# Artificial Financial Markets with Adaptive Trading Agents

Adlar Jeewook Kim, Sanmay Das, Tomaso Poggio and Andrew Lo

,

**The Problem:** This project aims to study various ways of designing intelligent trading and market-making agents. We are simultaneously devising and refining an artificial market environment, and using it to study cooperative and competitive agent behavior.

**Motivation:** In the last decade there has been a surge of interest within the finance community in describing equity markets through computational agent models [5]. At the same time, financial markets are an important application area within artificial intelligence for the fields of agent-based modeling and machine learning, since agent objectives and interactions tend to be more clearly defined, both practically and mathematically, in these markets than in other areas. Computational modeling of markets allows for the opportunity to push beyond the restrictions of traditional theoretical models of markets through the use of computational power. At the same time, the artificial markets approach allows a fine-grained level of experimental control that is not available in real markets. Thus, data obtained from artificial market experiments can be compared to the predictions of theoretical models and to data from real-world markets, and the level of control allows one to examine precisely which settings and conditions lead to the deviations from theoretical predictions usually seen in the behavior of real markets. This project is also an application area for the general problems of distributed intelligence such as collective learning, coordination and competition. We are interested in studying how software agents endowed with learning abilities might interact, co-evolve, and cooperate in *societies of learning agents*.

**Previous Work:** The project draws on at least three distinct subfields: market microstructure, experimental markets, and simulated markets. Studies in market microstructure theory provide important background and context for the experiments and simulations[6]. An alternative to the theoretical approach is an experimental one in which individuals are placed in a controlled market setting, given certain endowments of securities and cash, and allowed to trade with each other[1, 4]. Lastly, computer simulations of markets populated by software agents extend the experimental approach by allowing the experimenter to test various theories of learning behavior and market microstructure in a controlled environment([3, 2, 5] *inter alia*).

**Approach:** Within the artificial markets project, we are pursuing four major research directions, some of which are discussed in detail in companion abstracts.

1. We are investigating the structures and trading mechanisms of markets, with particular reference to the role of market-makers, both monopolistic market-makers like NYSE specialists, and competitive market-makers like those on the NASDAQ. We are designing automated mechanisms for market-making based on machine learning techniques and studying the emergent properties of the markets.

2. We are interested in designing richer, more complex agent-based market models. In pursuit of this goal, we are designing trading agents that use sophisticated techniques from machine learning and artificial intelligence to populate our markets.

3. We are examining the aggregate statistical properties of order flow in our markets and the time series properties of the prices processes generated by our agents, and comparing these to the properties empirically known to hold in real markets, like the fat- tailed nature of return distributions. This work will provide insight into the basic mechanisms underlying real-world phenomena observed in financial markets.

4. We are continuing to develop and improve our artificial market software, which provides a testbed for many experiments and allows artificial and human agents to interact with each other in a controlled setting.

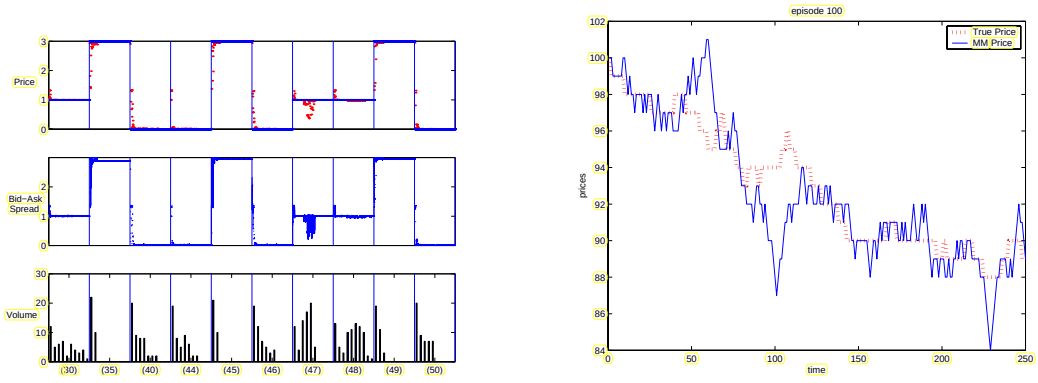


Figure 1: (a) Typical Realization of Artificial Market Experiments (Information Dissemination with Identical Preferences. (b) Typical Realization of Market-Making using Reinforcement Learning (Episode 100)

**Impact:** This research will provide insights into the impact of market structure and design on market efficiency, patterns of information flow and price processes. For example, we hope to investigate the advantages of monopolistic vs. competitive dealer markets given different assumptions about market volatility. Simultaneously, investigating automated trading algorithms will provide insight into the kinds of environments where particular trading strategies may be successful. The questions we ask in this project lie at the intersection of several disciplines, from computer science (distributed systems of agents), to learning (which is a key aspect of the artificial agents and possibly also of the market structure), to economics (financial markets are the primary focus), to cognitive sciences (interaction between agents' biases and properties with the overall behavior of the market).

**Future Work:** We are researching more sophisticated learning algorithms for our agents and the dynamics created by heterogeneous preferences. In the long term we are looking into the stability and evolutionary dynamics of different learning strategies in societies of agents. Additionally, we will try our adaptive market-making strategies in more realistic and complex market environments, and study the possible refinement of learning techniques to deal with such complex environments.

**Research Support:** Research at CBCL is sponsored by grants from: Office of Naval Research (DARPA) Contract No. N00014-00-1-0907, National Science Foundation (ITR / IM) Contract No. IIS-0085836, National Science Foundation (ITR) Contract No. IIS-0112991, National Science Foundation (KDI) Contract No. DMS-9872936, and National Science Foundation Contract No. IIS-9800032.

Additional support was provided by: AT&T, Central Research Institute of Electric Power Industry, Center for e-Business (MIT), DaimlerChrysler AG, Compaq / Digital Equipment Corporation, Eastman Kodak Company, Honda R&D Co., Ltd., ITRI, Komatsu Ltd., Merrill-Lynch, Mitsubishi Corporation, NEC Fund, Nippon Telegraph & Telephone, Oxygen, Siemens Corporate Research, Inc., Sumitomo Metal Industries, Toyota Motor Corporation, WatchVision Co., Ltd., and The Whitaker Foundation.

**References:**

[1] D. Davis and C. Holt. *Experimental Economics*. Princeton University Press, Princeton, NJ, 1993.

[2] D. Friedman and J. Rust. The Double Auction Market Institutions, Theories, and Evidence. Technical report, Santa Fe Institute Studies in the Sciences of Complexity, 1991.

[3] D. K. Gode and S. Sunder. Allocative Efficiency of Markets with Zero Intelligence Traders: Markets as a Partial Substitute for Individual Rationality. *Journal of Political Economy*, pages 119–137, 1993.

[4] J. Kagel and A. Roth, editors. *Handbook of Experimental Economics*. Princeton University Press, Princeton, NJ, 1995.

[5] B. LeBaron. Agent-based Computational Finance: Suggested Readings and Early Research. *Journal of Economic Dynamics and Control*, 24:679–702, 2000.

[6] A. Madhavan. Market Microstructure: A Survey. *Journal of Financial Markets*, pages 205–258, 2000.