Intelligent Market-Making in Artificial Financial Markets

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The Problem: Market-makers serve important functions in financial markets, providing liquidity to the markets and immediacy to the execution of trades. We are designing algorithms for automated market-making in different market conditions such as competitive vs. monopolistic dealer markets and studying outcomes in terms of indicators of market quality such as the bid–ask spread.

Motivation: Progress in machine learning techniques has led to the development of various techniques well suited to online estimation and rapid aggregation of information. Theoretical models of market-making have led to price-setting equations for which solutions cannot be achieved in practice, whereas empirical work on algorithms for market-making has so far focused on sets of heuristics and rules that lack theoretical justification. We are developing algorithms that are theoretically justified by results in finance, and at the same time flexible enough to be easily extended by incorporating modules for dealing with considerations like portfolio risk and competition from other market-makers.

Previous Work: Previous research at CBCL on market-making has focused on heuristics that use the limit-order book to set prices [3] and on reinforcement learning for market-making in very simple environments [8, 2]. Our work draws heavily on the market-microstructure literature, especially the price setting equations derived by Glosten and Milgrom under conditions of information asymmetry and perfect competition between market-makers [6]. Some simulations of the NASDAQ stock market have been carried out, but none of them have focused on market-maker behavior or on adaptive agents [4, 1]. An overview of the microstructure literature is given by O'Hara [7].

Approach: We are developing a market model loosely based on standard models of informed traders who trade based on their perception of the "true" or "fundamental" value of a stock, and uninformed or liquidity traders who add noise to the market. Under these conditions of information asymmetry, the market-maker attempts to track the fundamental value of the stock by maintaining an online probability density estimate based on the orders it receives. In addition, the market-making algorithm can be extended by controlling inventory and increasing or decreasing the spread in response to competition. Results indicate that the algorithms are very successful in tracking the "true" value, making profit while maintaining a small bid-ask spread and also respond as expected to market conditions (by, for example, increasing the spread in more volatile market conditions) in the stylized market models we consider [5]. See figure 1 for results on tracking of the fundamental value using our density estimation technique and examples of profits obtained in different market conditions.

Impact: This research will provide insight into the dynamics of financial markets with liquidity provided by the presence of market-makers. Also, simulating markets with electronic market-makers allows one to determine the effects of various structural and regulational changes to markets without the expense of experimenting in a real market. This research is also an important application of machine learning techniques like nonparametric density estimation and online estimation. The fact that we can set prices by approximately solving equations for which closed form solutions may not exist demonstrates that computational methods have important applicability in both theoretical and practical financial market domains.

Market-making is an important institutional activity in financial markets. However, there is a wide gap between the theoretical work on optimal market-making and how market-makers actually set prices and execute orders in practice. Over the last few years, computational methods to bridge the gap between theory and practice have become more popular, and we hope that simulations of markets will yield insights into the behavior of real markets and their connection to simpler, stylized models.

Future Work: We are working on several extensions to the market-making algorithm based on machine learning. For example, we are trying to add modules for predicting price jumps and for raising and lowering the spread in response to competition in an automated manner. In addition, we are interested in extending our model of market-making to richer, more complex market models.

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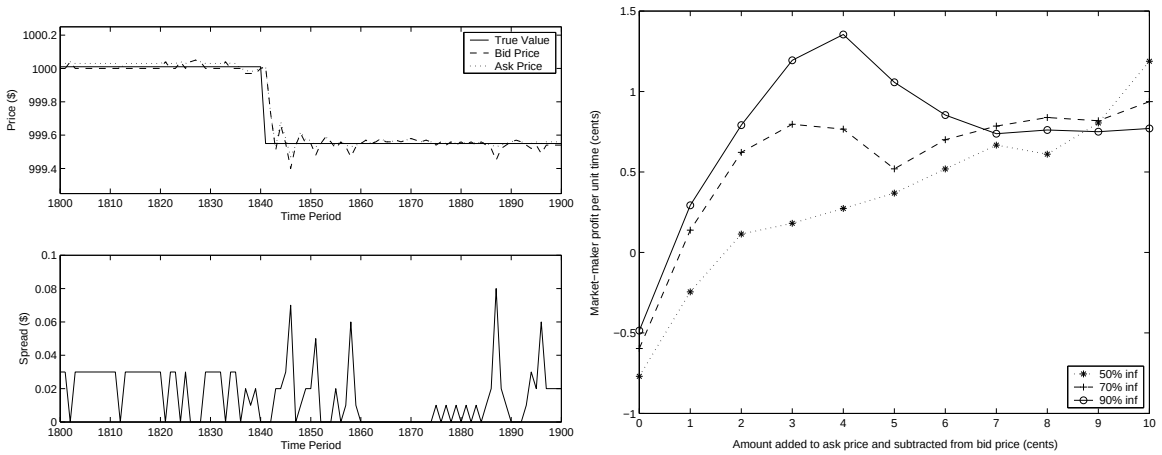

Figure 1: Market-maker's tracking of the "true" value (left) and profits in a monopolistic environment as a function of spread under different market conditions (right)

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References:

[1] M. Brown and V. Darley. The Future of Trading: Biology-based Market Modeling at Nasdaq. *Perspectives in Business Innovation*, 4, 1999.

[2] N. T. Chan and C. R. Shelton. An Electronic Market Maker. Technical Report 2001-005, MIT Artificial Intelligence Laboratory, 2001.

[3] T. Chan. *Artificial Markets and Intelligent Agents*. PhD thesis, Massachusetts Institute of Technology, 2001.

[4] V. Darley, A. Outkin, T. Plate, and F. Gao. Sixteenths or Pennies? Observations from a Simulation of the Nasdaq Stock Market. In *IEEE/IAFE/INFORMS Conference on Computational Intelligence for Financial Engineering*, 2000.

[5] Sanmay Das. Intelligent Market-Making in Artificial Financial Markets. Technical Report 2003-005, MIT AI Lab/CBCL, 2003.

[6] L.R. Glosten and P.R. Milgrom. Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders. *Journal of Financial Economics*, 14:71–100, 1985.

[7] M. O'Hara. *Market Microstructure Theory*. Blackwell, Malden, MA, 1995.

[8] C. Shelton. *Importance Sampling for Reinforcement Learning with Multiple Objectives*. PhD thesis, Massachusetts Institute of Technology, 2001.