High-Frequency Trading

New Realities for Traders, Markets and Regulators

Edited by David Easley, Marcos López de Prado and Maureen O'Hara

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About the Editors

David Easley is the Henry Scarborough professor of social science, professor of economics and professor of information science at Cornell University. He served as chair of the Cornell economics department from 1987 to 1993 and 2010 to 2012. He is a fellow of the Econometric Society and has served as an associate editor of numerous economics journals. David recently co-authored the book *Networks, Crowds and Markets: Reasoning About a Highly Connected World*, which combines scientific perspectives from economics, computing and information science, sociology and applied mathematics to describe the emerging field of network science.

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Yuriy Nevmyvaka has extensive experience in quantitative trading and statistical arbitrage, including roles as portfolio manager and head of groups at SAC Capital, Bank of America and Lehman Brothers. He has also published extensively on topics in algorithmic trading and market microstructure, and is a visiting scientist in the computer and information science department at the University of Pennsylvania. Yuriy holds a PhD in computer science from Carnegie Mellon University.

Richard B. Olsen founded OLSEN in 1985 and is chief executive officer. He oversees all portfolio investments as part of a comprehensive risk-management process and is involved in the ongoing development of trading models. Richard has written and co-authored many scientific papers and published a book, numerous articles and opinion pieces on a variety of topics. Richard's unorthodox but compelling ideas have made him a very welcome speaker at conferences around the world. His goal is "to create tools of finance that are as slick and elegant as the most sophisticated tools of technology". Richard holds a Licentiate in Law from the University of Zurich, a Masters in economics from Oxford University and a PhD from the University of Zurich. He worked as researcher and foreign exchange dealer before founding OLSEN.

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Preface

High-frequency trading (HFT) is now the norm for trading financial assets in electronic markets around the world. Be it in equities, foreign exchange, futures or commodities, high-frequency traders provide not only the bulk of volume in these markets, but also most liquidity provision. In so doing, high-frequency trading has changed how individual markets operate and how markets dynamically interact. In this book, we give a comprehensive overview of high-frequency trading, and its implications for investors, market designers, researchers and regulators.

Our view is that HFT is not technology run amok, but rather a natural evolution of markets towards greater technological sophistication. Because markets have changed, so, too, must the way that traders behave, and the way that regulators operate. Low-frequency traders (shorthand for everyone who does not have their own high-performance computers and co-located servers) need to understand how high-speed markets work in order to get effective execution, minimise trade slippage and manage risk. Regulators, who face the daunting task of crafting new rules and regulations for high-frequency environments, need to understand better how and why high-frequency markets falter. Perhaps most importantly, individual investors need to understand that high-frequency markets need not be the milieu of Terminator-like adversaries, but rather, with careful design and regulation, can be venues in which they can trade at lower costs and better prices than ever before.

The chapters in this book take on many facets of high-frequency trading, but for any of them to make sense it is important for our readers to understand some basic features of high-frequency trading. First, HFT is microstructure based, and it operates to exploit the inefficiencies in how markets operate. A market's microstructure refers to the rules and design of the trading platform. All microstructures have inefficiencies arising, for example, from tick size specifications, matching engine protocols or latency issues in sending orders both within and across markets.[1] By exploiting these inefficiencies, at its best HFT lowers transaction costs and enhances market efficiency; at its worst, HFT takes advantage of resting orders, "simple-minded"

trading algorithms and pricing conventions to transfer profits from low-frequency traders to high-frequency traders. The latter outcome arises because HFT is also strategy based: it is designed to take advantage of predictable behaviours in markets. Thus, momentum ignition strategies or attempts to move quote midpoints artificially are all designed to fool and exploit "uninformed" traders, who rely on simple trading rules and strategies.

A third feature of HFT is that it uses a new type of information. Traditionally, informed traders in markets were those who had better information on asset fundamentals, but HFT information relates to the trading process and not to the asset itself. At longer time horizons, fundamental information predominates in determining asset prices, but in the very short run it is trading information that matters. Thus, information on order flows, the structure of the book or the "toxicity" of the market can all help a high-frequency trader predict where market prices are going both in a single market and across markets. This trading information is useful because of the millisecond speed at which HFT algorithms operate. Consequently, to shave a few milliseconds off order transmission, it becomes optimal to spend hundreds of millions of US dollars to lay a new cable underneath the Atlantic Ocean (as was done in Project Hibernia) or to build towers between New Jersey and Chicago (as is being done in a joint project between Nasdaq and the CME) to send orders via microwaves, thereby improving transmission speed relative to ground-based fibre-optic cables. It is only natural to question whether such expenditures are socially optimal.

It would be a mistake, however, to believe that HFT is only about speed. There have been, and always will be, some traders who are faster than others. In today's markets, distinctions are being drawn between algorithmic traders (machines that are programmed to follow specific trading instructions), high-frequency traders (also machines but typically faster than algorithmic traders and may have more complex trading behaviours) and ultra-high-frequency traders (machines that use the fastest supercomputers, lowest latency linkages, etc). Indeed, it is safe to say that the latencies of the larger broker/dealer firms are now at the levels HFT firms were at just one or two years ago. The speed differentials between different trader groups will continue to decrease, but the strategic nature of HFT will remain as an important differentiator in markets.

It would also be a mistake to assume that all HFT strategies are the same. Just as markets, and their microstructures, differ, so too do the behaviours of high-frequency traders. Strategies that are optimal in short-term interest rate futures, for example, are very different from strategies that are successfully deployed in equity markets. Moreover, these strategies are constantly evolving as high-frequency traders employ more complex and technologically advanced approaches to trade within and across markets.

These two points are the subject of the first four chapters of the book. David Easley, Marcos López de Prado and Maureen O'Hara argue in Chapter 1 that HFT is not simply faster trading, but instead represents a new paradigm for trading financial assets. This paradigm is volume-based, reflecting that machines operate not on a time basis but rather on an event basis. Recognising this new paradigm is crucial for understanding why high-frequency markets are not just the same old markets "on steroids". These authors explain how, acting strategically, high-frequency algorithms interact with exchange-matching engines to exploit inefficiencies in markets and predictabilities in other traders' behaviours. This chapter sets the stage for understanding how high-frequency trading affects low-frequency traders, and it suggests strategies that LFTs should adopt to thrive in this environment.

Chapters 2–4 then discuss in detail how high-frequency trading "works" in equity markets, fixed-income futures markets and foreign exchange markets. Their authors discuss the particular strategies used and how these strategies have evolved over time. In Chapter 2, Michael G. Sotiropoulos describes how equity trading algorithms work and how they can be structured to meet the needs of a wide variety of market participants. He discusses how trading has evolved from simple deterministic trade algorithms, such as volume weighed average price (VWAP), to new adaptive algorithms that adjust trading speeds to a variety of high-frequency indicators such as queuing time and order book imbalance. Sotiropoulos also discusses how incorporating order protection strategies into adaptive algorithms can minimise transaction costs for low-frequency traders.

In Chapter 3 Robert Almgren examines the distinctive features of trading futures on interest rate products. Fixed-income trading algorithms must have special defensive features built in to protect the trader from the shocks arising from public information events

such as Treasury auction results or scheduled government data releases. Moreover, fixed-income futures are cointegrated, meaning that individual contracts are not independent of other contracts due to linkages with the term structure, varying maturities, and the like. Thus, algorithmic strategies must take account of the inherent tendency for prices to move congruently. Almgren describes analytical approaches to characterising cointegration and how this can be used for price prediction. He also highlights the role played by priority rules in affecting trading strategies.

In Chapter 4, Anton Golub, Alexandre Dupuis and Richard B. Olsen describe the unique market structure of foreign exchange (FX) trading and the main algorithms used in the industry. FX markets feature a spectrum of traders from manual traders (ie, humans using a graphical user interface) to ultra-high-frequency traders submitting (and cancelling) thousands of orders over millisecond ranges. This chapter highlights the different roles played by these traders, and in particular draws attention to the changing composition of trading during periods of market instability. Olsen *et al* also suggest a new priority rule to enhance market liquidity production and stability.

Having established the basic frameworks used in high-frequency trading, we then turn in Chapters 5 and 6 to the foundations of high-frequency trading by examining the roles of machine learning and "big data". In Chapter 5, Michael Kearns and Yuriy Nevmyvaka discuss the role that machine learning plays in developing predictive algorithms for high-frequency trading. Machine learning is an area of computer science that draws on research in statistics, computational complexity, artificial intelligence and related fields to build predictive models from large data sets. Kearns and Nevmyvaka demonstrate how techniques such as reinforcement learning can determine optimal dynamic state-based policies from data; for example, such an approach could be used to determine an optimal execution algorithm that decides whether to slow down or speed up trading depending upon current microstructure data. They also show how machine learning can use order book data to predict future price movements. This chapter, while showcasing the extensive technological sophistication underlying high-frequency trading, also makes clear the role that "human inputs" have in designing such analytical tools.

In Chapter 6, Kesheng Wu, E. Wes Bethel, Ming Gu, David Leinweber and Oliver Rübel look at another dimension of high-frequency trading: the role of "big data". Algorithmic and high-frequency trading generate massive amounts of hard-to-process data. Some of this comes from trade executions, but a much greater amount arises from the placement and cancellation of orders both within and across markets. Handling, let alone analysing, such massive databases (which can be of the order of a petabyte) is almost impossible using standard data management techniques. Wu *et al* discuss how new file formatting and computational techniques can be applied to high-frequency trading data. They use these techniques to test the predictive ability of VPIN, a measure of order toxicity, for future volatility.[2] Their results illustrate how "big data" can play a critical role in testing new risk-management tools for high-frequency markets.

The remaining four chapters focus on the implications of high-frequency trading for markets, traders and regulators. In Chapter 7, David Easley, Marcos López de Prado and Maureen O'Hara examine how volatility contagion can take place across markets. High-frequency market makers often engage in inter-market arbitrage, a strategy in which market makers "lift" liquidity by placing bids in one market and asks in another. Easley *et al* show how this results in order toxicity spreading across markets, which in turn results in volatility contagion. Using data from energy futures, they demonstrate that these contagion effects can be sizeable. These results show that the volatility process in high-frequency markets is now interdependent across markets, a result of interest to both researchers and regulators.

George Sofianos and JuanJuan Xiang consider in Chapter 8 the challenges facing low-frequency traders in markets with high-frequency traders. Trading algorithms are designed to minimise a trade's execution cost, and they generally do so by splitting orders into many smaller pieces that then have to be traded over time in the market. If high-frequency traders can detect in market data the early trades in the sequence (known as the algorithm's "footprint"), then they can front-run the subsequent trades and profit at the low-frequency trader's expense. Sofianos and Xiang discuss how feasible this is, and present an extensive empirical study to determine how easy it is to find these patterns in the data. The analysis here

demonstrates how important it is for low-frequency traders to use sophisticated trading techniques in high-frequency settings.

This issue of new trading tools and techniques is also the focus of Chapter 9. Terrence Hendershott, Charles M. Jones and Albert J. Menkveld develop a new approach for measuring the effect of transitory trading costs for transaction cost analysis. The ability to measure trading costs is crucial for institutional traders, and is greatly complicated when algorithms chop orders into sequences of trades. Hendershott *et al* construct an efficient price estimator that allows an enhanced ability to compute the execution cost of a large trade. Their analysis shows the importance of temporary price effects on trading costs, and it illustrates the need to develop new analytical tools designed for high-frequency settings.

Our final chapter turns to the challenges of regulation in a high-frequency world. In Chapter 10, Oliver Linton, Maureen O'Hara and J. P. Zigrand argue that, while HFT has increased market quality on average, it has made markets more vulnerable to episodic instability. This is due, in part, to the changing nature of liquidity provision in high-frequency markets, but this vulnerability also arises because HFT has opened the door to both new forms of manipulation and market failures arising from errant technology. Linton *et al* argue for a new *ex ante* regulatory approach that relies on technology to monitor markets in real time, pre-specifies regulatory actions in the event of faltering markets and applies across, and not merely within, market settings. They also examine a variety of existing and proposed regulatory reforms in the US and Europe.

We hope this book makes the high-frequency world more accessible to our readers.

ACKNOWLEDGEMENTS

We thank our outstanding co-authors and the editors at Risk Books (particularly, Sarah Hastings) for making this book possible.

1 Latency is a measure of time delay in a system. In the context of trading financial assets, it refers to the time it takes to get orders from a trader's computer to the trading venue (and, depending on context, it may also include the time to confirm trades back to the trader). Latencies in high-frequency markets are often measured in milliseconds (thousandths of a second), or even microseconds (millionths of a second).

2 Volume-synchronised probability of informed trading (VPIN) is a measure of order imbalance and it signals when the order flow is likely to be disadvantageous, or "toxic", to market makers. High toxicity can cause market makers to withdraw from the market, and this can lead to disruptions in liquidity provision. Because of this linkage, VPIN can signal future toxicity-related volatility in markets: an issue of importance to both regulators and traders.

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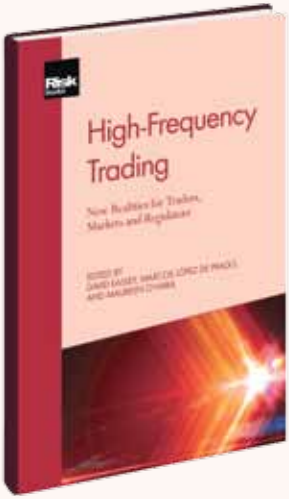
EDITED BY
DAVID EASLEY, MARCOS LÓPEZ DE PRADO, AND MAUREEN O'HARA

A Survival Guide to High-Frequency Trading



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Equip yourself with this book to gain a full understanding of high-frequency trading. What opportunities are available for you to take advantage of? Do new regulations affect you? How might your competitors be using high-frequency trading? Can you compete in the high-frequency world?

High-frequency trading now predominates in markets, with upwards of 60% of trading in equities and futures, and 40% in foreign exchange. It is the subject of extensive debate, particularly as to whether it is beneficial for traders and markets or instead allows some traders to benefit at others expense. This book provides you with an important overview and perspective on this area, with a particular focus on how low-frequency traders can survive in the high frequency world.

With chapters written by the leading practitioners and academics in the area the book will show you how issues such as big data come into play, how high-frequency should affect optimal execution algorithms and how markets interconnect in new ways that affect volatility and market stability. Contributors also discuss the new regulatory challenges that arise in the high-frequency world.

Chapters include:

- High-Frequency Trading Strategies in FX Markets (Anton Golub, Alexandre Dupuis, Richard B. Olsen)
- Execution Strategies in Fixed Income Markets (Robert Almgren)
- The Regulatory Challenge of High-Frequency Markets (Oliver Linton, Maureen O'Hara and J.P. Zigrand)
- Machine Learning for Market Microstructure and High-Frequency Trading (Michael Kearns and Yuriy Nevmyvaka)

This book is essential reading for anybody who wants or needs to learn about this changing subject area, including institutional traders, exchanges and trading system operators, regulators and academics.

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