

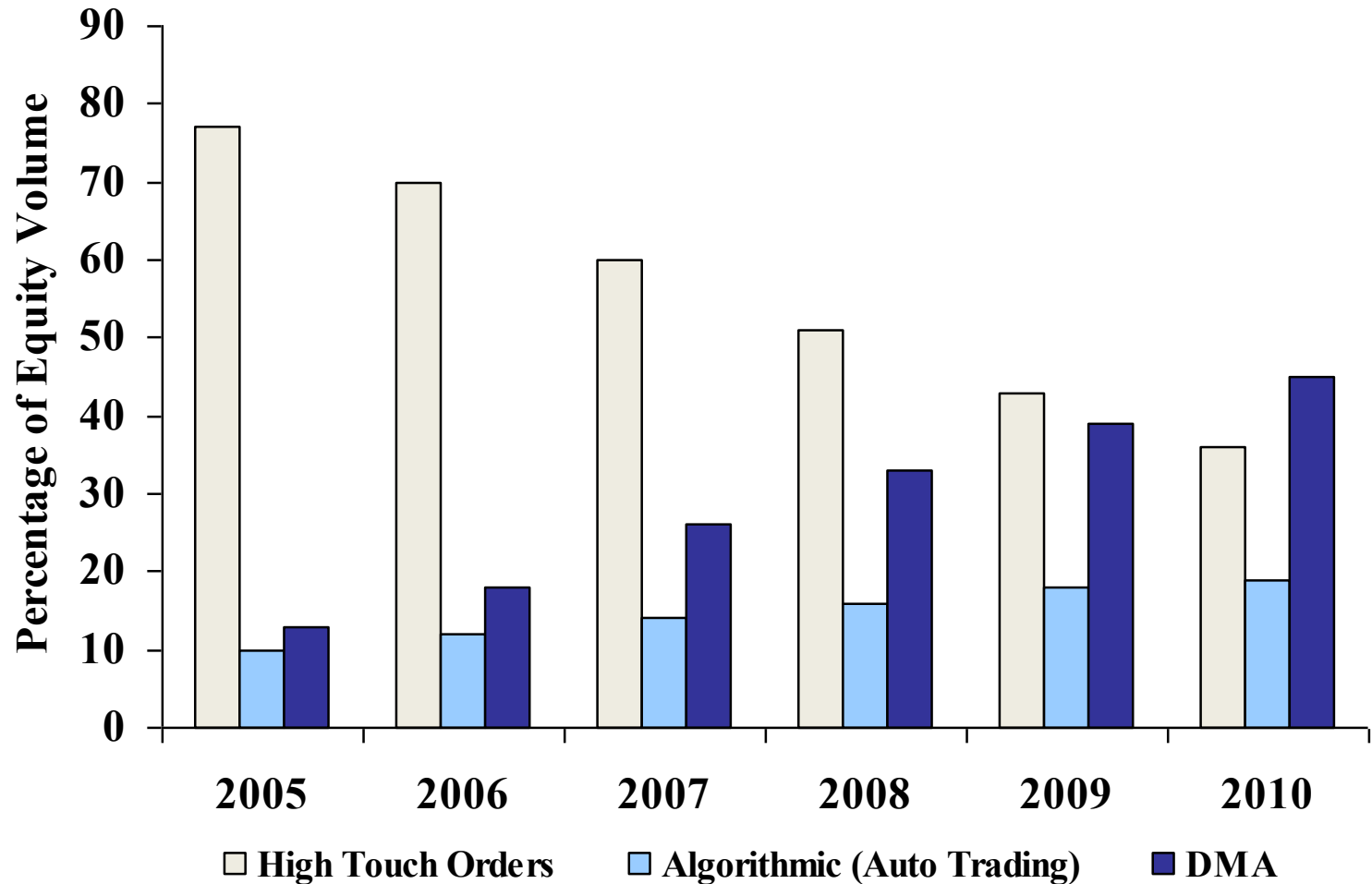
# Algorithmic and High-frequency trading: an overview

Marco Avellaneda

New York University &  
Finance Concepts LLC

ICBI Global Derivatives, April 11 2010

# US Equities markets: percentage of orders generated by algorithms



# The market in numbers

- US Equities volumes: 5 and 10 billion shares per day
- **1.2 – 2.5 Trillion shares per year**
- **Annual volume: USD 30 – 70 trillion**
- At least 30% of the volume is algorithmic: 360 a 750 billion shares/year
- Typical large “sell side” broker trades between 1 and 5 USD Tri per year using algos
- Each day, between 15,000 and 3,000 orders are processed
- An algorithmic execution strategy can be divided into 500 – 1,000 small daughter orders

# Algorithmic trading

- **Algorithmic trading:** the use of programs and computers to generate and execute (large) orders in markets with electronic access.
- Orders come from institutional investors, hedge funds and Wall Street trading desks
- The main objective of algo trading is not necessarily to maximize profits but rather to control execution costs and market risk.
- Algorithms started as tools for institutional investors in the beginning of the 1990s. Decimalization, direct market access (DMA), 100% electronic exchanges, reduction of commissions and exchange fees, rebates, the creation of new markets aside from NYSE and NASDAQ and **Reg NMS** led to an explosion of algorithmic trading and the beginning of the decade.

Today, brokers compete actively for the commission pool associated with algorithmic trading around the globe – a business estimated at USD 400 to 600 million per year.

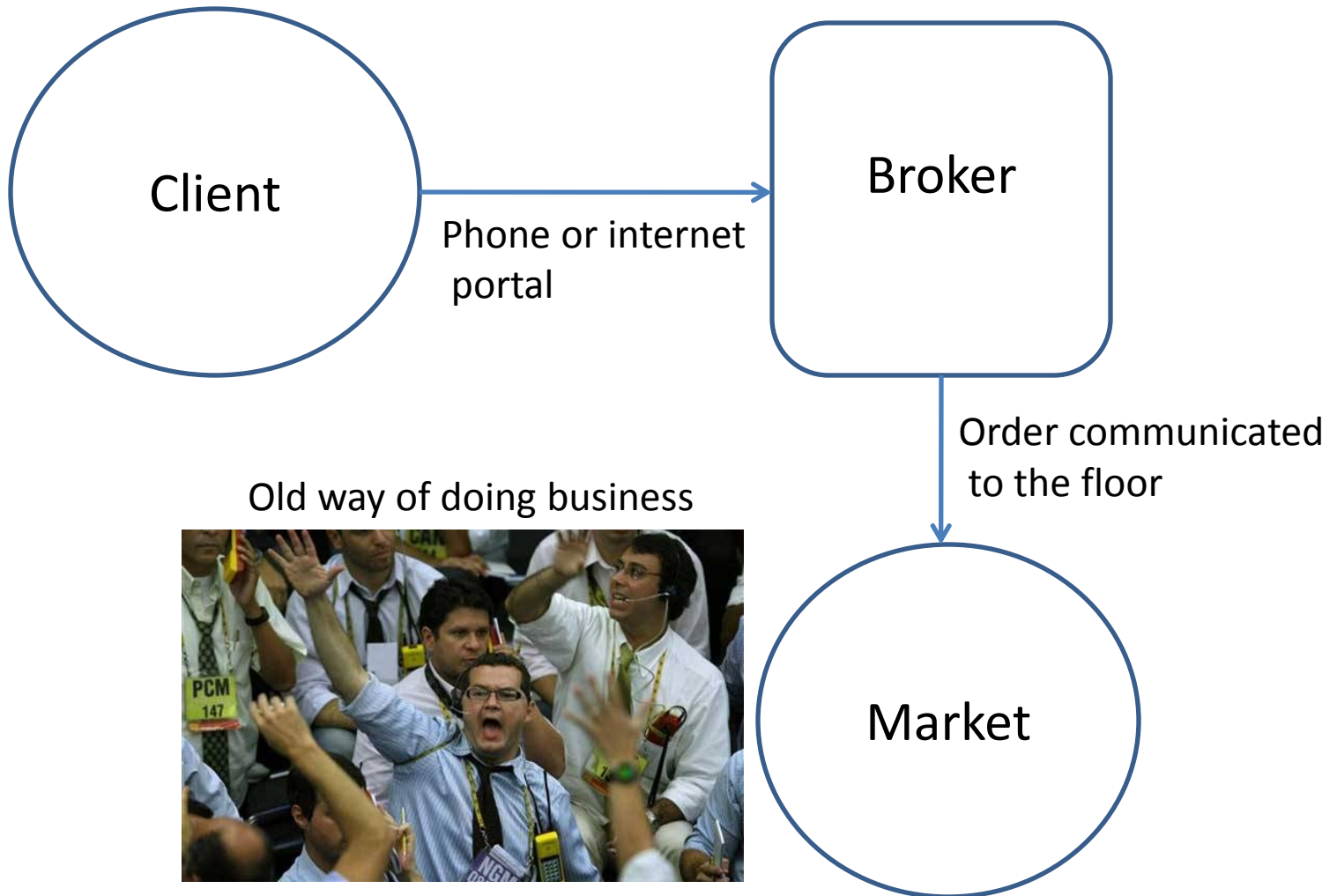
# Why Algorithms?

- Institutional clients need to trade large amounts of stocks . These amounts are often larger than what the market can absorb without impacting the price.
- The demand for a large amount of liquidity will typically affect the cost of the trade in a negative fashion (``slippage’’)
- Large orders need to be split into smaller orders which will be executed electronically over the course of minutes, hours, day.
- The procedure for executing this order will affect the average cost per share, according to which algorithm is used.
- In order to evaluate an algorithm, we should compare the average price obtained by trading with a market benchmark (``global average’’ of the daily price, closing price, opening price, ``alpha decay’’ of a quant strategy, etc).

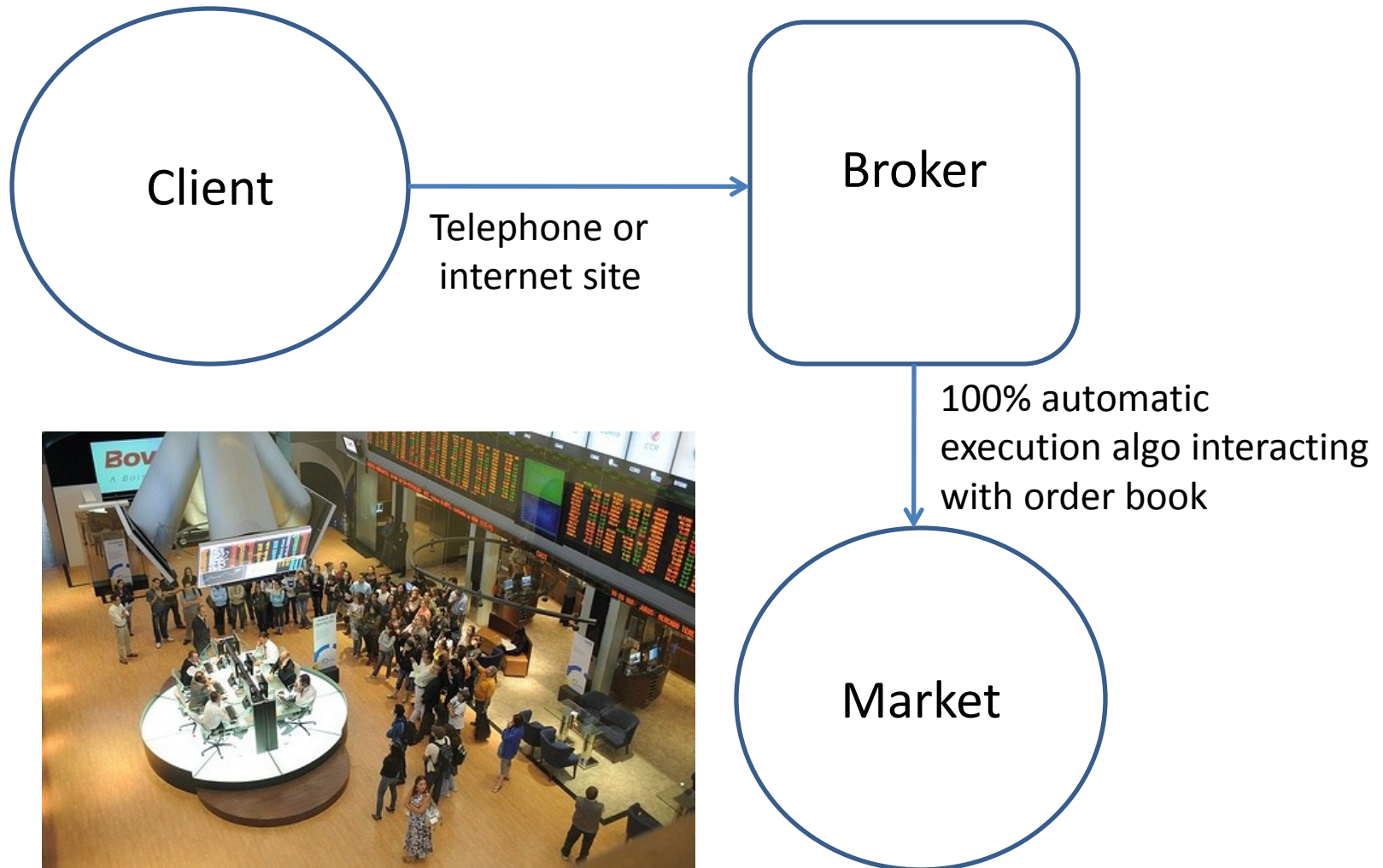
# Main issues in Algorithmic Trading

- The decision of how to split the order in smaller pieces is just one of several issues.
- Once an algo is chosen the smaller orders need to be executed electronically
- Execution strategies interact with the market and decide how to place orders (Limit, Market, etc) and at what prices
- Objective: to achieve the “best price” for each daughter order
- Recent changes in the US equity market structure (in particular, different liquidity sources) make things more interesting and complicated
- Dark Pools (liquidity pools that do not show the order book), ECNs (electronic communications networks), autonomous liquidity providers

# 1. “Ancient” brokerage model



## 2. Electronic market





# Electronic order-management and execution system (client-broker)

Simulated Trading - Interactive Brokers Trader Workstation - DU60008

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Portfolio Untitled Pending (All)

Select Account DU60008

Market Value

Currency	Cash	Stock	Options	Futures	FOPs	Net Liquidation Value	Unrealized P&L	Realized P&L
USD	10,510,613.92	73,361.75	0.00	0.00	0.00	10,582,651.15	-11,874.49	0.00

Order Management

Show zero position rows Show orders and trades for all accounts

Underlying	Exchange	Description	Position	Avg Price	Market Value	P&L	Unrealized P&L	Realized P&L	Bid Size	Bid	Ask	Ask Size	Last	Change
			Allocation	Method	Pct. Change	Time in Force	Action	Quantity	Type	Lmt Price	Destination	Status		
TOTAL	DU60008	USD			73384.76		-11851.26							
XLK	SMART	Stock (ARCA)	12,709	21.5404	276,293.66	0.00	2536.72						C21.74	
RTH	SMART	Stock (ARCA)	1,361	92.465	125,878.69	0.00	34.82						C92.49	
OIH	SMART	Stock (ARCA)	1,000	101.307	107,140.00	0.00	5833.00						C107.14	
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PBI	SMART	Stock (NYSE)	4,356	19.365	87,655.60	0.00	3201.66						C20.10	
PEP	SMART	Stock (NYSE)	1,311	64.245	87,063.51	0.00	2838.31						C66.41	
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VFC	SMART	Stock (NYSE)	1,132	74.5532	85,477.32	0.00	1083.10						C75.51	
BHI	SMART	Stock (NYSE)	2,162	39.205	85,161.18	0.00	399.97						C39.39	
MSFT	SMART	Stock (NASDAQ.NMS)	3,555	23.825	84,786.75	0.00	88.88						C23.85	
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MAR	SMART	Stock (NYSE)	0.17	22.0667	6.07	0.00	2.30						C35.51	
SWK	SMART	Stock (NYSE)	0.10	0.534	5.93	0.00	5.88						C59.29	
XLE	SMART	Stock (ARCA)	-885	54.505	-48,250.20	0.00	-13.28						C54.52	
APH	SMART	Stock (NYSE)	-1,830	46.345	-83,942.10	0.00	869.25						C45.87	
DISH	SMART	Stock (NASDAQ.NMS)	-4,524	18.705	-84,372.60	0.00	248.82						C18.65	
FIS	SMART	Stock (NYSE)	-3,085	27.445	-84,436.45	0.00	231.38						C27.37	
ORCL	SMART	Stock (NASDAQ.NMS)	-3,378	25.055	-84,618.90	0.00	16.89						C25.05	
CA	SMART	Stock (NASDAQ.NMS)	-4,279	19.775	-84,638.62	0.00	-21.40						C19.78	
BBBY	SMART	Stock (NASDAQ.NMS)	-2,102	40.275	-84,815.70	0.00	-157.65						C40.35	
MOT	SMART	Stock (NYSE)	-10,752	7.855	-85,155.84	0.00	-698.88						C7.92	
EP	SMART	Stock (NYSE)	-7,003	12.065	-85,296.54	0.00	-805.35						C12.18	
NOV	SMART	Stock (NYSE)	-2,099	40.365	-86,268.90	0.00	-1542.76						C41.10	

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Market data 13:41:03

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**Portfolio** **Untitled** **Pending (All)**

Select Account DU60008

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**Order Preview**

**Order Description**

BUY 1,000 XLK Stock (ARCA)  
(TECHNOLOGY SELECT SECT SPDR)

Order Type LMT Routing SMART Time in Force DAY Account DU60008  
Limit Price 21.74 Origin Customer

**Current Price**

Bid	Ask	Last
		C21.74

**Amount**

Amount	Margin Impact
21,740 USD	Initial Margin 1,393,528.19
Commission (est.) 5 USD	Maintenance Margin 1,393,528.19
Total 21,745 USD	Equity With Loan 10,582,646.15

Transmit Close

**Order Wizard**

TECHNOLOGY SELECT SECT SPDR (XLK) Stock  
BUY 1,000 LMT 21.74

**Basic**

Action Set Action to: BUY or SELL

Quantity Enter Quantity 1,000

Day (DAY)

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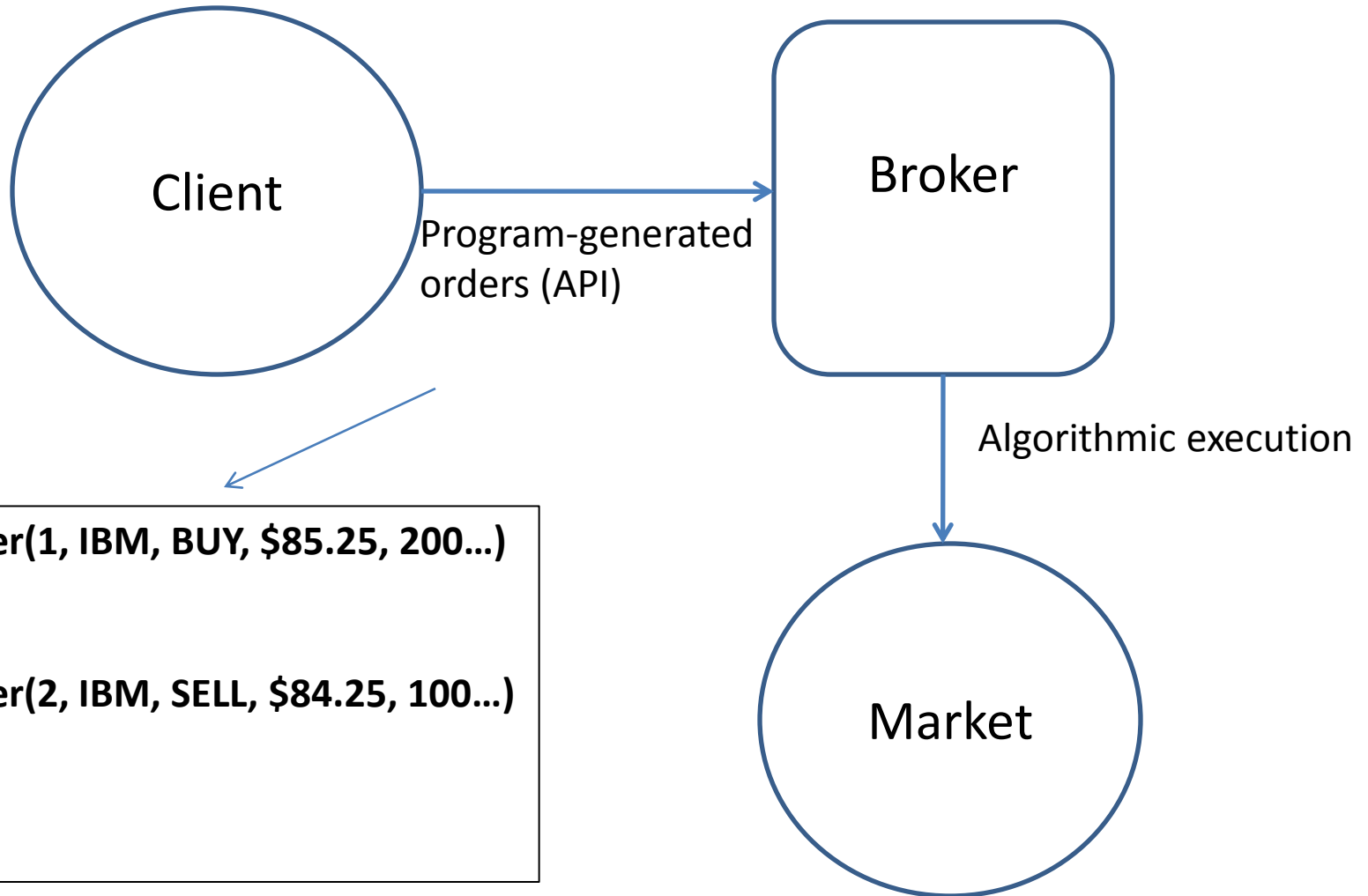
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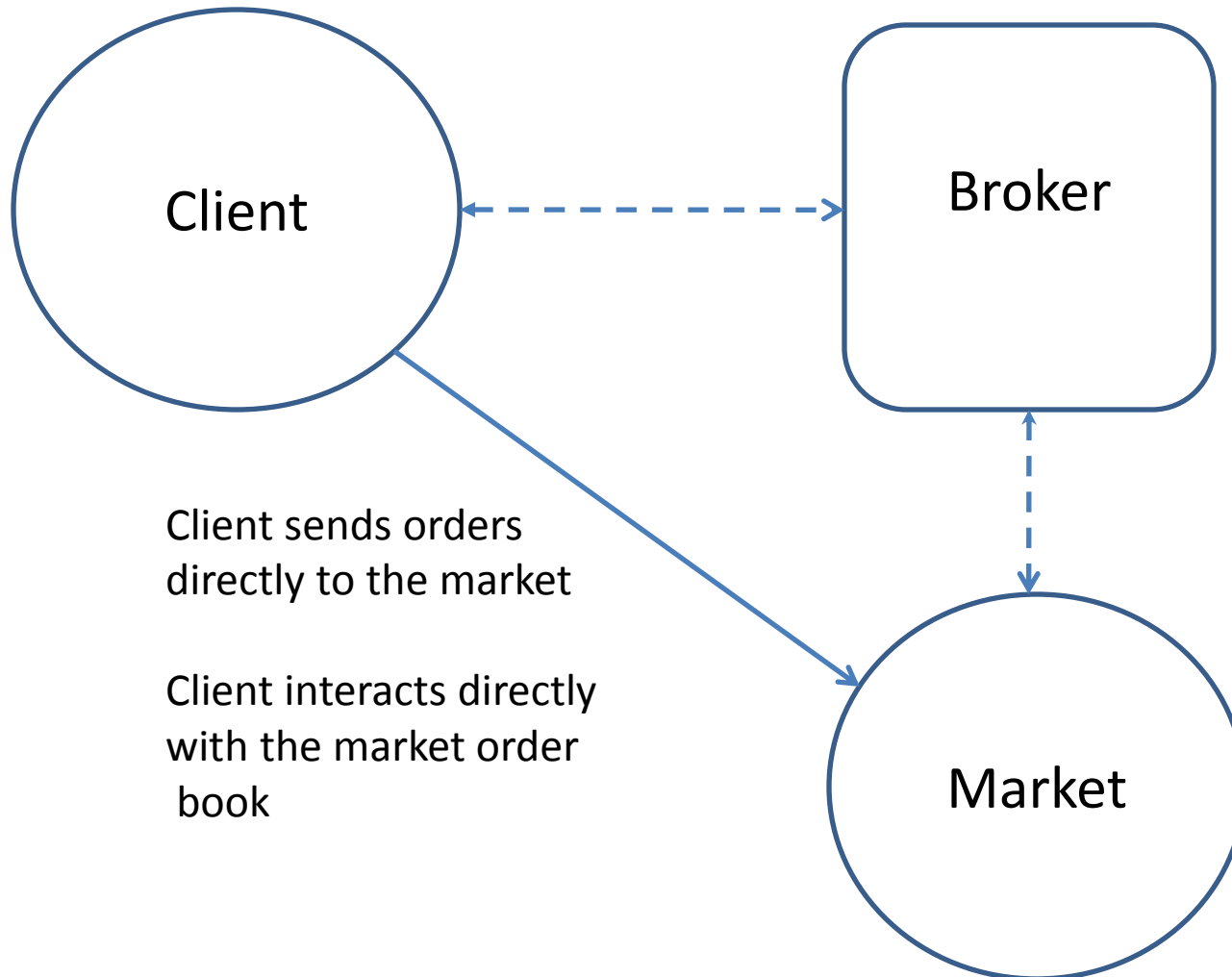
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Client builds an order ticket which is communicated to the broker that executes it accordingly

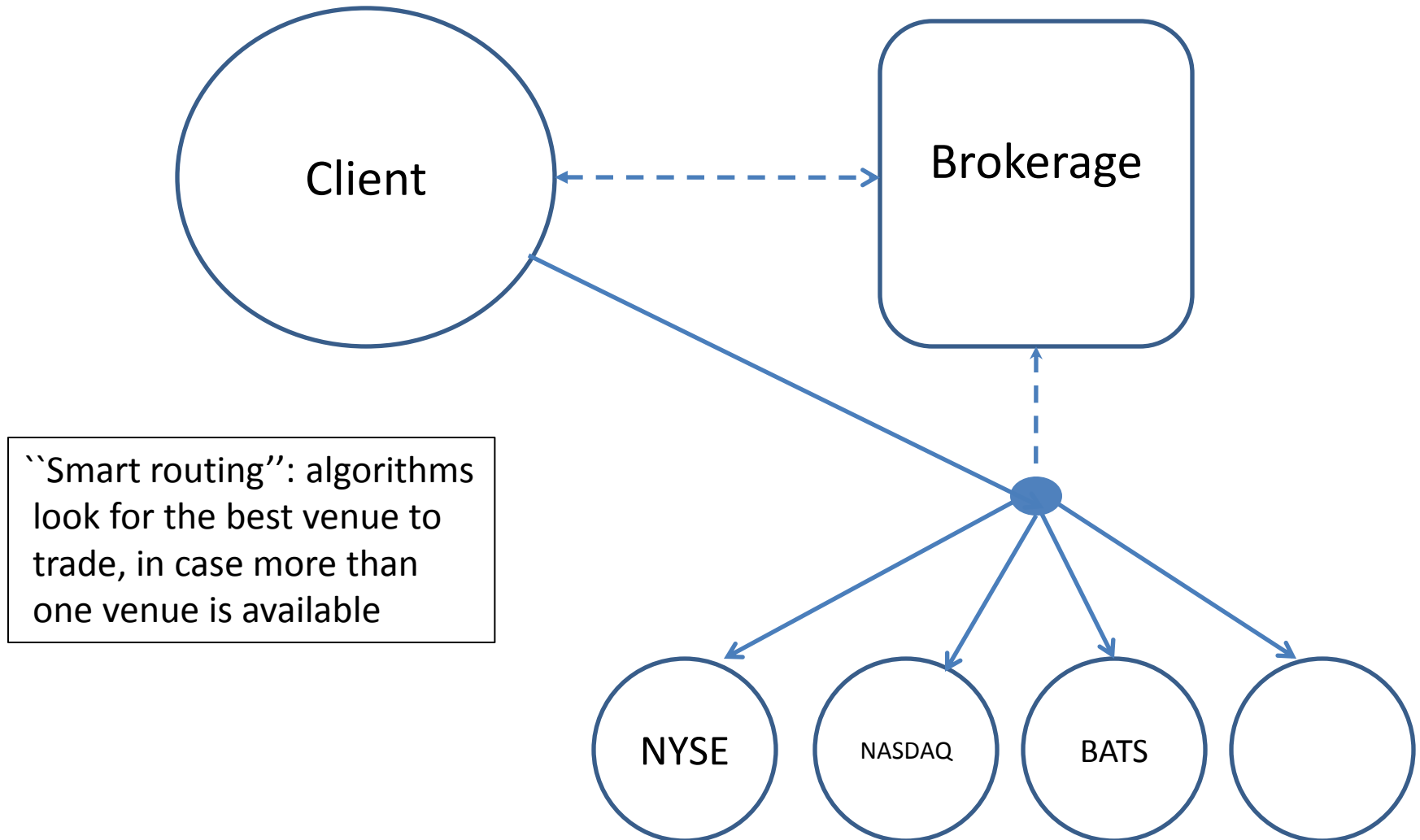
### 3. Electronic execution model with API



## 4. Direct Market Access (DMA)



# ECNs, Dark Pools, Multiple Execution Venues



# A few trading venues for US equity markets

- ARCA-NYSE: electronic platform of NYSE (ex- Archipelago)
- BATS: (Kansas)
- BEX: Boston Equity Exchange
- CBSX: CBOE Stock Exchange
- CSXZ: Chicago Stock Exchange
- DRCTEDGE: Direct Edge (Jersey City, NJ)
- ISE: International Securities Exchange
- ISLAND: Acquired by Nasdaq in 2003
- LAVA: belongs to Citigroup
- NSX: National Stock Exchange (Chicago)
- NYSE: New York Stock Exchange
- TRACKECN: Track ECN

# Reg NMS (``National market system'')

**Order Protection Rule (Trade-thru rule)** - protects visible liquidity at the top of book of automated market centers (SROs + ADF participants) from being traded through by executions outside each market's BBO.

**Access Rule** - caps access fees for top of book access at \$.003

**Sub-Penny Rule** - prohibits market centers from accepting quotes or orders in fractions under \$.01 for any security priced greater than \$1.00.

**Market Data Rule** - changes the allocation of market data revenue to SROs for quotes and trades

SRO: NYSE, NASD, FINRA

ADF: Alternative Display Facility/ consolidation of NYSE/NASDAQ

# The three steps in algorithmic trading

Algorithmic trading strategy  
(Macrotrader)

Order placing algorithms  
(Microtrader)

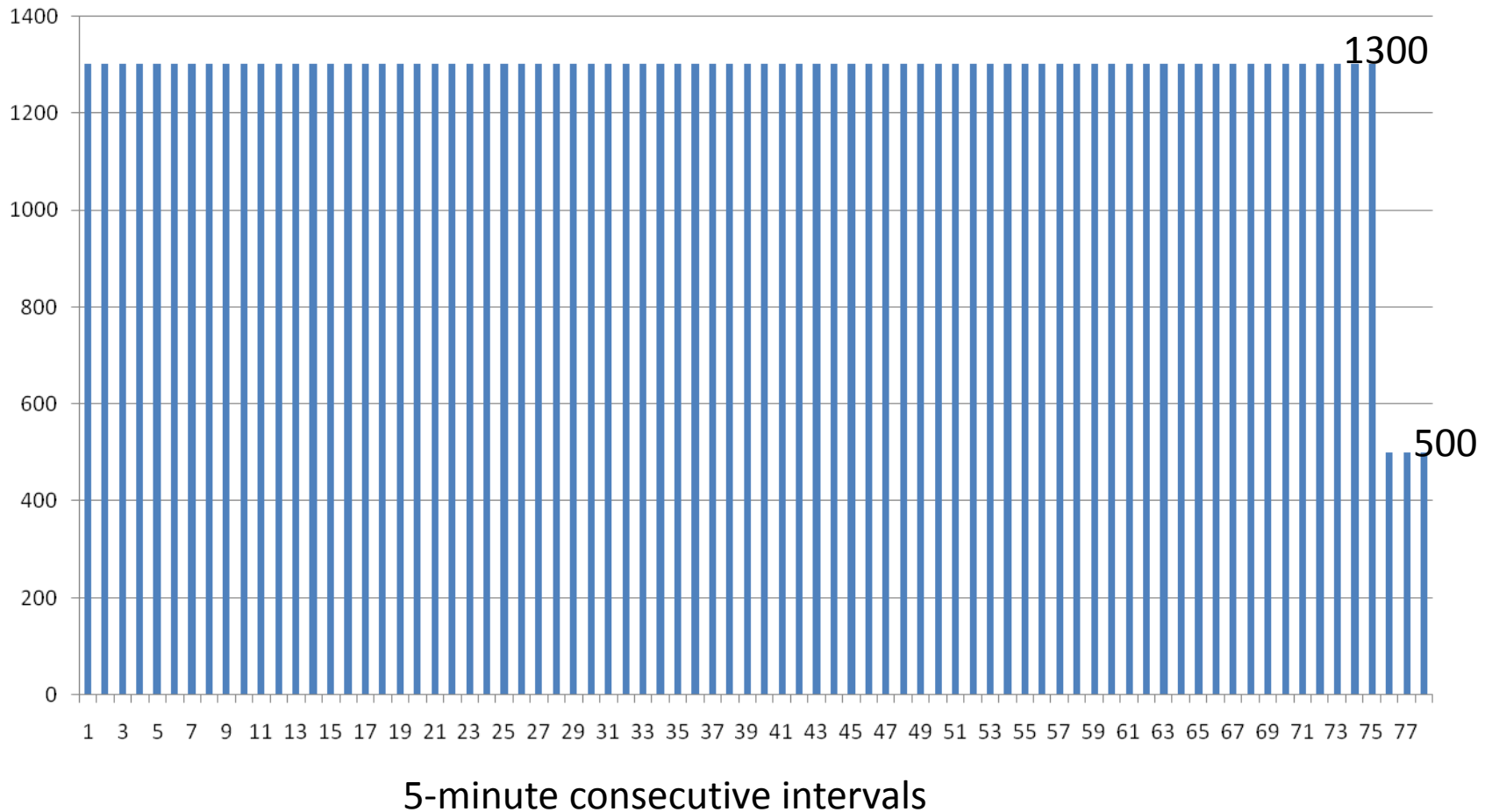
Smart routing in case of more than one available  
Trading venue



# Time-weighted average price (TWAP)

Equal amount of shares in each period of time.

Example: 100,000 shares TWAP/all day





Volume is greater in the beginning and at the end of the day

# Volume-weighted average price (VWAP)

Volume changes in the course of the day (less volume in the middle).

VWAP: To execute a large order, the way in which we split it depends on the time of day (minimize impact)

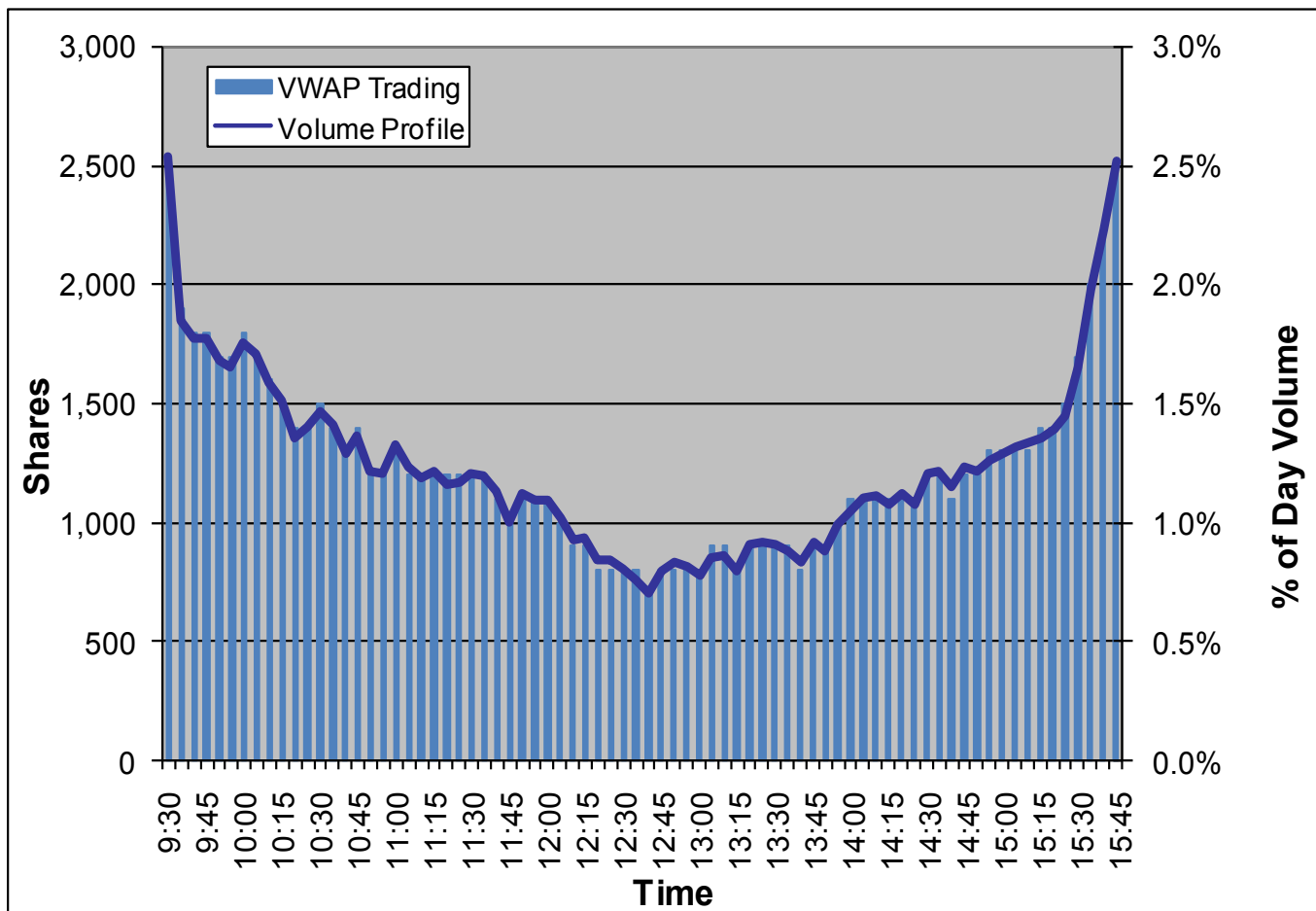
Objective: obtain an average price ``weighted by volume''

Algorithm:

1. estimate the average volume traded in every 5 minute interval
2. In each time-interval, execute an amount proportional to the normative volume for that interval

Properties:

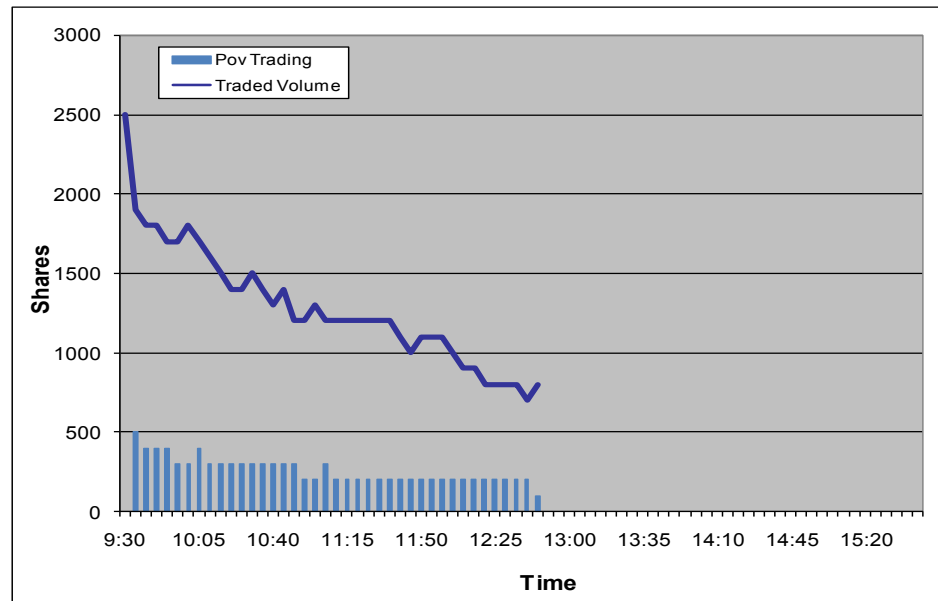
1. the algorithm always concludes (trade sizes are known in advance)
2. volume function is estimated using historical data. This may not correspond exactly to *ex-post* VWAP.



$$VWAP(t_1, t_2) = \frac{\sum_{t=t_1}^{t_2} \delta V(t) P(t)}{\sum_{t=t_1}^{t_2} \delta V(t)}$$

# Percentage of Volume (POV)

- The PoV (Percentage of Volume) algorithm addresses the problem of VWAP by using the actual traded volume of the day as benchmark. The idea is to have a constant percentage participation in the market along the trading period.
- If the quantity that remains to be traded is  $Q$ , and the participation ratio is  $\gamma$ , the algo computes the volume  $V$  traded in the period  $(t - \Delta T, t)$  and executes a quantity  $q = \min(Q, V * \gamma)$



$V(t)$  = total volume traded in the market up to time  $t$

$Q(t)$  = number of shares that remain to be traded. ( $Q(0)$  = initial quantity)

$$Q(t + \delta t) - Q(t) = -\min[\gamma(V(t) - V(t - \delta t)), Q(t)]$$

$$\begin{cases} \frac{dQ}{dt} = -\gamma \frac{dV}{dt} & ; Q(t) > \gamma \frac{dV}{dt} \delta t \approx 0 \\ \frac{dQ}{dt} = 0 & ; Q(t) \leq \gamma \frac{dV}{dt} \delta t \approx 0 \end{cases}$$

$$\frac{dQ}{dt} = -\gamma \frac{dV}{dt} \quad \therefore Q(T) - Q(0) = -\gamma \cdot V(T) \quad \therefore Q(0) = \gamma \cdot V(T)$$

$$\frac{dQ}{dt} p(t) = -\gamma \frac{dV}{dt} p(t) \quad \therefore \int_0^T \left| \frac{dQ}{dt} \right| p(t) = \gamma \int_0^T \frac{dV}{dt} p(t)$$

$$\frac{\int_0^T \left| \frac{dQ}{dt} \right| p(t)}{Q(0)} = \frac{\int_0^T \frac{dV}{dt} p(t)}{V(T)}$$

POV is similar to  
WVAP if ratio is small

(Or is it? More later 😊)

# Almgren-Chriss (``Expected Shortfall'')

Market impact combined with ``urgency in execution'' (price risk)

$$dp(t) = -\underline{av(t)}dt + \sigma dZ(t) \quad v(t) = -\frac{dQ(t)}{dt}$$

Dynamic price model with price impact (``permanent impact')

$$\underline{\bar{p}(t)} = p(t) - b|v(t)|$$

Execution price (``temporary impact')

$$E = -\mathbf{E}\left\{\int_0^T \underline{\bar{p}(t)} \frac{dQ(t)}{dt} dt\right\} = -\mathbf{E}\left\{\int_0^T p(t) \frac{dQ(t)}{dt} dt\right\} + b \int_0^T \left(\frac{dQ(t)}{dt}\right)^2 dt$$

Expected execution cost

$$V = \sigma^2 \int_0^T (Q(0) - Q(t))^2 dt$$

Execution risk

$$\min_Q \{E + \lambda V\}$$

Optimization problem

# Analytic solution

$$Q(t) = Q(0) \frac{\sinh\left(\sqrt{\frac{\lambda\sigma^2}{a+b}}(T-t)\right)}{\sinh\left(\sqrt{\frac{\lambda\sigma^2}{a+b}}T\right)}$$

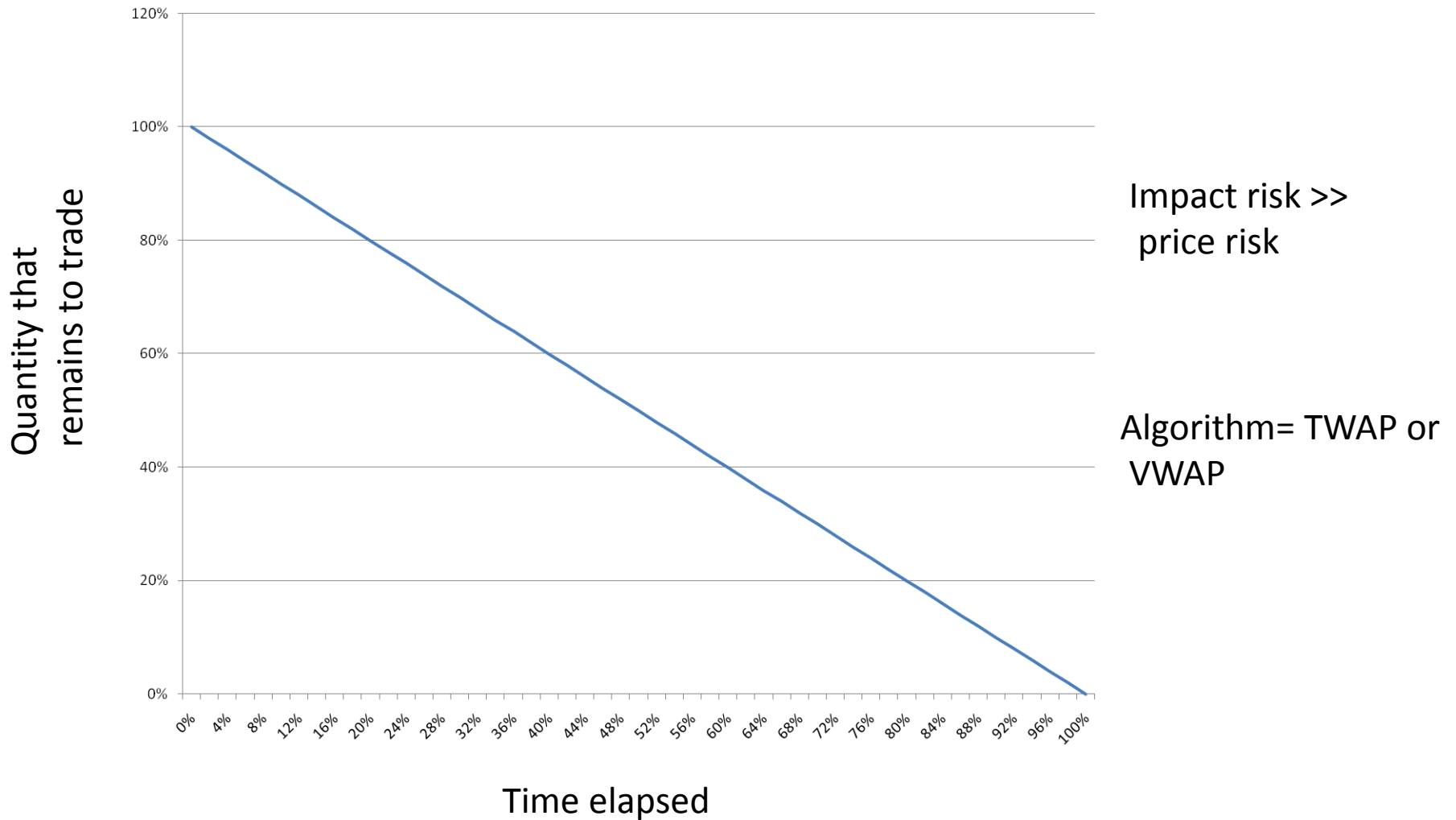
$$\frac{Q(t)}{Q(0)} = \frac{\sinh(\Omega(1-\tau))}{\sinh \Omega}, \quad \Omega = T\sqrt{\frac{\lambda\sigma^2}{a+b}}, \quad \tau = \frac{t}{T}$$

Omega: proportional to execution time, varies directly with risk-aversion and volatility, inversely to market impact elasticities

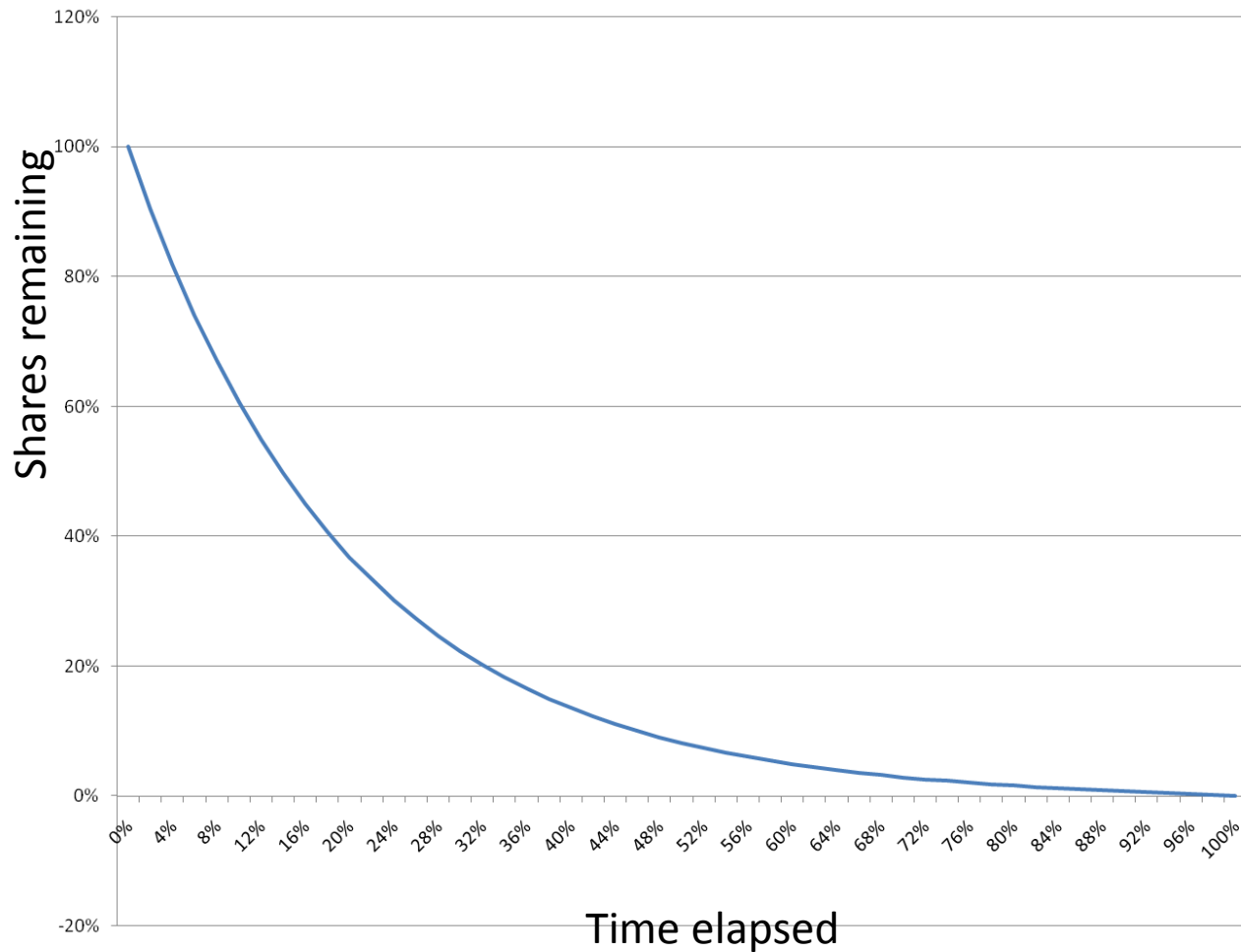
$$\Omega = (\text{price risk})/(\text{impact risk})$$



# Case $\Omega = 0$ , TWAP (VWAP)



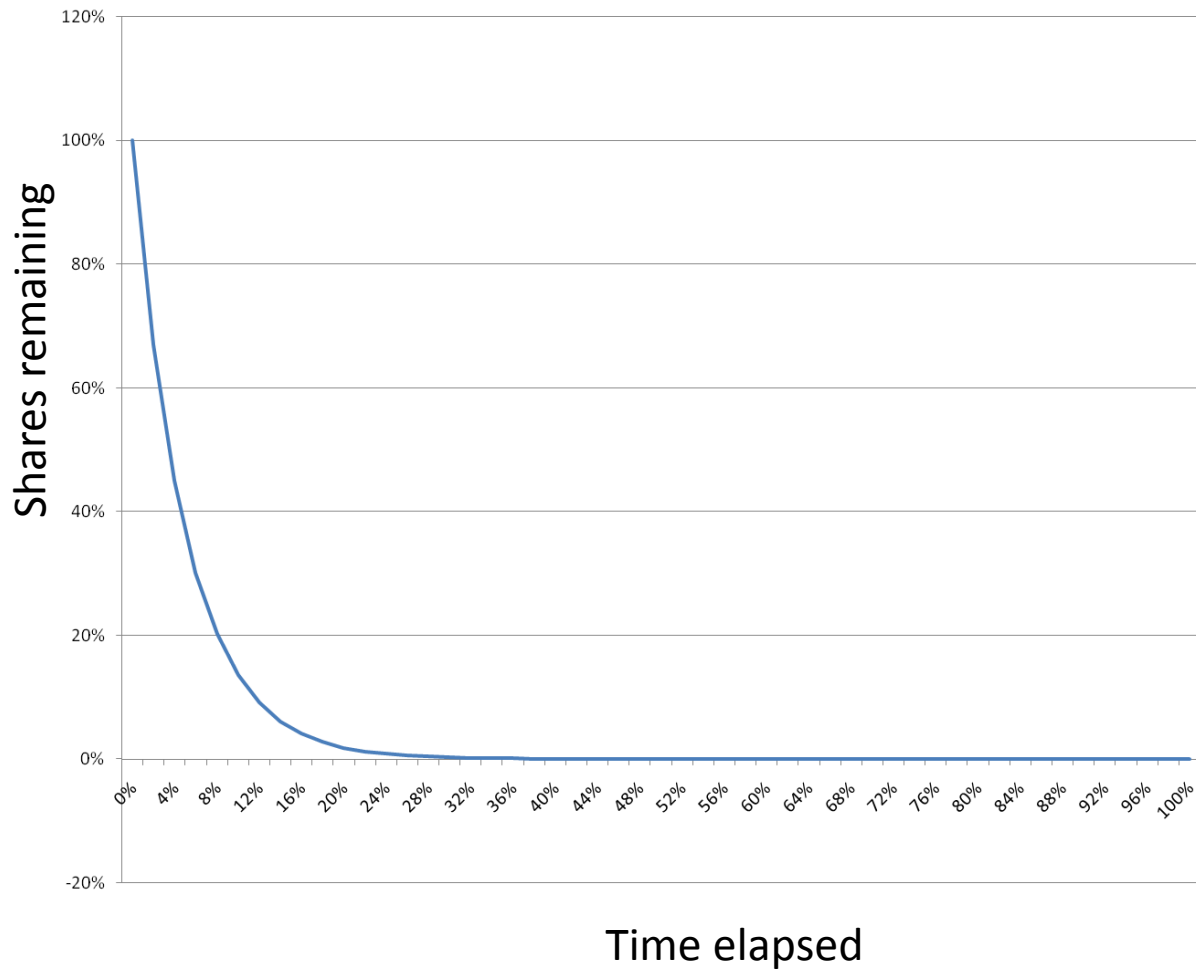
# Case $\Omega = 10$



Significant market risk

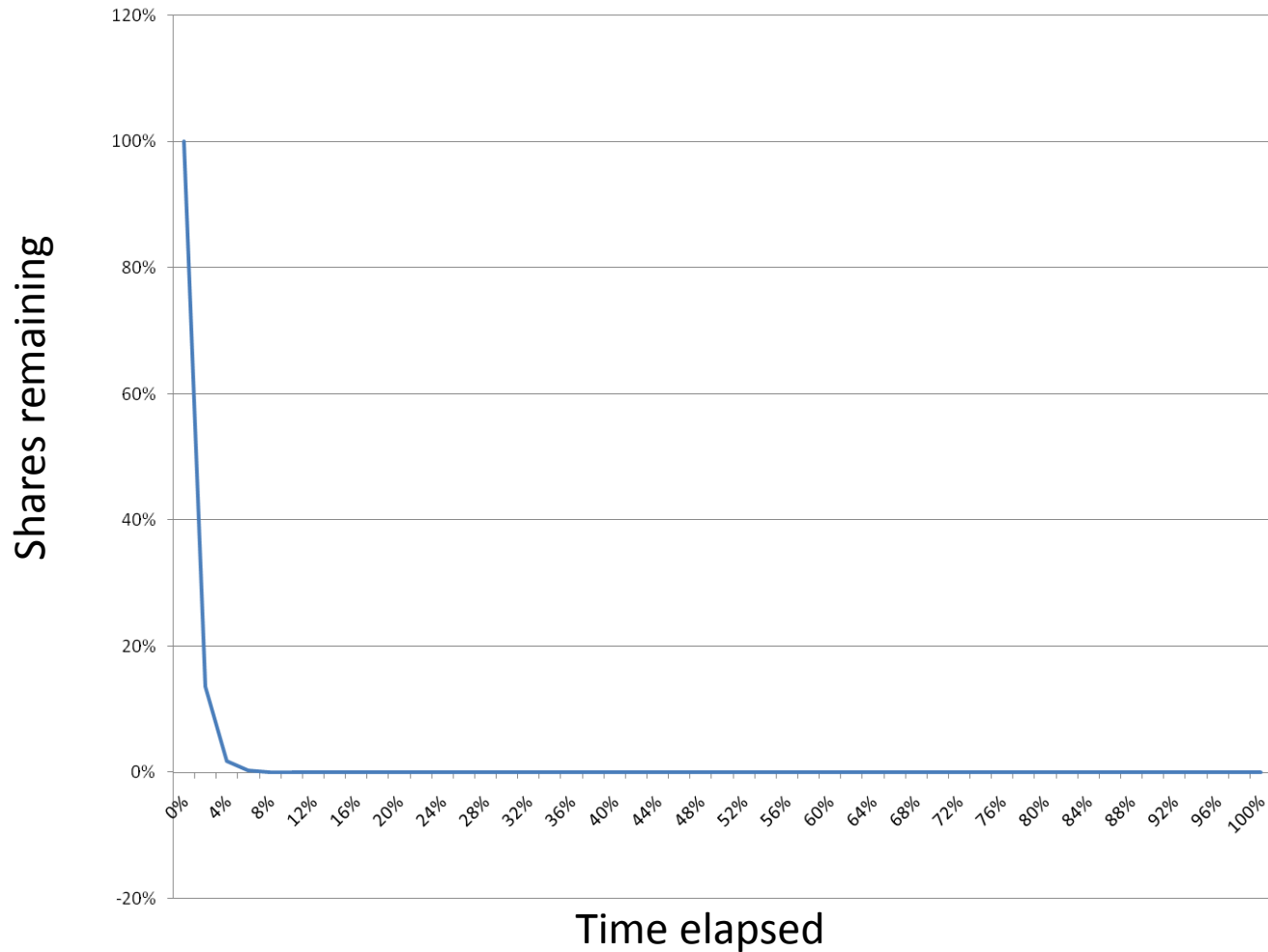
Execution must be faster

# Case $\Omega = 20$



Faster execution

# Case $\Omega = 100$



“Slam” the market!

# Generalizations of Almgren-Chriss order-splitting algorithm

- Incorporate intraday volume in the impact model (modification of VWAP)
- Incorporate drift in the price model (momentum)
- Incorporate exchange fees, rebates and other costs
- Almgren-Chriss & generalizations are now part of the standard toolkit that execution brokers offer to clients

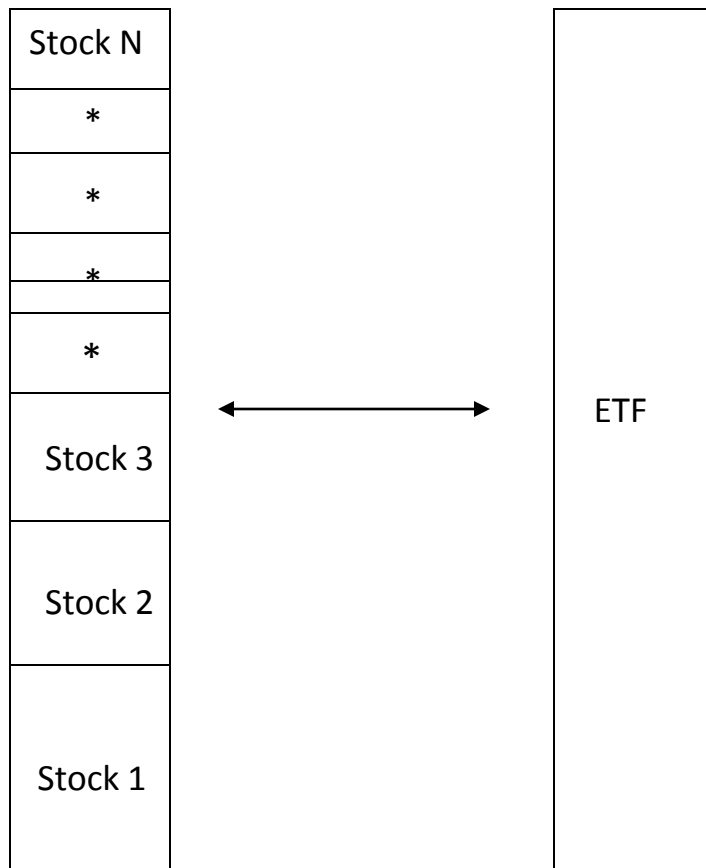
# Examples of quant strategies that make use of algorithms

- Index and ETF arbitrage
- Statistical arbitrage (“Stat Arb”)
- Liquidity providing (“Market making”)
- Volume providing (“High-frequency, selective, market-making”)
- High frequency trading and price forecasting

# ETFs

- ETF: similar to mutual funds (holding vehicles) but which trade like stocks
- Short-selling, margin financing allowed.
- Began like equity index & basket trackers, then generalized to currencies and commodities
- **Authorized participants** may create or redeem ETF shares at NAV, enforcing the theoretical relationship between the ETF and the underlying basket
- ``creation units``: 25K to 100K shares
- Authorized participants are typically market-makers in the ETFs (but not always).

# Arbitrage of ETFs against the underlying basket



1. Buy/sell ETF  
against the underlying share holdings
2. Creation/redemption of ETFs  
to close the trade

This requires high-frequency algorithmic trading to lock-in arbitrage opportunities



# Statistical Arbitrage

Long-short shares/etfs – market neutral

Sector	ETF	Num of Stocks	Market Cap		
			Average	Max	Min
Internet	HHH	22	10,350	104,500	1,047
Real Estate	IYR	87	4,789	47,030	1,059
Transportation	IYT	46	4,575	49,910	1,089
Oil Exploration	OIH	42	7,059	71,660	1,010
Regional Banks	RKH	69	23,080	271,500	1,037
Retail	RTH	60	13,290	198,200	1,022
Semiconductors	SMH	55	7,303	117,300	1,033
Utilities	UTH	75	7,320	41,890	1,049
Energy	XLE	75	17,800	432,200	1,035
Financial	XLF	210	9,960	187,600	1,000
Industrial	XLI	141	10,770	391,400	1,034
Technology	XLK	158	12,750	293,500	1,008
Consumer Staples	XLP	61	17,730	204,500	1,016
Healthcare	XLV	109	14,390	192,500	1,025
Consumer discretionary	XLY	207	8,204	104,500	1,007
Total		1417	11,291	432,200	1,000

January, 2007

# Statistical Arbitrage (II)

systematic  
component

idiosyncratic  
component

$$\frac{dS_i(t)}{S_i(t)} = \beta_i \frac{dI(t)}{I(t)} + \varepsilon_i(t)$$

Stock return is compared to the return on the **corresponding sector ETF** (regression, co-integration)

$$\varepsilon_i(t) = \alpha_i dt + dX_i(t)$$

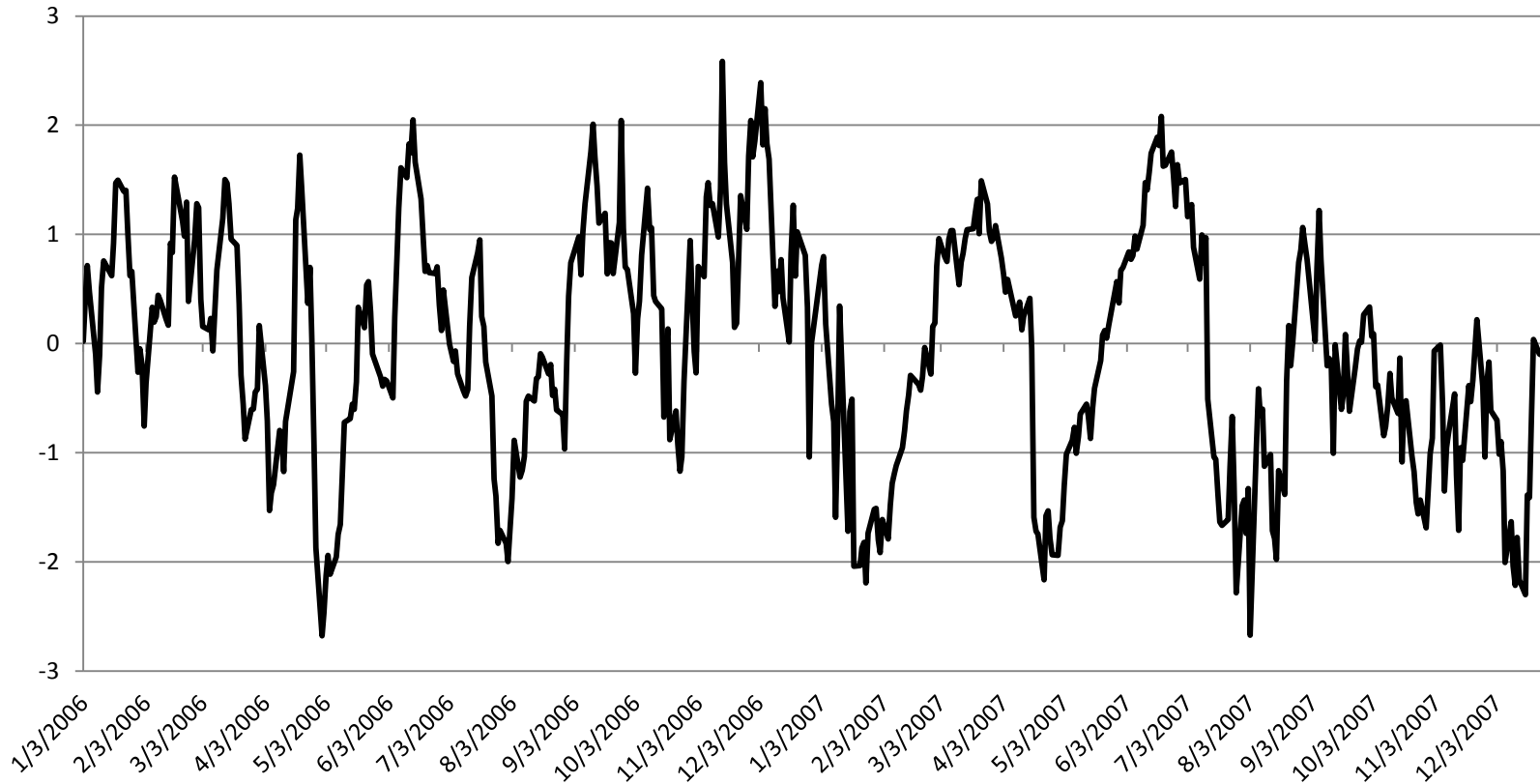
Residuals: modeled as a mean-reverting process

$$dX_i(t) = \kappa_i (m_i - X_i(t)) dt + \sigma_i dW_i(t)$$

Ornstein-Uhlenbeck  
(AR-1)

Example of sampling window = 3 months (~ 60 business days)

# $X(t)$ process for JPM/XLF (Financial sector ETF from State Street)



# Constructing Stat Arb strategies

- Diversified universe of stocks, “good choice” of shares/ETF pairs
- Buy or sell the spread (pair) according to the statistical model
- Risk-management using real-time VaR
- Execution: VWAP
- Taking volume into account is important to avoid “adverse selection”  
(the reason for divergence of  $X(t)$  in practice)

# Example of Stat-Arb portfolio

Simulated Trading - Interactive Brokers Trader Workstation - DU60008

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

SIMULATED TRADING

File

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View

Chart

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Msg. Center

Trader Chat

Features

Configure

Search TWS

X Portfolio

Untitled

Pending (All)

Select Account DU60008 X

Market Value

Currency

Cash

Stock

Options

Futures

FOPs

Net Liquidation Value

Unrealized P&L

Realized P&L

USD

10,616,280.57

-15,647.94

0.00

0.00

0.00

10,599,148.96

-2,695.35

0.00

Order Management

☒ Show zero position rows

☒ Show orders and trades for all accounts

Underlying

Exchange

Description

Position

Avg Price

Market Value

P&L

Unrealized P&L

Realized P&L

Bid Size

Bid

Ask

Ask Size

Last

Change

Allocation

Method

Pct. Change

Time in Force

Action

Quantity

Type

Lmt Price

Destination

Status

EIN

SMART

Stock (NYSE)

1,070

79.1597

85,728.40

428.00

1027.52

4

80.11

80.15

2

80.12

+0.40

FIS

SMART

Stock (NYSE)

-3,085

27.445

-84,837.50

-30.85

-169.68

29

27.49

27.50

30

27.50

+0.01

FRX

SMART

Stock (NYSE)

-2,764

30.635

-86,236.80

-663.36

-1561.66

37

31.20

31.21

52

31.20

+0.24

GLW

SMART

Stock (NYSE)

5,184

16.365

88,076.16

-207.36

3240.00

233

16.99

17.00

173

16.99

-0.04

GPC

SMART

Stock (NYSE)

1,983

42.685

86,498.46

614.73

1854.10

13

43.61

43.63

3

43.62

+0.31

IMO

SMART

Stock (AMEX)

2,225

38.1241

83,526.50

-1134.75

-1299.62

3

37.53

37.54

2

37.54

-0.51

IYR

SMART

Stock (ARCA)

-5,872

53.7025

-316,618.24

-469.76

-1277.16

7

53.92

53.93

399

53.92

+0.08

JOYG

SMART

Stock (NASDAQ.NMS)

1,537

55.1174

103,286.40

1752.18

18570.96

2

67.20

67.23

3

67.20

+1.14

KIM

SMART

Stock (NYSE)

-5,348

15.835

-86,156.28

-1069.60

-1470.70

91

16.10

16.11

17

16.11

+0.20

KO

SMART

Stock (NYSE)

1,476

57.445

84,929.04

44.28

140.22

72

57.54

57.55

42

57.54

+0.03

LBTYA

SMART

Stock (NASDAQ.NMS)

2,879

29.455

85,132.03

1266.76

331.09

51

29.56

29.57

12

29.57

+0.44

MAR

SMART

Stock (NYSE)

0.17

22.0667

6.11

0.09

2.35

14

35.79

35.80

13

35.80

+0.50

MOT

SMART

Stock (NYSE)

-10,752

7.855

-90,424.32

0.00

-5967.36

1,272

8.40

8.41

1,082

8.41

0.00

MSFT

SMART

Stock (NASDAQ.NMS)

3,555

23.825

89,479.35

-568.80

4781.48

519

25.16

25.17

545

25.17

-0.16

MXIM

SMART

Stock (NASDAQ.NMS)

-4,999

16.905

-84,639.09

-449.91

-24.99

59

16.90

16.91

80

16.91

+0.09

NHP

SMART

Stock (NYSE)

2,158

39.285

84,226.74

0.00

-550.29

1

39.02

39.04

8

39.03

0.00

OIH

SMART

Stock (ARCA)

-800

107.695

-85,648.00

-424.00

508.00

3

107.05

107.07

6

107.06

+0.53

ORCL

SMART

Stock (NASDAQ.NMS)

-3,378

25.055

-91,847.82

-6181.74

-7212.03

223

27.19

27.20

1,302

27.19

+1.83

PEP

SMART

Stock (NYSE)

1,282

66.085

85,060.70

-393.32

339.73

18

66.34

66.35

22

66.35

+0.16

QQQQ

SMART

Stock (NASDAQ.NMS)

769

46.585

36,942.76

76.90

1119.90

787

48.03

48.04

3,358

48.04

+0.20

ROK

SMART

Stock (NYSE)

-1,588

53.185

-94,835.36

-508.16

-10377.58

2

59.72

59.74

3

59.72

+0.32

RTH

SMART

Stock (ARCA)

1,361

92.465

128,818.65

-231.37

2973.79

20

94.64

94.65

2

94.66

-0.16

RYN

SMART

Stock (NYSE)

1,733

48.8385

86,008.79

883.83

1371.67

2

49.63

49.64

2

49.63

+0.51

SMH

SMART

Stock (ARCA)

6,500

25.6696

172,315.00

-260.00

5462.60

746

26.60

26.61

25

26.61

-0.04

SPG

SMART

Stock (NYSE)

894

94.745

84,786.96

223.60

84.93

2

94.82

94.86

2

94.84

+0.25

STJ

SMART

Stock (NYSE)

2,378

35.615

88,009.78

546.94

3317.31

12

37.01

37.02

12

37.01

+0.23

SWK

SMART

Stock (NYSE)

0.10

0.534

5.95

0.02

5.89

3

59.48

59.49

12

59.48

+0.18

TLM

SMART

Stock (NYSE)

5,161

16.405

84,124.30

-1393.47

-541.91

91

16.30

16.31

102

16.30

-0.27

TWC

SMART

Stock (NYSE)

0.67

26.32

34.26

0.35

16.75

10

51.49

51.50

14

51.49

+0.53

TWX

SMART

Stock (NYSE)

-2,654

31.905

-83,494.84

-132.70

1181.03

59

31.46

31.47

34

31.46

+0.05

VNO

SMART

Stock (NYSE)

985

86.123

84,975.95

137.90

144.79

5

86.27

86.30

3

86.27

+0.14

WMB

SMART

Stock (NYSE)

4,433

19.125

81,833.18

88.66

-2947.95

159

18.45

18.46

55

18.46

+0.02

XLE

SMART

Stock (ARCA)

-4,665

54.6079

-251,630.10

2192.55

3115.75

209

53.93

53.94

632

53.94

-0.47

XLF

SMART

Stock (ARCA)

-3,206

13.8259

-46,903.78

288.54

-2577.94

50,421

14.62

14.63

10,575

14.63

-0.09

XLI

SMART

Stock (ARCA)

-6,867

30.1772

-210,404.88

-480.69

-3178.05

5,498

30.63

30.64

108

30.64

+0.07

XLK

SMART

Stock (ARCA)

12,422

21.5404

279,619.22

248.44

12044.37

8,857

22.50

22.51

7,757

22.51

+0.02

XLP

SMART

Stock (ARCA)

-5,529

27.4311

-152,710.98

1105.80

-1044.43

4,085

27.61

27.62

3,197

27.62

-0.20

XLV

SMART

Stock (ARCA)

-3,019

29.9131

-90,388.86

483.04

-81.21

269

29.94

29.95

2,060

29.94

-0.16

XLX

SMART

Stock (ARCA)

-6,921

32.3297

-226,731.96

69.21

-2978.11

255

32.75

32.76

399

32.76

-0.01

Last Login: Sep 17, 11:45

Market Data

12:38:58

Start

Risk 2002

ISDA

Stat Arb

Search Results

Internet E...

Microsoft ...

Agenda For ...

McAfee Secur...

ACCESS.CIM...

psftp

TeXnicCenter ...

Microsoft Exc...

2 Adobe Acr...

Simulated T...

12:39 PM

## Liquidity providing (high frequency)

## Strategic placing of limit/cancel orders (liquidity) in the order book

Quote Panel

Underlying

Exchange

QQQQSMART

Buttons

Close Position

Reverse Position

View Account

Modify Allocation

Deep Book Buttons

ArcaBook

NASDAQ TotalView

Others

Orders

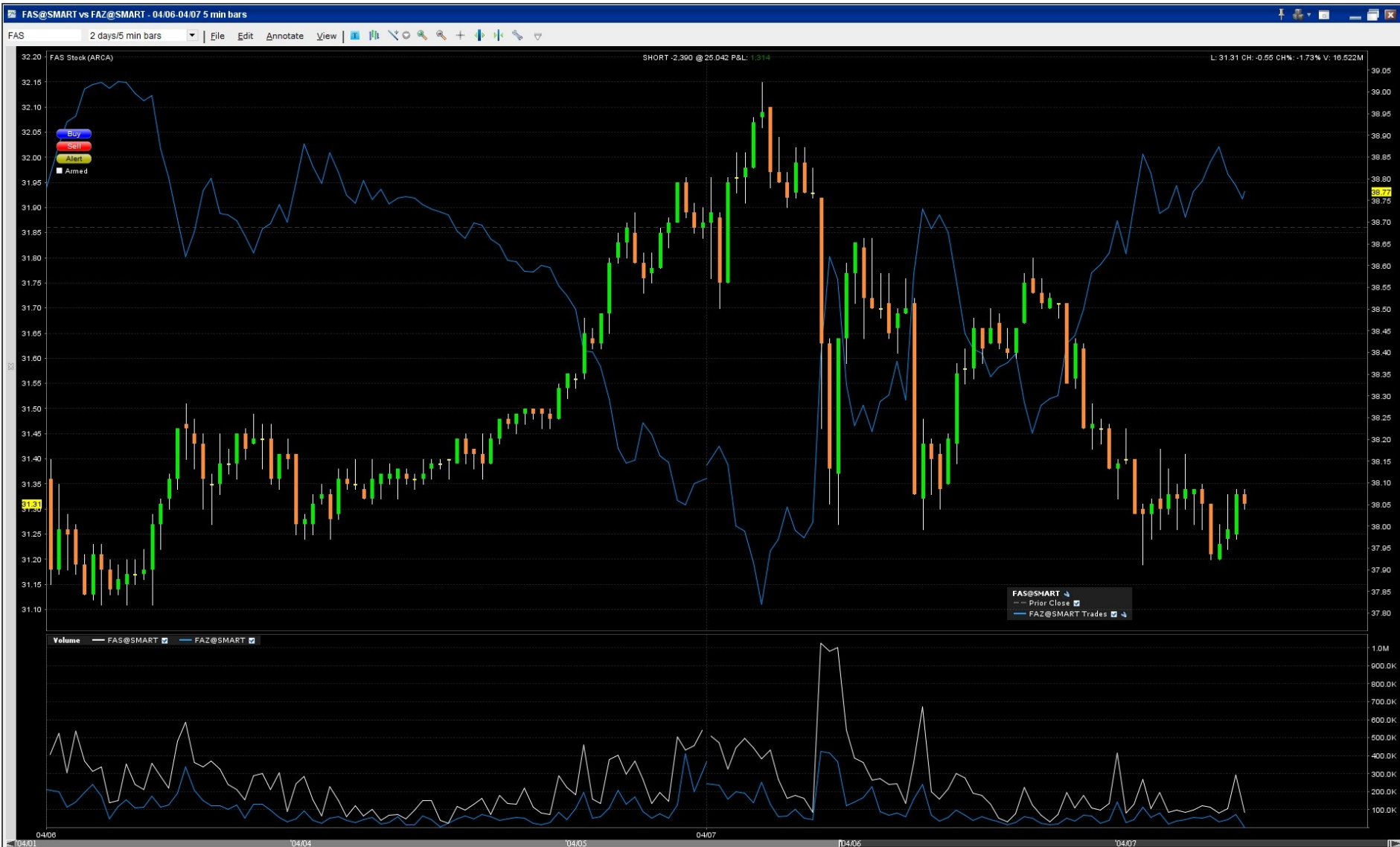
Log

Trades

Portfolio

Allocation	Time in Force	Action	Quantity	Type	Lmt Price	Aux. Price	Destination	Status
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# HF Pairs trading? Intraday evolution of FAZ & FAZ (inverse leveraged ETFs)



# Algorithmic trading and the ``flash crash'' (May 6, 2010)



The reasons behind the ``crash of 2:15'' were studied in a joint CFTC/SEC report available online.

Institutional trader sold **75,000 S&P E-mini contracts in 15 minutes PoV**.

- \* Drop in S&P futures, SPY etf, etf components
- \* Withdrawal of autonomous MMs; ``stub quotes''
- \* HFTs provide a lot of volume but not a lot of liquidity (``hot potato trading'')



# Forecasting prices in HF?

- Models for the dynamics of order books
- Modeling **hidden liquidity** in the market (not visible in the OB)
- Computing the probabilities of price changes (up or down) given liquidity on the bid side and ask-side  
(Avellaneda, Stoikov, Reed, 2010: pre-published in SSRN, Oct-10)

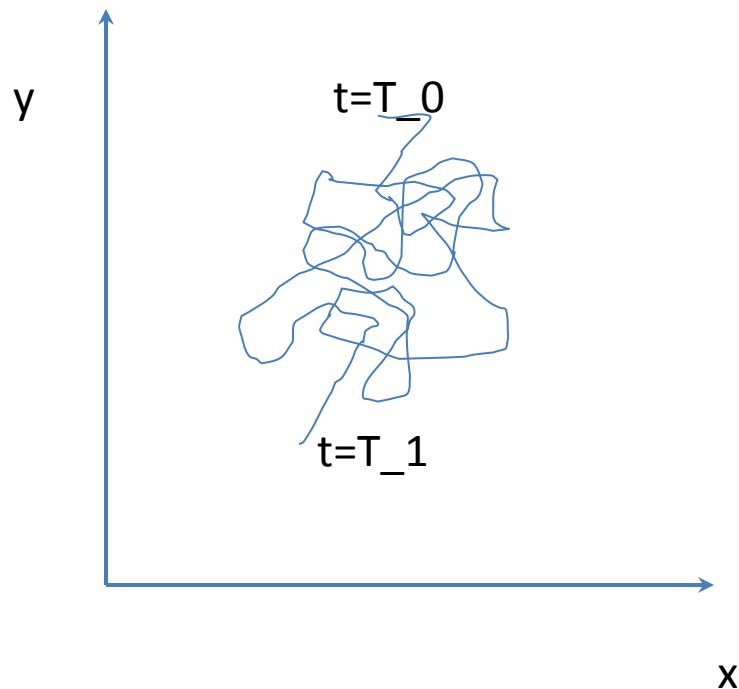
Bid	Q(bid)=x	Ask	Q(ask)=y
100.01	527	100.03	31

Simple formula that we are testing with HF data

$$P(\uparrow) = \frac{H + x}{2H + (x + y)}$$

$H$  = "hidden liquidity"

# Mathematical framework: Diffusion Approximation for Quote Sizes (Level I)



X= bid size  
Y = ask size

$$X_t = \sigma W_t$$

$$Y_t = \sigma Z_t$$

$$E(dW_t dZ_t) = \rho dt$$

A price change occurs when (i) one of the sizes vanishes and  
(ii) either there is a new bid or a new ask level

## Probability that the Ask queue depletes before the Bid queue

$$u(x, y) = \frac{1}{2} \left( 1 - \frac{\tan^{-1} \left( \sqrt{\frac{1+\rho}{1-\rho}} \frac{y-x}{x+y} \right)}{\tan^{-1} \left( \sqrt{\frac{1+\rho}{1-\rho}} \right)} \right)$$

$$\rho = 0 \quad \Rightarrow \quad u(x, y) = \frac{2}{\pi} \tan^{-1} \left( \frac{x}{y} \right)$$

$$\rho = -1 \quad \Rightarrow \quad u(x, y) = \frac{x}{x+y}$$

$$p \uparrow (x, y, H) = u(x+H, y+H)$$

Probability  
of an upward  
price change.

H='hidden liquidity'.

# Estimating hidden liquidity in different exchanges (ability to forecast price moves)

Sample data

symbol	date	time	bid	ask	bsize	asize	exchange
QQQQ	1/4/2010	9:30:23	46.32	46.33	258	242	T
QQQQ	1/4/2010	9:30:23	46.32	46.33	260	242	T
QQQQ	1/4/2010	9:30:23	46.32	46.33	264	242	T
QQQQ	1/4/2010	9:30:24	46.32	46.33	210	271	P
QQQQ	1/4/2010	9:30:24	46.32	46.33	210	271	P
QQQQ	1/4/2010	9:30:24	46.32	46.33	161	271	P

Estimated H across markets

Ticker	NASDAQ	NYSE	BATS
XLF	0.15	0.17	0.17
QQQQ	0.21	0.04	0.18
JPM	0.17	0.17	0.11
AAPL (s=1)	0.16	0.9	0.65
AAPL (s=2)	0.31	0.6	0.64
AAPL (s=3)	0.31	0.69	0.63

# Conclusions

- Over 50% of all trades in the US equity markets are algorithmic. Algorithmic execution of block trades is an important tool allowing for systematic and disciplined execution of size
- The main idea is to split large orders into smaller ones according to available market liquidity, generally following volume (TWAP, VWAP, PoV)
- Algorithmic trading is essential to implement quant strategies such as stat arb and ETF arb
- With DMA and low-latency trading, we see the emergence of autonomous market-makers
- HFT traders provide volume but not necessarily liquidity when needed. Neither do the autonomous MMs (flash crash). Can we detect “good liquidity” ?
- Regulation on HFT and electronic market-making is being drafted and implemented as we speak. Recently, **stub quotes were forbidden by the SEC**. Other measures to regulate HF trading will follow.
- Algorithmic trading, DMA, autonomous market-making and HFT are here to stay and are rapidly expanding to new markets in Asia and Latin America.