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On NASDAQ Order Book Dynamics: New Problems for the Control Field[†]

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Extended Tutorial Session Abstract — The NASDAQ is an electronic stock market which is run entirely by high-speed computers. With this as context, the main objectives of this tutorial are as follows:

First Objective: To demonstrate that NASDAQ order book dynamics provide a rich source of many new research problems of a control-theoretic nature.

Second Objective: To provide context and motivation driving new order book research in the control area by presenting a review of the critical issues and results in the finance literature.

Third Objective: To provide a detailed explanation of order book "mechanics" and a review of existing literature providing the basis for state space and simulation models.

Fourth Objective: To describe some specific new examples of Order Book Control Problems that are amenable to solution using the tools and expertise of our community. This includes control problems involving regulation in volatile markets, stock-price manipulation and robustness issues arising from dynamic model uncertainty.

Fifth Objective: To provide broader context for the research based on the role of the order book in a larger financial network, the tutorial includes a review of some existing results in the area of Network Identification which are relevant to areas being surveyed. When traders submit their orders, either to a broker or directly to the exchange, entries are made into the NASDAQ order book which evolves over time. The state of the order book consists of two lists: one for the buyers and one for the sellers. On the buy side, at a fixed moment in time, the i-th entry is an ordered pair (N_i, p_i) which is interpreted as follows: Buyer i is willing to buy N_i shares provided the price paid is p_i or less. This is called a *limit order*. Similarly, on the sell side (N_i, p_i) denotes the willingness of Seller i to sell N_i shares provided the price received is p_i or more. The order engine is basically an algorithm in software matching buyers and sellers dynamically over time.

With the setting and stated objectives above providing the context, the first talk in the session will be by a Financial Economist, Professor Scott Condie, an expert in large financial market data sets, especially Nasdaq ITCH data. His tutorial review will be tailored to a control audience and will require almost no expertise in finance. The next four talks to follow will be more technical in nature; see titles and descriptions below. The goal will be to get the ACC attendee "up to speed" on the critical aspects of state-space modeling of the order book dynamics and simulation methods commonly used to study the evolution of stock prices. As far as the control side is concerned, two aspects will be considered: (i) The role of order entry, be it innocently or with intent to manipulate price, and (ii) Regulatory control problems arising out of government concern about stock-price stability in volatile periods or market manipulation.

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The Big Picture: Electronic Markets and the Financial System

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***Abstract*— The financial system provides a way for individuals and corporations to employ capital profitably, diversify risk, save and speculate. This tutorial presents an overview of the U.S. Financial System with particular emphasis on electronic equity markets like NASDAQ. The place of equity markets in the overall financial system as well as the goals and mechanics of equity market trading will be covered. In addition, the roles of various players in the market, including market makers, liquidity demanders, trading algorithms and regulators will be covered. Finally, we present an overview of the regulatory frameworks in which these market participants operate.**

A Tour of the Order Book: ITCH Data and Graphical Representation

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Abstract— **At the center of the NASDAQ Stock Exchange is a fully electronic order book within which buyers and sellers interact according to a well-defined set of rules which are implemented in software. New buyers and sellers are arriving dynamically over time and the rules for order matching, when implemented, result in a discrete-time stock price $p(k)$. In this talk we detail the parts of an order book by illustrating how orders to buy and sell various quantities of a given security affect the distribution of the order book. In particular, we emphasize the bid-ask spread and discuss how this feature results in a price of the security at any given time. We illustrate these concepts using actual order book data from NASDAQ from 2014-2015 and conduct a guided tour of the dynamics of real order book data. In particular, we demonstrate differences in properties of the book depending on time scale of trades, i.e. high frequency traders versus nominal traders, and we explore the data set for evidence of attempted market manipulation by looking for the signatures of algorithmic traders placing orders on the book to shape the distribution rather than orders that are actually intended to be executed.**

On Market Making Mechanics: Dynamic Modeling and Simulation

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Abstract— **After review of the rules for operation of the order book for the NASDAQ Stock Exchange, we describe the mechanics involved in an algorithm for implementation. This includes specifications for market and limit order entry and cancellation, rules for matching of buyers and sellers and various details for smooth execution such as Security and Exchange Commission Regulation NMS. Subequently, order book simulation is considered. This begins with a model, typically a Poisson process, for new order arrivals and and cancellations. In such a simulation, we also consider special inputs such as large block orders by hedge funds and order book "spoofing" by traders trying to manipulate the stock price.**

On State Space Modeling of the Order Book

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Abstract— **The purpose of this talk is to walk through state space modeling of the order book. To this end, we develop an input-output model of the order book in order to explore price response to the submission of various buy/sell orders. By tapping into standard state space modeling, we consider issues such as low-dimensional order-book characterizations, transition models, impulse and step response, and stability analysis. This approach suggests new insights and research problems for the control community. Finally, we consider the problem of systems identification and validation from NASDAQ ITCH data.**

MIMO Order Book Considerations

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Abstract— **The U.S. equity trading system is composed of a set of independent, but connected markets including the NYSE, NASDAQ, BATS, DirectEdge, etc. Characterizing this system requires an understanding of the legal and mechanical ways that individual markets and traders may interact and the economic incentives that these markets face when interacting. Modeling this system requires an understanding of the above as well as of the types of measurements that can be taken from markets in order to calibrate and potentially falsify these models. This tutorial will cover current models of intermarket interactions as well as the nature of available data on market interactions. Strategies and challenges for dealing with these data will also be discussed.**

On Network Reconstruction Problems

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Abstract— **Deriving a network topology that describes the correlation structure of a set of stocks is a useful tool to verify if a portfolio is balanced and to direct trading strategies. In this context, we consider the Epps effect. It is an empirically observed phenomenon used in the analysis of financial time series where the sample correlation between the logarithmic return of two assets depends on the sampling time of the price sequences. Typically, a shorter sampling time leads to a smaller correlation coefficient. Thus, in fast trading, the Epps effect tends to produce a less reliable and less accurate reconstruction of the coupling between stocks. This tutorial gives a comprehensive explanation of the Epps effect as statistical artifact that is originated by asynchronous transactions in the order book. Also using a signal processing perspective, it is illustrated how filtering techniques can be adapted to mitigate it.**