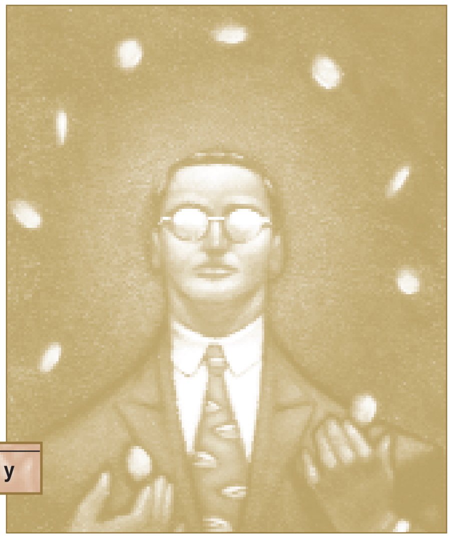
THE FUTURE OF TRADING:

BIOLOGY-BASED MARKET MODELING AT NASDAQ



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Vince Darley is a Senior Scientist at Bios Group LP, a partnership between Ernst & Young and biologist Dr. Stuart Kauffman. Darley's doctoral dissertation is concerned with understanding the natural dynamics of large systems of autonomous, optimizing agents and how to design local interactions to bring about particular global goals. At Bios Group, he is applying these insights to understanding the behavior of stock markets by using agent-based simulation and developing more robust, dynamic scheduling algorithms.

Stock market behavior is frustratingly complex: settling at times into what seems like reliable rhythms, then jumping , falling, or bouncing, all as millions of investors negotiate the trading of billions of shares of securities each day. Each participant's actions change the landscape for others; prices and availability are in constant flux. And given today's new information and communications technologies, the markets are not only changing *more,* but are changing far *more rapidly* than ever before.

The conditions that make the markets so alive and unpredictable—the speed of information diffusion among mutually dependent actors, coupled with global participation and the financial scale of a robust equities market—are, it turns out, remarkably familiar to complexity scientists. Accustomed to modeling intricate dynamics such as those found in weather, traffic, and immune systems, the scientists at Bios Group are natural teammates for the decisionmakers at Nasdaq whose work demands deep understanding of market dynamics and mechanisms. Our market simulation collaboration has been under way for nearly two years.

Good Rules Make Good Markets

Because of the central place of securities markets in the commercial infrastructure and in capital formation, the trading public must be ever-assured that these rapidly evolving markets operate fairly and accurately. The Board and Management of Nasdaq works closely with two main partners, the NASD Regulation and the Securities Exchange Commission, to keep a vigilant eye

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on the maintenance of appropriate trading and price discovery. The key tool here, of course, is the right kinds of regulations. The challenge is in understanding both the desired and possible unintended consequences of any changes they might make.

Nasdaq and its Quality of Markets Committee have always used a sophisticated set of analyses to evaluate and attempt to predict the results of its new rules. The approach is broad, too, combining economic studies and financial models with feedback from market participants, issuers, lawyers, lobbyists, regulators, and policy makers. These efforts have not gone unnoticed in the marketplace: over its short lifetime, Nasdaq has become the most closely watched market in the all-important technology sector and, in raw trade volume, is one of the largest stock markets in the world.

Methods from Biology Test the Rules for the Market Ecology

Our collaboration began with agreement that a complex adaptive systems approach seemed well suited to representing the Nasdaq markets. The idea was that agent-based models, with their roots in the study of ecological systems, would emulate well the complex "ecology" of traders, market makers, and investors buying, selling, and competing for orders, while simultaneously adapting their behavior and strategies in a continual struggle for survival.

We believe market dynamics are better understood—and more realistically studied—this way: as the result of a complex web of interactions among market rules, individual strategies, new information, and market structure. These are, after all, the naturally hard-to-predict, nonlinear behaviors of the connected world we live in. The ultimate goal is a simulation that will allow regulators to test and predict the effects of different rules, observe the behavior of agents in response to changes, and monitor the behavior of the entire market.

Think of this particular agent-based simulation as a kind of laboratory for investigating the market's dynamics as a function of the trading regulations in place, the types of strategies used by investors and market makers, and certain exogenous factors such as tick size (the smallest possible increment of change in a stock's price), and the arrival of new information. What is most exciting about this faster-than-real-time laboratory is that it means regulators can study what might happen with the introduction of new rules without making risky early concept tests in the real-life marketplace where real money is made and lost by real people.

The work of modeling involves, among other more technical steps, finding appropriate expression of the issues regulators care about. In other words, we have to create in the simulated world an adequate translation of the variety of measures of goodness that can be applied to real markets: efficiency at assimilating new information into prices ("price discovery"); fairness to all participants ("a level playing field"); removal of excessive, self-sustaining price fluctuations

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Stock markets have always been vastly complex. With today's information and communications technology, the markets themselves are prone to rapid change. Because the market serves as a critical part of the economic infrastructure, it is important to try to establish an orderly environment in which traders can play. The use of an agent-based model that simulates the effects of different rules on the market can help explain the complex web of interactions in the trading world.

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without outside cause ("excess volatility"); and so on. It is changes in these measures of goodness that one sees with the simulation as it investigates the effects of changes in market rules, market conditions, and participants' strategies.

The result so far is a model that is "robust"—meaning that in the simulated market, the exchange, investors, and dealers perform realistically under a fairly wide variety of conditions. Second, the market dynamics produced by the model have the same qualitative properties as those observed in real markets.

Tick Size Matters

While we have some preliminary results pertaining to volatility, liquidity, bid-ask spread sizes, and spread clustering, the main focus so far has been on the market impact of reducing the tick size. Among market professionals, the perceived wisdom is that providing greater granularity of price denomination is good for investors because it promotes competition among buyers and sellers who can negotiate in more precise terms, and thus it drives the market's spread down, which results in better prices for investors.

This wisdom is difficult to test empirically: the complexity of market behavior makes isolating cause and effect highly problematic. Without a computer simulation, rule makers are stuck with an intuitive argument, and one that is poor in detail, judging market interaction by only one measure: competition (and hence price). Other dimensions of the problem go unaddressed: If better prices are available, do only small investors benefit, or will large ones too? Will smaller tick sizes make the market more jittery and volatile? These questions are extremely difficult to answer. It is easy to see how a rich, robust, realistic simulation model has the potential to provide much better answers than intuition alone will allow.

Most of the results of the Bios/Nasdaq simulation assume that investors make their decisions based on their estimate of the fundamental value of the security. But when many investors are trend followers or technical traders, the simulation suggests a smaller tick size is problematic. One version of the simulation includes traders who are executing "parasitic" strategies played out by agents programmed to behave similarly to "SOES bandits"—the nickname given to day traders who use the Small Order Execution System. When they are in the game, and tick size is reduced from 1/16 to 1/100, the market's ability to perform price discovery is significantly impeded. When parasitic investors are not present, price discovery is approximately the same in each case.

The results on tick size persist even as the model becomes more sophisticated. For example, as individual agents' improve their strategies over time, the simulated market's ability to track fundamental value also generally improves. Yet even in such a "smart" marketplace, as tick sizes go down, the presence of parasites worsens the market's ability to track the true value. In contrast, when the tick size is increased, the market's ability to track the true price is greatly improved.

This appears to be a case in which small changes in some factors can have a huge impact on outcomes—a common property of complex adaptive systems, by the way. In this case, there are pronounced differences between the market's tracking capabilities at a tick size of 1/16 and those same capabilities when tick size is reduced to 1/100. The bottom line revealed by the simulation is this: as tick size is reduced, parasitic strategies become more efficient (and perhaps realistic). This is the kind of knowledge that Nasdaq authorities need when considering regulatory options intended to maintain both market efficiency and market fairness.

Meanwhile, more and more markets are moving toward decimalization—meaning all prices will be quoted in decimals, e.g., $75.30, rather than fractions ($75 3/16) as is currently the case. The question of what tick size the markets should adopt in a decimalized era is a hot one.

The simulation clarifies that the decision as to which tick size to adopt through regulation in a decimalized system cannot be made intuitively. While there are simple arguments that suggest that reducing the tick size may encourage competition and reduce the spread, there are more subtle issues concerning the effect of a reduced tick size on volatility; volume; the likelihood of crossed markets; the ease with which market makers can provide liquidity (in both small and large orders); the transparency of information flow in the market; and, finally, the efficiency of price discovery. But we've learned that at least some of these subtler effects may be adversely affected by a reduction in tick size. We don't have a simple answer to the difficult policy decisions the markets now face, but we do have at hand a new way to explore—far beyond the limitations of our intuitions—the correct balance between these different factors.

Herd Effects and Other Explorations

It has long been observed that the price movements in the world's markets do not follow the standard "laws of large numbers," which dictate that aggregate statistics of large numbers of independent, identical random events should follow a normal distribution. Instead, price fluctuations in financial markets follow an aggregate distribution known as a truncated Levy distribution, the most salient characteristic of which is that large events—like big price movements—happen far more frequently than they would under a bell-shaped frequency distribution: depicted graphically, the distribution has "fat tails."

This is of great importance for the correct assessment of risk, since it is in the extreme events that most market risk lies. While the underlying reasons for this peculiar distribution of price fluctuations are not known, there is much speculation about "herd effects" as a possible cause. The same agent-based simulation we used to explore tick size effects is also an ideal test-bed for looking at theories such as this. Preliminary testing has shown that there may not be a single "effect," but rather a number of factors behind these fat-tailed price fluctuations.

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The agent-based simulation model used by Nasdaq shows that changing tick size can have a significant impact on investors. Results of the simulation assume that investors make their decisions based on their estimate of the fundamental value of the security. Under conditions in which many investors are trend followers or technical traders, tick size effects are typically enhanced.

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Another direction for further development of this simulation might be a focus on more sophisticated agents. Already the agents in the model learn and adapt over time, but we would like to know more about how agents respond to different incentive structures and different market rules. With more back and forth between the simulated and real worlds, we expect this kind of agent-based market model to produce many valuable insights into how real-life investors and dealers will respond to changes in market rules and to the vast array of new opportunities that are constantly being created in contemporary markets.

Finally, we believe that this simulation may have a valuable and practical role as an educational tool. Imagine training investors with this kind of simulation: one or more people can join the simulated market (when it is slowed to an acceptable speed) and participate as market makers or investors, setting quotes, buying and selling, submitting limit orders. Besides having the instructive experience of participating in a realistic market without the usual risk, the user can begin to understand how his or her actions impact the actions of the other participants in the market: a heavy buyer will see the market respond by raising prices, for example.

Essential Tools for Trading in a Nonlinear World

The Securities and Exchange Commission's reaction to this kind of biological modeling has been positive. But you don't have to be a rule maker to gain something from agent-based simulation modeling. The agent-based approach properly reorients our understanding of how markets defy prediction—particularly, prediction based on linear mathematics. This represents a new basic tool for understanding the way markets really work; agent-based models tune us into the inherently nonlinear realities of today's highly connected economy. As they develop, we predict they will be seen as essential to playing out potential implications of different trading strategies and understanding related risks and opportunities that investors face in a fast-paced, turbulent marketplace.