Algorithmic Trading : Introduction

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Introduction

- **Algorithmic Trading (AT)** : The use of computer algorithms that make trading decisions, submit orders, and manage those orders after submission

- **High-Frequency Trading (HFT)** : The subset of AT strategies that are characterized by their reliance on speed differences relative to other traders to make profits based on short-term predictions and also by the objective to hold essentially no inventories for more than a very short period of time

Introduction (cont'd)

Why AT? - One example

- **Institutional investors** need to **trade large volume** of securities. These quantities are too large for the market to process without prices moving in the 'wrong direction'.
- Thus, large orders are **broken up in small ones (order splitting)** and these are traded over time (in a range of minutes, hours, days, weeks, or even months) and across different venues (for the US).
- Deciding how to break up and execute a large order can mean saving millions of dollars for large players

Introduction (cont'd)

Why AT? - Another example

- **Proprietary traders** devise strategies to maximize profits
- Speed based : short-lived signals, news, arbitrage across exchanges
- Exploit predictable patterns : statistical arbitrage, pair trading, co-integrated prices

Introduction (cont'd)

Applications of AT

- Order execution
- Targeting VWAP
- Market making
- Pair trading and statistical arbitrage strategies

Course Outline

Topics covered in the course

- Lecture 1 : Introduction to Algorithmic Trading
- Lecture 2 : Optimal Execution
- Lecture 3 : Targeting VWAP
- Lecture 4 : Market Making
- Lecture 5 : Risk Management
- If time allows, we will cover “Pair Trading and Statistical Arbitrage Strategies”

Programming exercises (subject to change)

- Programming 1 : Basic Data View
- Programming 2.1 : Liquidation with Permanent Price Impact
- Programming 2.2 : Optimal Execution Strategy Incorporating Order Flow
- Programming 3 : Targeting Percentage of Market’s Speed of Trading
- Programming 4 : Market Making at the Touch with Short-Term Alpha

Exchanges

Exchanges

A exchange is a ‘place’ where ‘people’ meet to buy/sell securities: shares, commodities, derivatives, etc.

- **Order Driven Market** : All buyers and sellers display the prices and quantities at which they wish to buy or sell a particular security. In other words, they can post limit buy or sell orders

- **Quote Driven Market** : Designated market makers and specialists display bids and asks for a specific security - e.g., even now FX markets are like this.

Order Driven Market

All participants can post **buy or sell limit orders (LOs) - provide liquidity**

Limit orders show an intention to buy or sell and must indicate the **amount of shares** and **price** at which the agent is willing to trade

- Limit buy order with the highest price is known as the **best bid**
- Limit sell orders with the lowest price is known as the **best offer/ask**

The difference between the best bid and offer is called the **(bid-ask) spread**

All participants can execute **market orders (MOs)** for buy/selling at the best available prices - **take liquidity**

Evolution of Markets

- Old days brokerage model : Ring a broker, broker sends order to the pit and after screaming and hand signalling the order is executed
- Electronic market : Ring or use internet to contact broker who sends the order th the electronic exchange (no screaming)
- Direct Access Market : clients send orders directly to market

Multiple Markets

- **Consolidated markets** : A market can be organized so that by law or established custom, all trading in a security is consolidated, and occurs through a single exchange (e.g., Korea Exchange).

- **Fragmented markets** : Many present-day regulators, though, are reluctant to give one exchange a monopoly on trading. Allowing multiple exchanges results in a fragmented market which can simply result from having multiple limit order books for single security (e.g. U.S. trading venues).

If a stock were NYSE-listed, almost all of the trading would occur on the NYSE.

Though, there are many places where a trade might occur. In view of the fact that not all of them are exchanges, these places are called **trading venues** (or **trading centers**).

In the U.S., there are many venues and they are very competitive in trading fees and technologies.

Market Players

Who Participates Markets

Classifying market participants in view of high-frequency trading algorithm...

- **Fundamental (or noise or liquidity) traders** : those who are driven by economic fundamentals outside the exchange
- **Informed traders** : traders who profit from leveraging information not reflected in market prices by trading assets in anticipation of their appreciation or depreciation
- **Market markers** : professional traders who profit from facilitating exchange in a particular asset and exploit their skills in executing trades

<u>Examples</u>

- Medium-term or long-term investors whose trading strategies arises from portfolio management and risk-return trade-offs that have very little short-term price information
- High-frequency traders
- Individuals who buy stocks in the hope of being able to share in growth as the corporation increases its economic value-creation and its shares appreciate in value
- Individuals who may want to rebalance their investments due to a change in circumstances (in response to a sudden need for cash, a change in their taste for risk or their outlook for the future
- Individuals who capture short-term signals from the limit order book by using machine learning techniques and trade accordingly

Limit Order Book

Limit Order Book

- **Limit orders (LOs)** are accumulated in the **limit order book (LOB)** until they find a counterparty for execution or are cancelled
- The counterparty is a **market order (MO)** which is an order to buy or sell an amount of shares, regardless of the price, and is **immediately executed** against the **best prices**

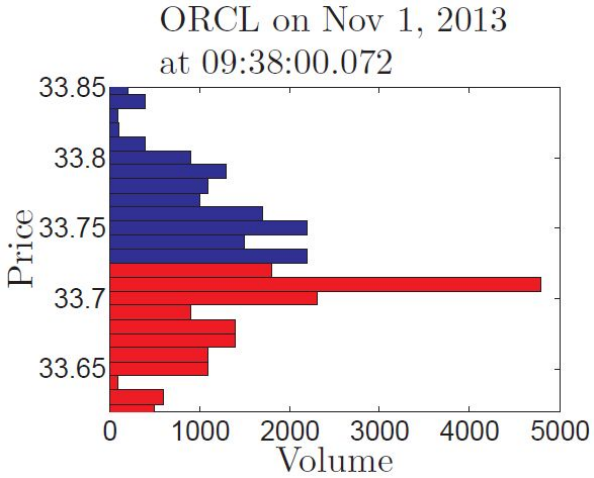


Figure 1-1. A snapshot of LOB of ORCL on Nov 1, 2013 at 09:38:00.072

Limit Order Book (cont'd)

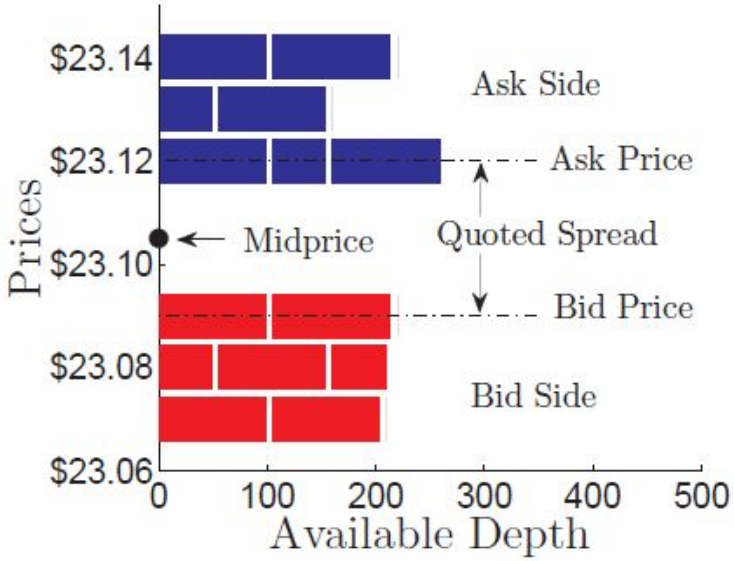


Figure 1-2. An illustration of LOB

Some standard measures

- **Tick** : a fixed discrete grid of prices, $0.01
- **Best bid price** : the highest bid price, $23.09
- **Best ask price** : the lowest ask price, $23.12
- **Midprice** : the arithmetic average of the best bid and ask prices, ($23.09 + $23.12) / 2 = $23.105
- **Quoted spread** : the difference between the best bid and ask prices, ($23.12 - $23.09) = $0.03
- **Effective spread** : twice the difference between the price at which a market order is executed and the midprice; for example, if a market buy order is submitted and is executed at $23.12, then the effective spread is 2*($23.12-$23.105) = $0.03

Limit Order Book (cont'd)

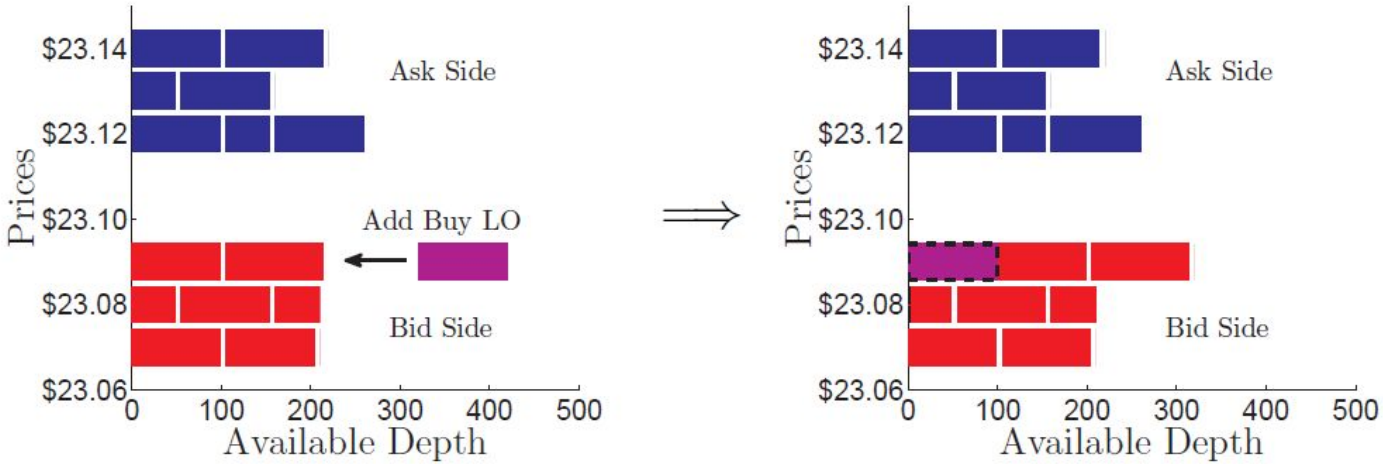


Figure 1-3. LOB illustration of a buy LO added to the queue at the best bid

Limit Order Book (cont'd)

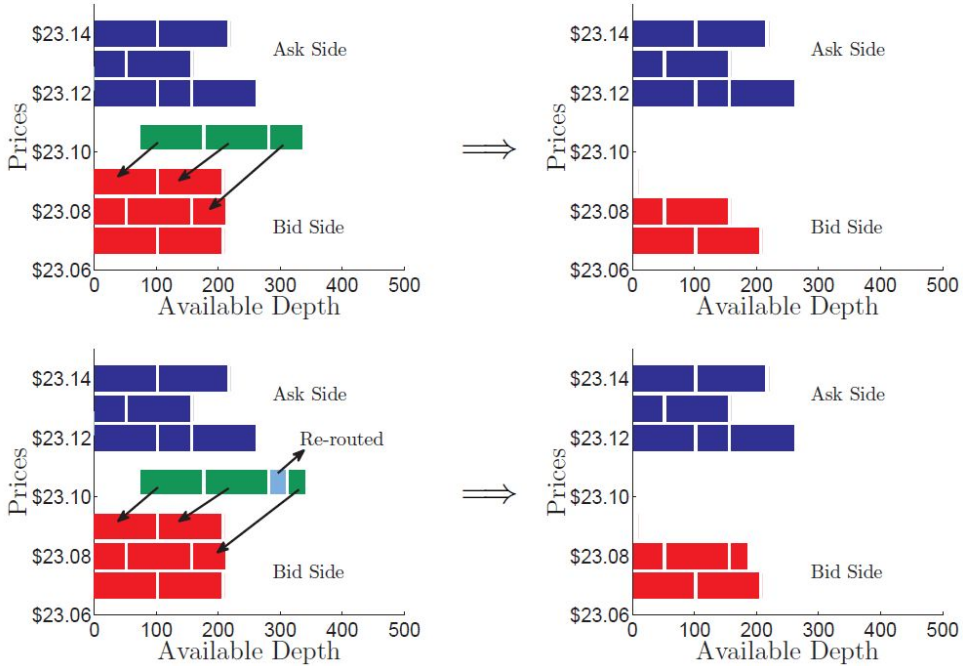


Figure 1-4. LOB illustration of a buy MO walking the LOB with and without re-routing

Limit Order Book (cont'd)

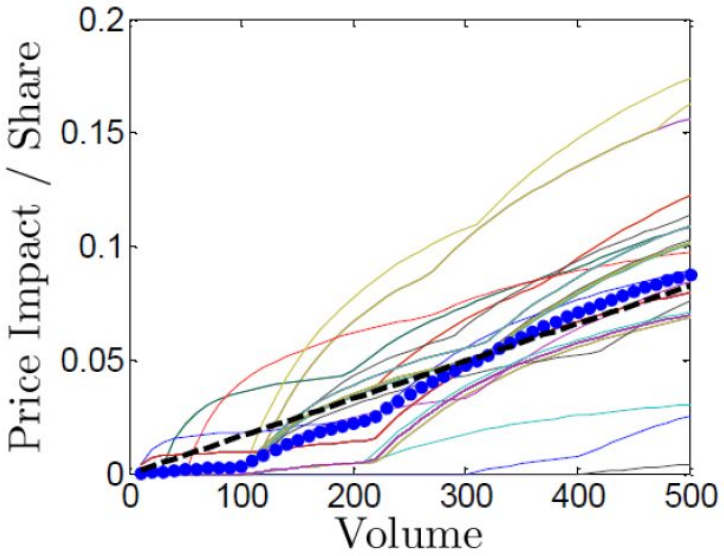


Figure 1-5. An illustration of price impact a periodic instant in time with the average of those lines (blue dotted line)

Market orders can **walk the LOB** and incur **immediate execution costs** (**temporary price impact**)

The blue dotted line can be proxied by the linear function $f(x) = kx$ where k is a measure of price impact, as described by the dash-dotted line

Limit Order Book (cont'd)

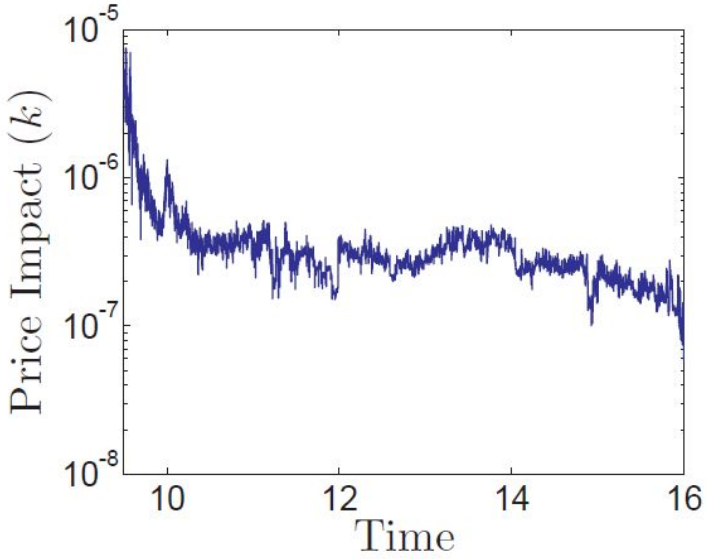


Figure 1-6. Impact dynamics throughout the day

Limit Order Book (cont'd)

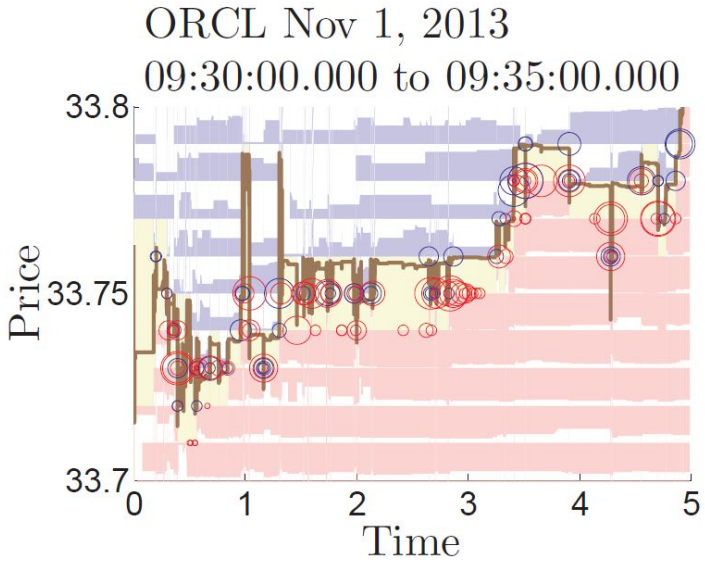


Figure 1-7a. Time series of the changes in the LOB for the asset ORCL

- The blue regions on top represent the ask side of the LOB, the posted sell volume, while the bid side is below in red, showing the posted buy volume
- The best prices are identified by the edges of the intermediate yellow region, which identifies the bid-ask spread
- The red/blue circles indicate the time, price and size (indicated by the size of the circle) of an aggressive MO
- The brown solid line depicts a variation of the asset known as the microprice defined as :

$$Microprice_t = \frac{D_t^b}{D_t^a + D_t^b} P_t^a + \frac{D_t^a}{D_t^a + D_t^b} P_t^b$$

where $D_t^{a,b}, P_t^{a,b}$ are posted depth at the best bid and volume and the bid and ask prices, respectively

Limit Order Book (cont'd)

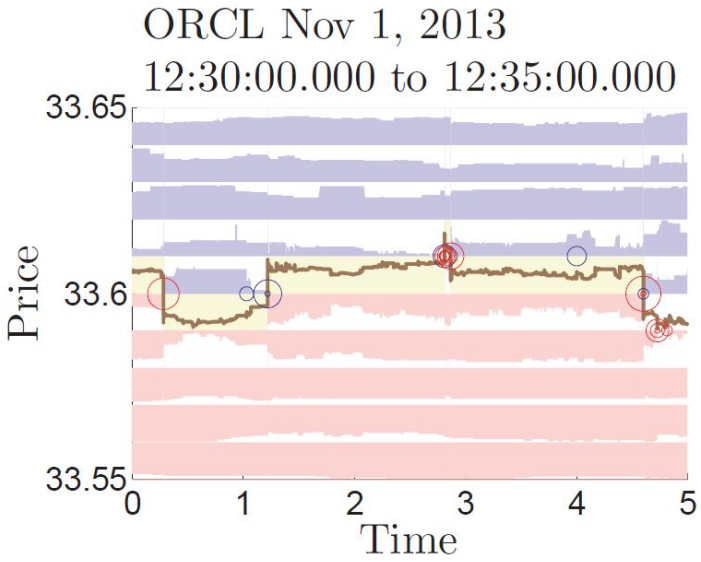


Figure 1-7b. Time series of the changes in the LOB for the asset ORCL

Limit Order Book (cont'd)

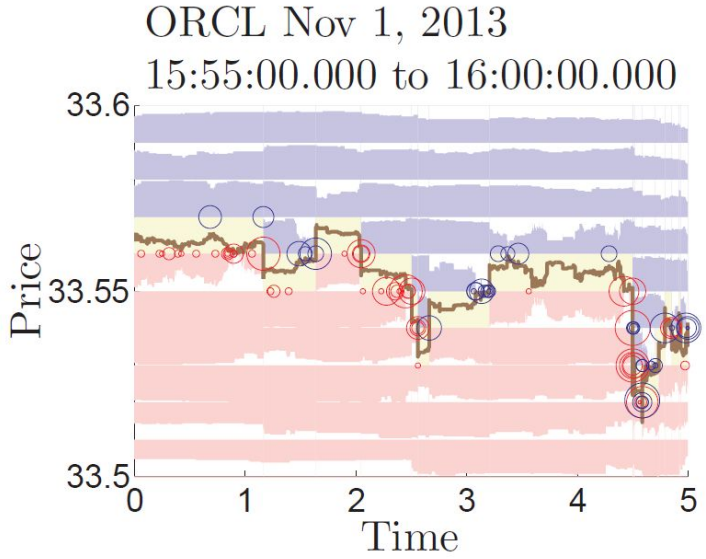


Figure 1-7b. Time series of the changes in the LOB for the asset ORCL

Limit Order Book (cont'd)

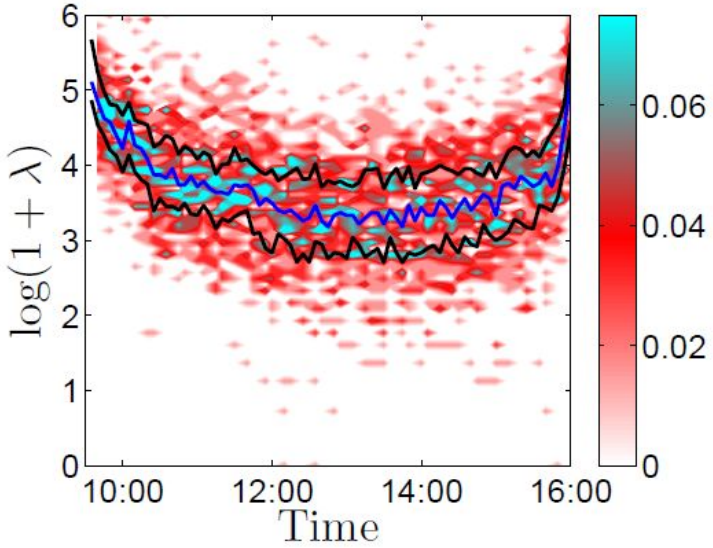


Figure 1-8a. An illustration of trade activity measured as an arrival rate of MOs of INTC for Oct-Dec, 2014 (5 min)

Limit Order Book (cont'd)

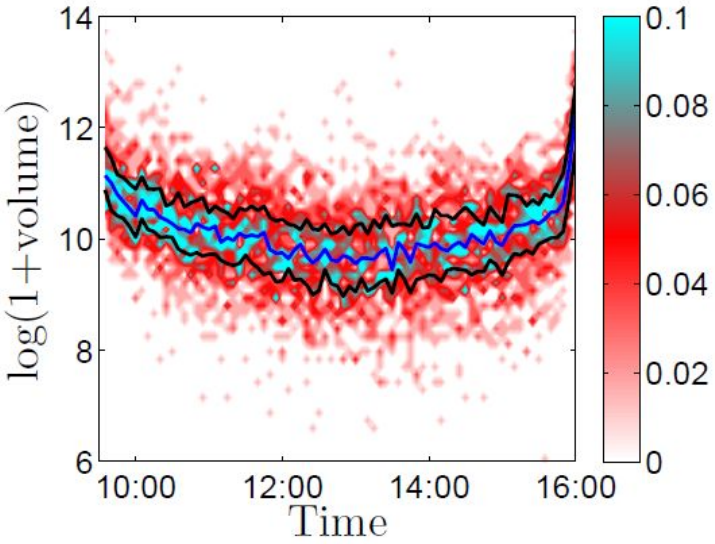


Figure 1-8b. An illustration of trade volume of INTC for Oct-Dec, 2014 (5 min)

Liquidity

Liquidity is a broad term that summarizes the level of cost and difficulty that we encounter when we try to trade; in a liquid market, trading is cheap and easy

Liquidity is a **multi-dimensional concept** which is characterized by the attributes of immediacy, tightness, depth, and resiliency :

- **Immediacy** is the ability to trade quickly - Modern securities exchanges that can be accessed instantaneously over the internet or some similar network have high immediacy. Over-the-counter markets that might require a customer to verbally contact many or more dealers have low immediacy
- **Tightness** (of the bid-ask spread) implies that a round-trip purchase and sale can be accomplished cheaply
- **Depth** refers to the existence of substantial buy and sell quantities at prices close to the best bid and offer
- **Resiliency**, in the sense of “bounce back”, suggests that any price changes that might accompany large trades are short-lived and quickly dissipate

Poisson Distribution

Poisson distribution

- The Poisson distribution is a discrete distribution that measures the probability of a given number of events happening in a specified time period
- In market microstructure, the Poisson distribution could be used to model the arrival of new buy or sell MOs entered into the market
- If $X \sim Poisson(\lambda)$, then

$$f(x;\lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!}$$
$$E[X] = \lambda$$
$$Var[X] = \lambda$$

Examples : 2012년 9월 5일 09:00:00~15:00:00 KOSPI200 지수 선물이 시장가 매도 주문 총 102,492개 발생

- 1초당 유입되는 시장가 매도 주문 수량은 얼마인가?

$$\lambda = \frac{102492}{6 \cdot 60 \cdot 60} = 4.745 \left[\#/s^{-1}\right]$$

- 1초당 유입되는 시장가 매도 주문 수량이 10건 이상일 확률은 얼마인가?

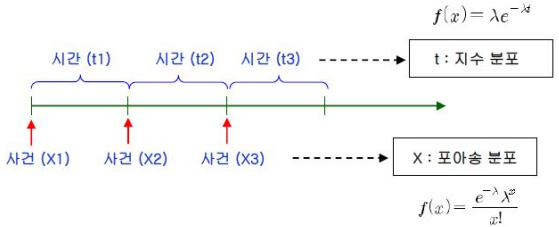
$$P(X \geq 10) = 1 - P(x < 10) = 1 - \sum_{i=0}^{9} \frac{e^{\lambda}\lambda^{i}}{i!}$$

Exponential Distribution

Exponential distribution

- If $X \sim \exp(\lambda)$, then

$$g(x) = \lambda e^{\lambda x}$$
$$E[X] = \frac{1}{\lambda}$$
$$Var[X] = \frac{1}{\lambda^2}$$



- Poisson distribution은 **단위 시간당 일어나는 사건의 횟수**에 대한 확률분포인 반면, Exponential distribution은 **발생하는 사건 사이의 시간**에 대한 확률분포임
- 단위 시간당 사건의 발생 수가 Poisson distribution을 따름 <-> 사건 발생 사이의 시간은 Exponential distribution을 따름

<u>Relation between Poisson and Exponential distribution</u>

- $f(x) = \frac{e^{-\lambda t}(\lambda t)^x}{x!}$: t 단위시간 동안 사건이 x번 발생할 확률
- $f(0) = e^{-\lambda t}$: t 단위시간 동안 사건이 일어나지 않을 확률 =>$1 - f(0) = 1 - e^{-\lambda t}$: t 단위시간 동안 사건이 발생할 확률
- $P(T \leq t) = 1 - e^{-\lambda t}$: 사건 발생 시간이 t 이하일 확률 (CDF)
- $g(t) = \lambda e^{-\lambda t}$
- CDF를 미분하면 PDF 도출 :

Order Imbalance

Order Imbalance

- Order imbalance (OI) measures whether the LOB is buy or sell heavy

$$\rho_t = \frac{V_t^b - V_t^a}{V_t^b + V_t^a} \in [-1, 1]$$

- Order imbalance is a good predictor of trade direction

Table 1-1. Buy and sell volume of the asset ORCL for different levels of order imbalance

ORCL Nov 1, 2013						
		buys		sells		Total
ρ	direction	num	perc.	num	perc.	
all		**1699**	**53%**	1526	47%	3225
< -0.5	sell heavy	67	12%	**506**	**88%**	573
< 0	sell	313	23%	**1059**	**77%**	1372
> 0	buy	**1385**	**75%**	462	25%	1847
$> +0.5$	buy heavy	**745**	**89%**	91	11%	836

Order Imbalance (cont'd)

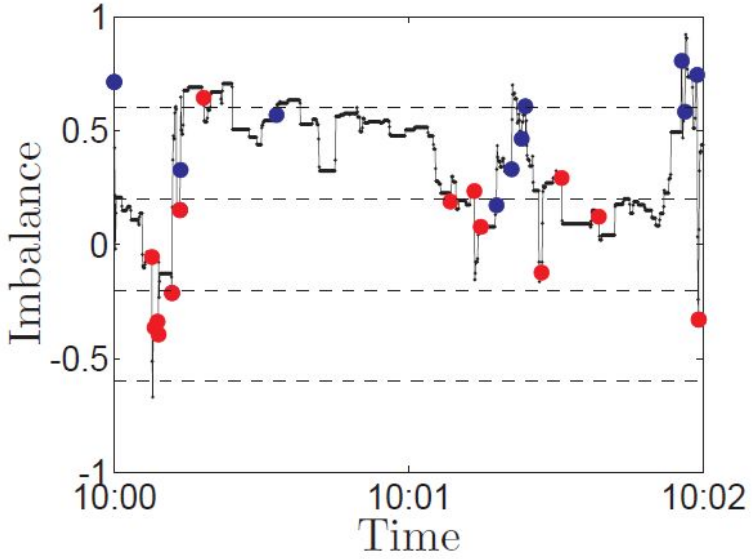


Figure 1-9a. A slice of OI for ORCL 10:00am to 10:02am on Nov 1, 2013

Order Imbalance (cont'd)

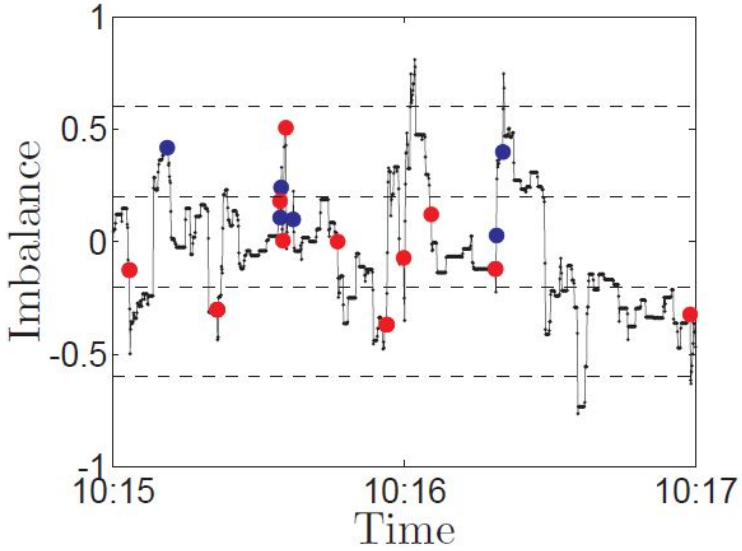


Figure 1-9b. A slice of OI for ORCL 10:15am to 10:17am on Nov 1, 2013

Order Imbalance (cont'd)

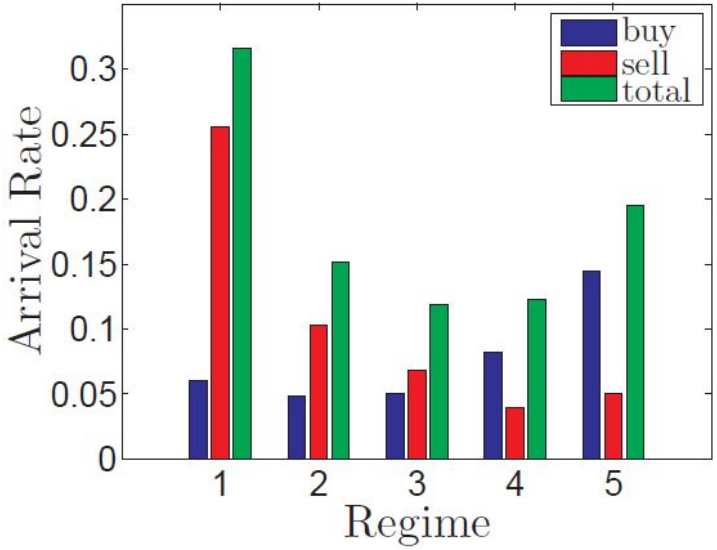


Figure 1-9c. MO arrival rates conditional on OI: ORCL on Nov 1, 2013

Order Imbalance (cont'd)

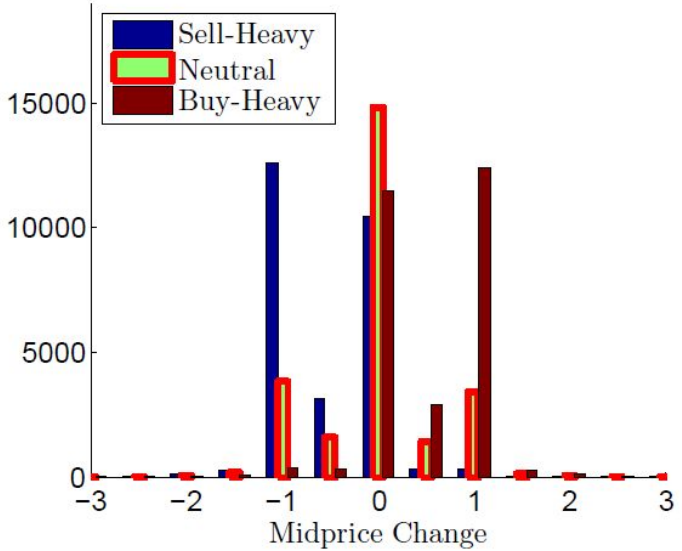


Figure 1-10a. Distribution of midprice change 10 ms after a market order for ORCL. Imbalance ranges are [-1, -0.33), [-0.33, 0.33], and (0.33, 1]. Neutral imbalances are emphasized in red boxes

Order Imbalance (cont'd)

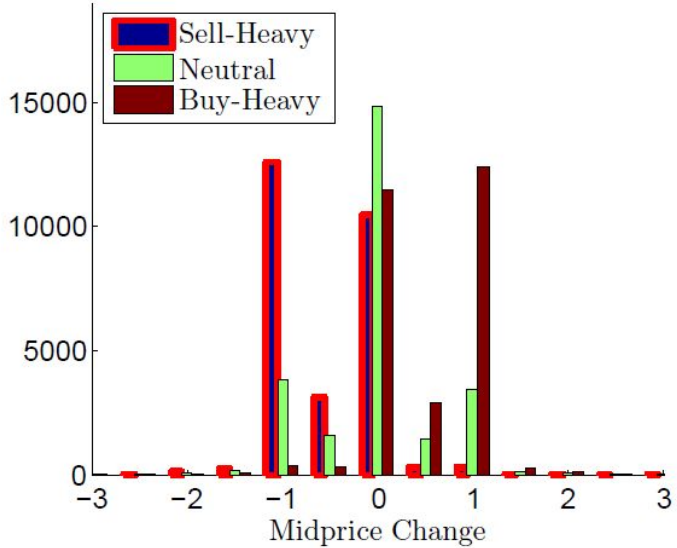


Figure 1-10b. Distribution of midprice change 10 ms after a market order for ORCL. Imbalance ranges are [-1, -0.33), [-0.33, 0.33], and (0.33, 1]. Sell-heavy imbalances are emphasized in red boxes

Order Imbalance (cont'd)

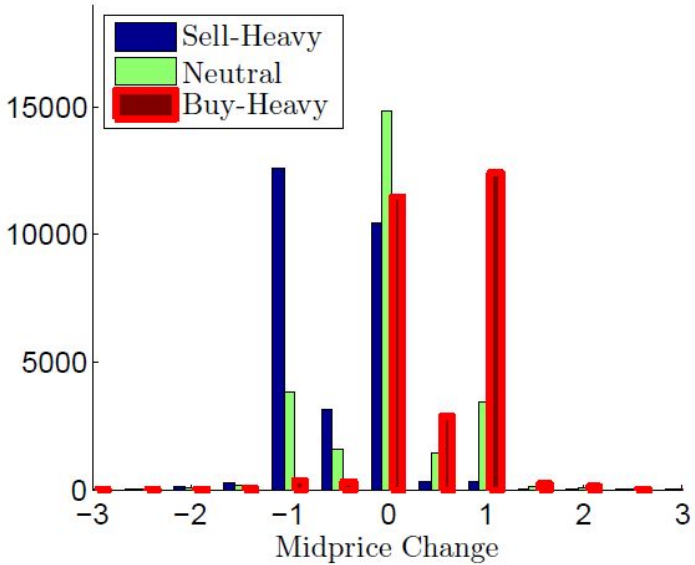


Figure 1-10c. Distribution of midprice change 10 ms after a market order for ORCL. Imbalance ranges are [-1, -0.33), [-0.33, 0.33], and (0.33, 1]. Buy-heavy imbalances are emphasized in red boxes