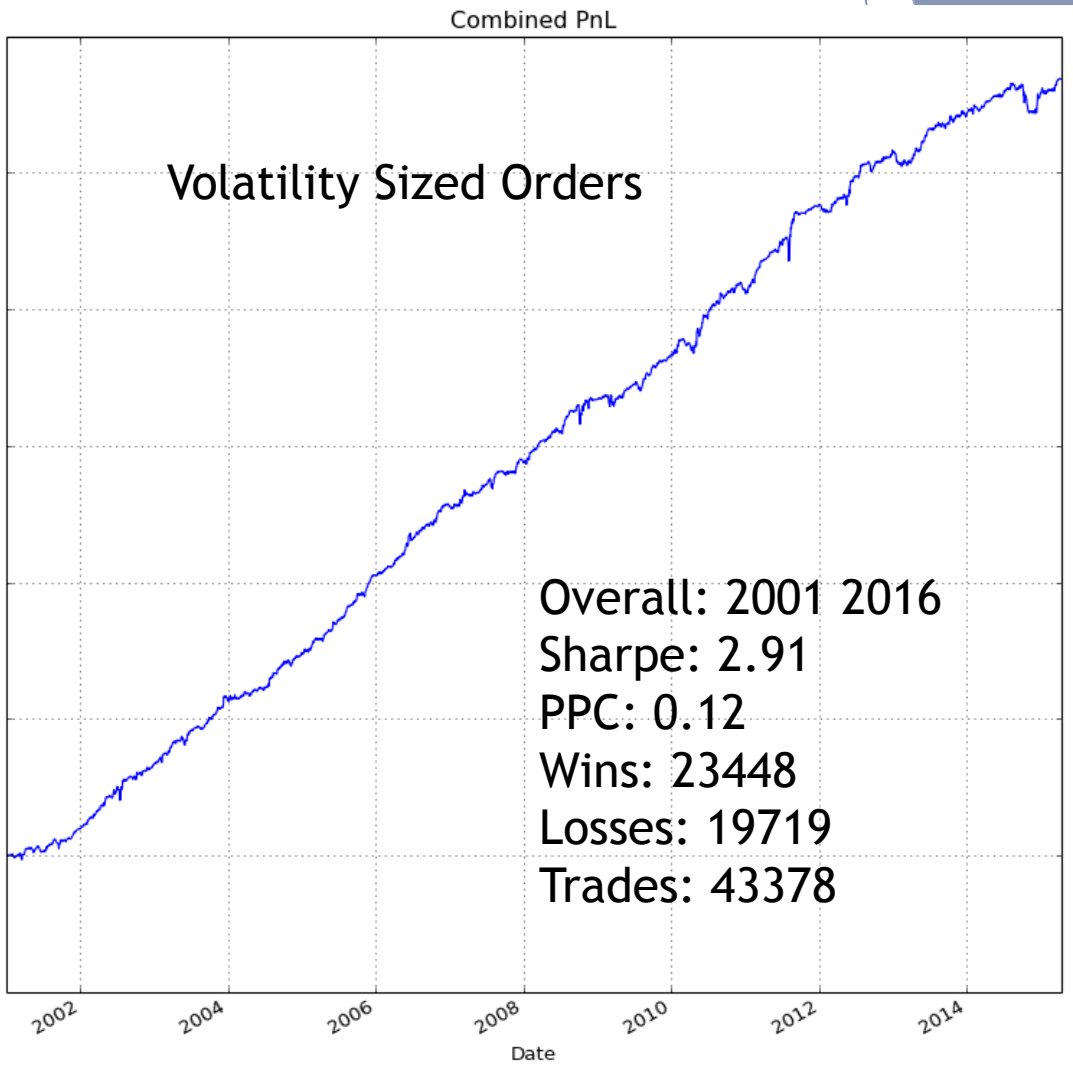
Order Sizing





- Generally size orders inversely proportional to volatility

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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

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System Architecture

How do I actually build an autonomous trading system?

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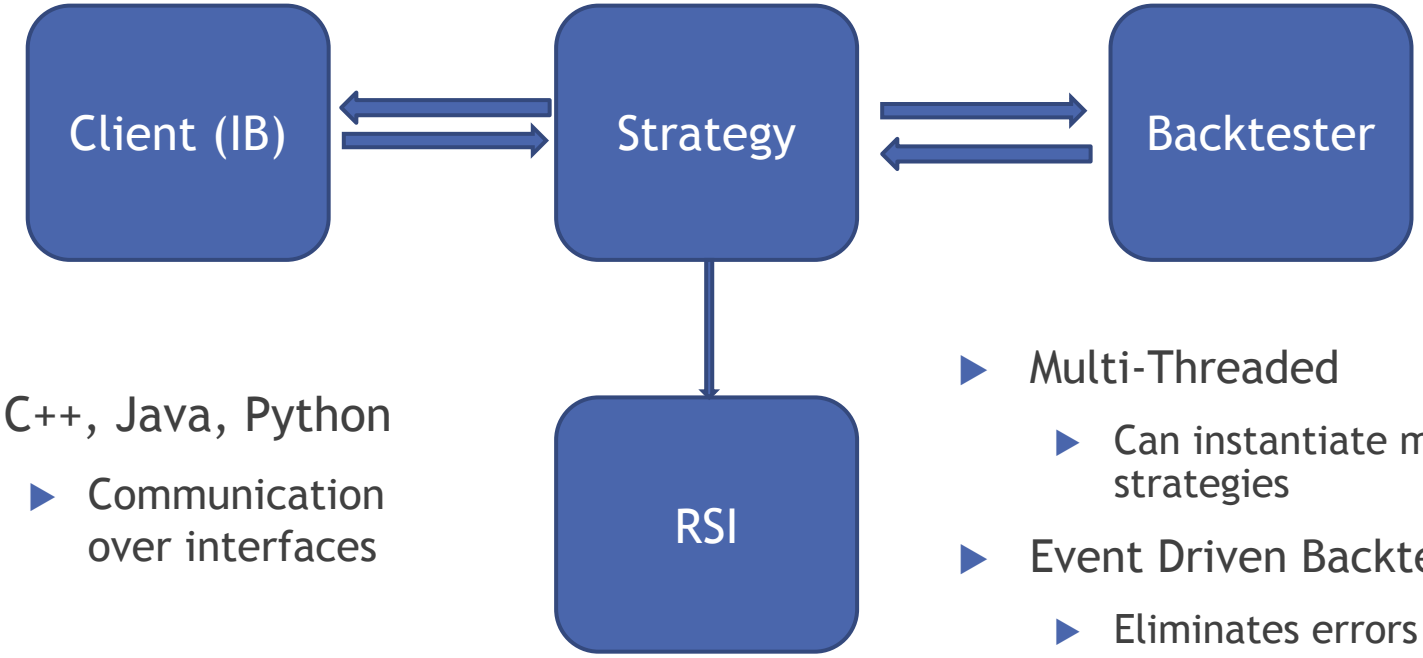
System Architecture Overview



- C++, Java, Python
  - Communication over interfaces

- Multi-Threaded
  - Can instantiate multiple strategies
- Event Driven Backtester
  - Eliminates errors
- Can use the same strategy for trading and backtesting

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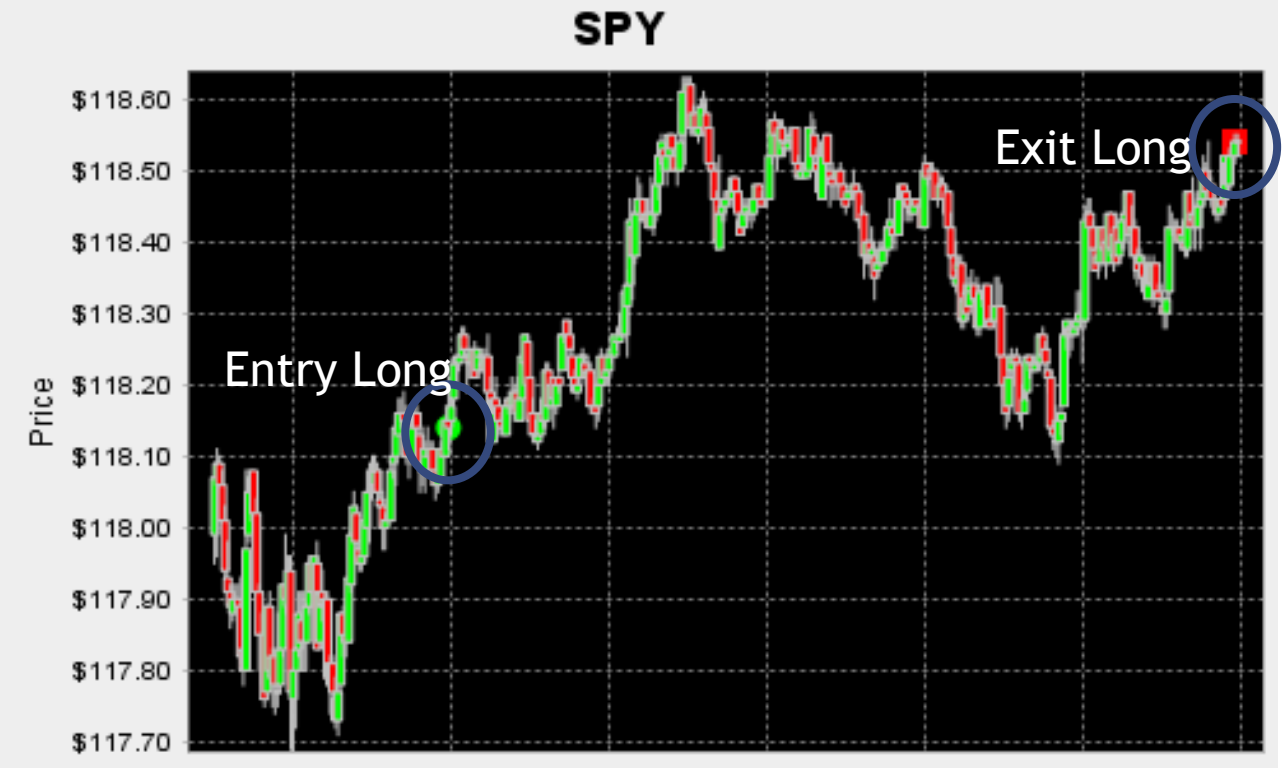
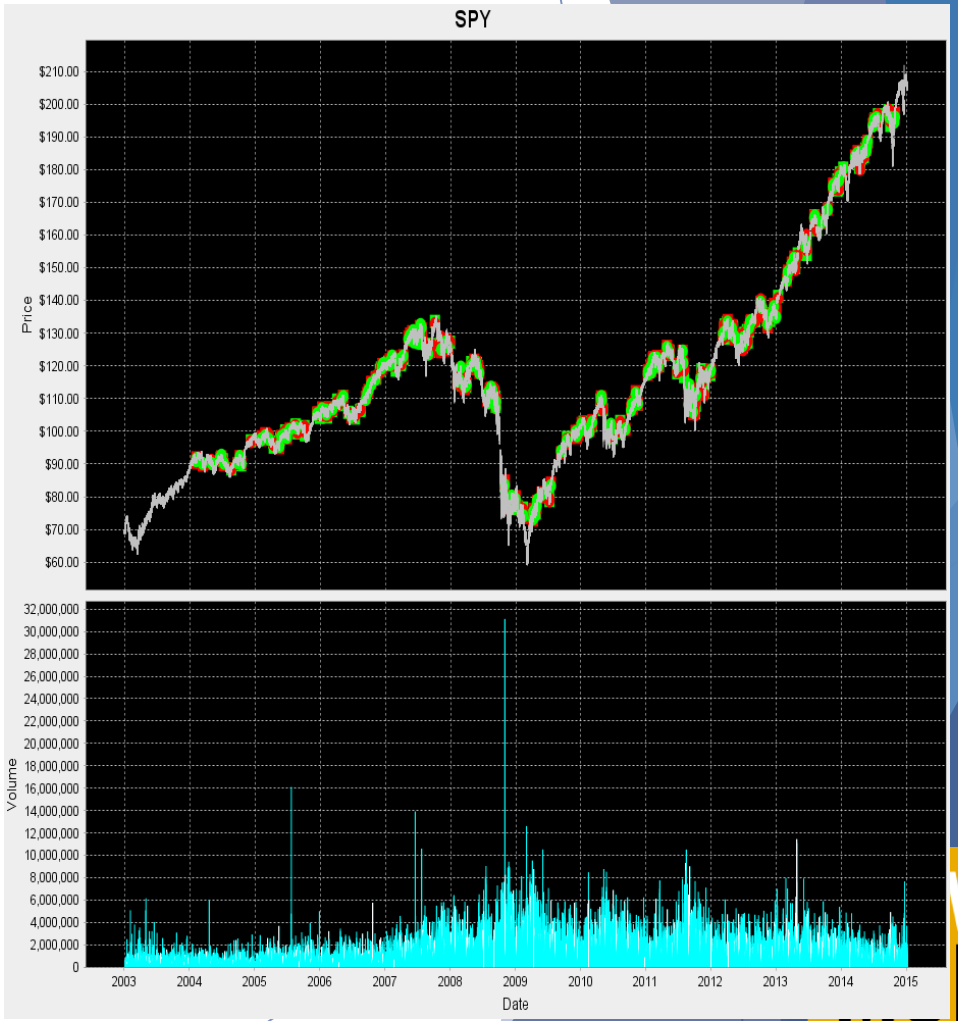
Visualizing an Intraday Strategy





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

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Questions?

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

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Appendix

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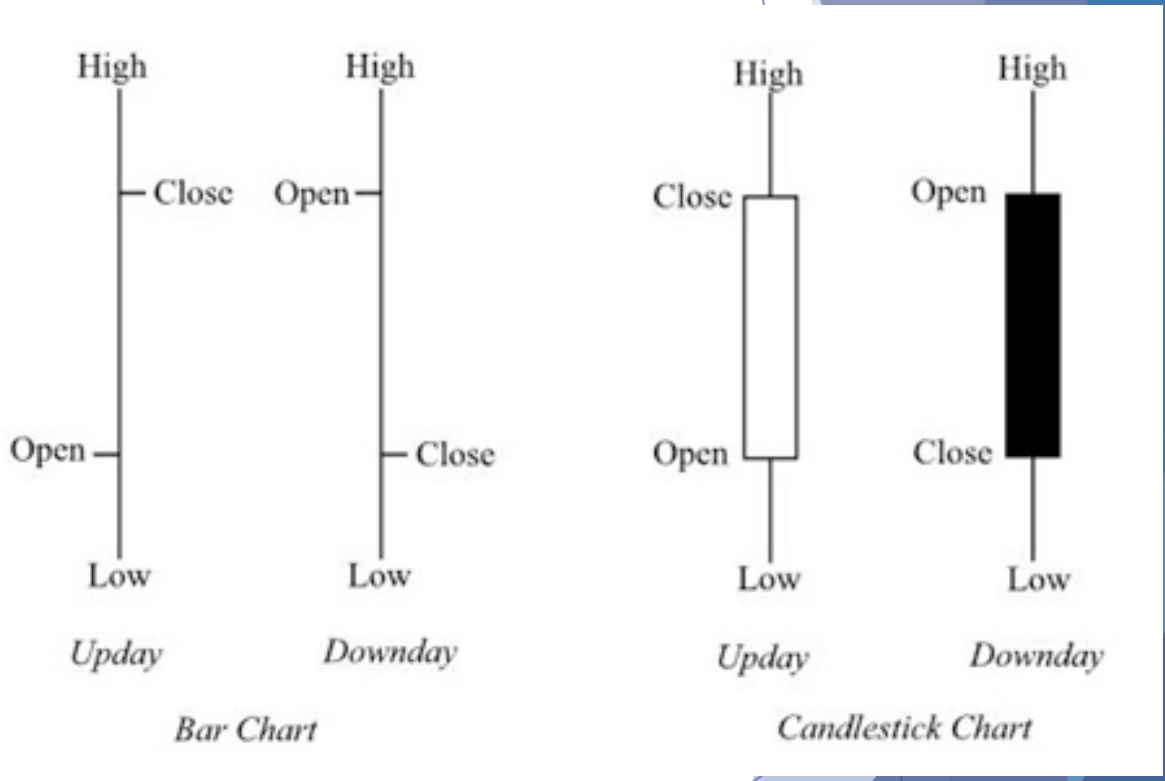
Appendix: Candlestick/Bar Data

- 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

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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

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

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

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

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

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Appendix: Sharpe Ratio

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

$$r_p = portfolio\ return$$

$$r_f = risk\ free\ rate$$

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

- Developed by William F. Sharpe
- Measures risk adjusted performance
  - Risk vs. Reward
- Higher is usually better
- Usually annualized
  - Adjust portfolio returns to a daily basis, average the returns and multiply by $\sqrt{252}$

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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!!!!!

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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)

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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

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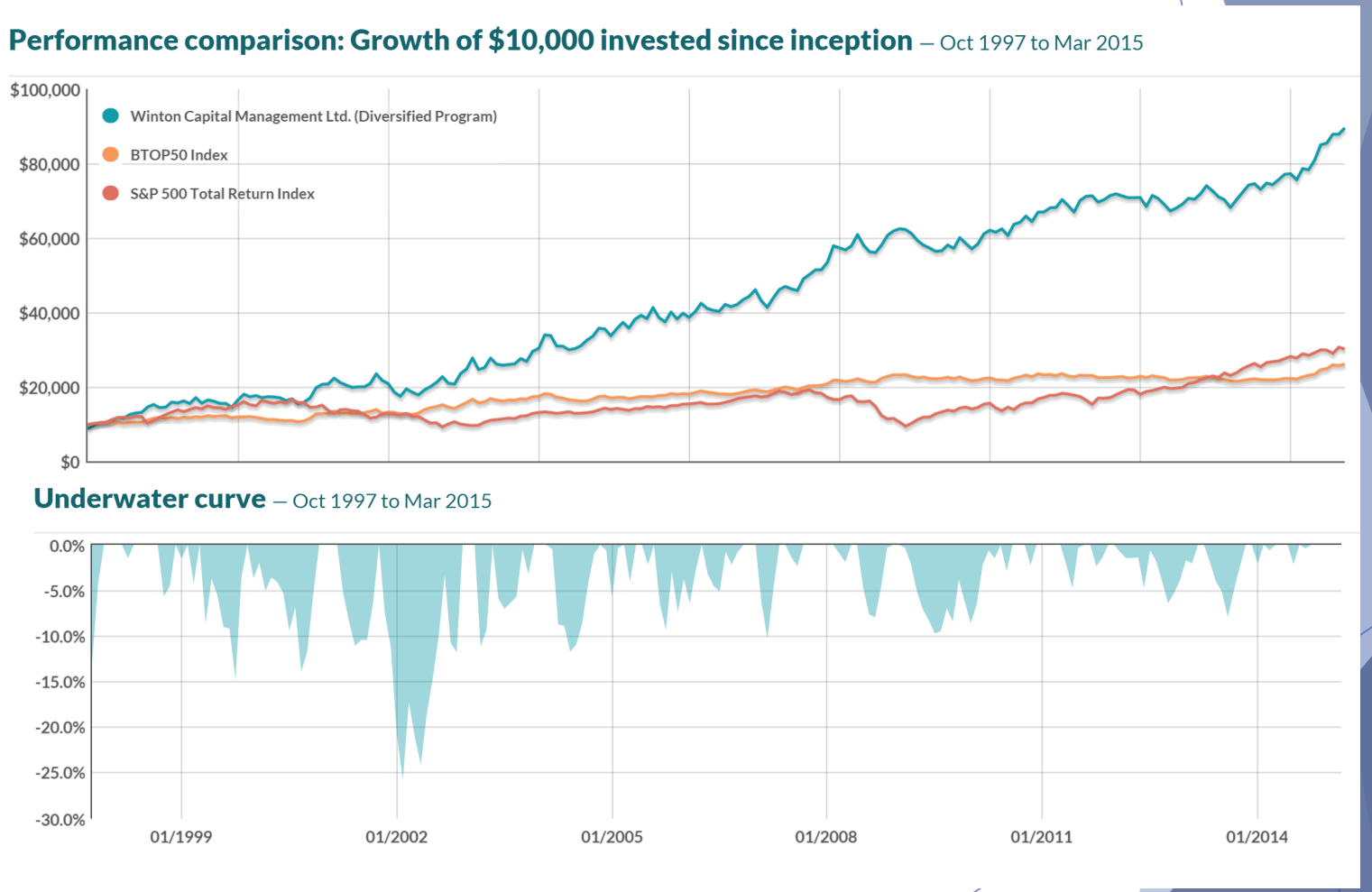
Appendix: Underwater Curve

- 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

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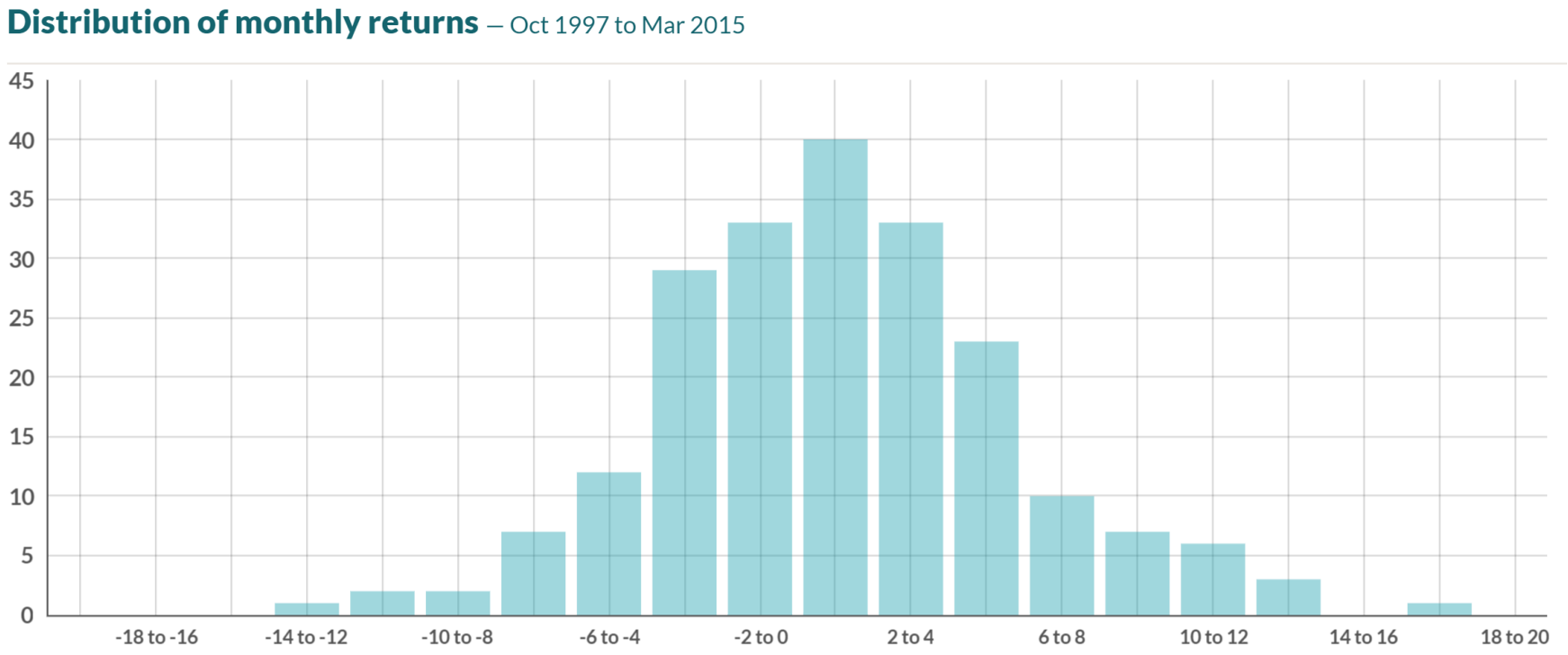
Appendix: Distribution of Returns



http://ctaperformance.com/wntn

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

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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

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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

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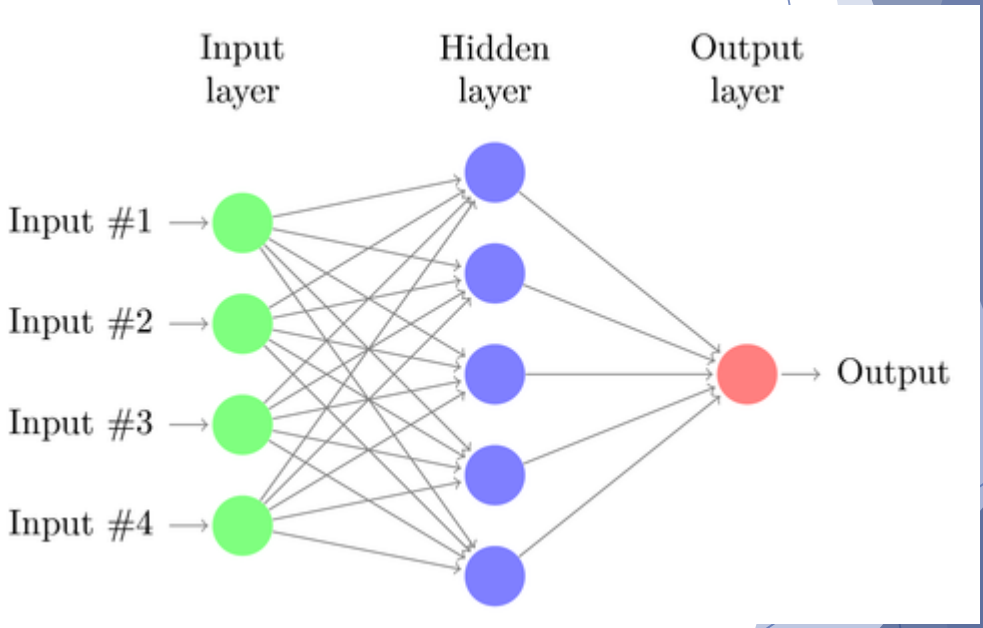
Appendix: Machine Learning

- Neural Networks (with and without reinforcement), support vector machines, clustering, Bayesian networks…
- Garbage in == Garbage out
  - You cannot expect this tool to give you good results from nothing
- You are data mining!
  - Be careful of over-fitting data
  - Be sure to test, in-sample, out-of-sample and out-out-of-sample



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Appendix: RSI
Relative Strength Index

- Momentum indicator
- Compares recent gains to recent losses to determine oversold and overbought conditions

$$RSI(N) = 100 - \frac{100}{1 + RS(N)}$$

$$RS(N) = \frac{Average\ Gains\ last\ N}{Average\ Losses\ last\ N}$$

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