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# Nerds on Wall Street

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Advances in technology have set the stage for unprecedented information-processing capabilities in the investment management profession. Four current techniques include visualization, artificial intelligence, genetic algorithms, and trading robots.

Today, investment managers can put more computing power on their desks than was available to the entire U.S. Department of Defense 20 years ago—and plenty of room is left on the desk. Computers are better, faster, cheaper, and smaller than ever. The first Apples and IBM personal computers appeared in the early 1980s. Since then, users have seen 286-based PC-ATs, then 386s, then 486s and their Macintosh brethren. Now, a manager can have a Pentium or some other silicon blazer. No matter how snazzy a machine you buy, however, it always seems to be obsolete before you get it out of the box. What are the implications for investment management?

The explosive growth in information technology increases the opportunities for investment managers to exploit quantitative methods. They can apply substantial technological leverage to expand and improve methods already in use, and they can do things that are completely different from what they have done before.

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## Growth in Computer Power

The pace and scope of computational progress is easy to take for granted. Computer systems are pervasive in the investment world, particularly desktop machines. People tend to overlook the relentless progress of the past decades that has placed unprecedented information-processing capabilities in managers' hands. Putting this progress in perspective helps explain the prodigious rise of nerds on Wall Street.

The computational capacity of computer hardware can be measured in terms of memory size (in megabytes) and execution speed (in millions of instructions per second, or MIPS). An eminently reasonable way to measure the cost of computational capacity is simply to consider the price of the ma-

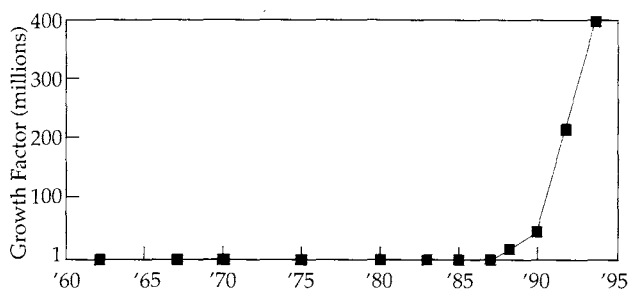
chine: Multiply the two good characteristics (speed times memory size) and divide by the bad characteristics (cost) to come up with a performance/dollar "figure of merit." The first person to suggest this calculation was Gordon Moore, founder of Intel, the company that makes the microprocessors and other bits inside PCs.

The growth in computing power per dollar during the past 30 years is staggering. A 1960-vintage PDP-1 or IBM-701-style computer filled a large room. It had 0.008 megabytes of memory (which the salesperson would have called 8K), operated at about 0.1 MIPS, and cost \$250,000. These figures translate into a performance/dollar of 0.0000000032. The number itself is not as important as how it compares with the figure for a modern, high-end workstation, such as a Sun Microsystems Sparc 10, with 256 megabytes of memory, running at 200 MIPS. It is the size of a medium-pizza box and costs about \$40,000. The performance/dollar figure for this computer is 1.28—an improvement from the early 1960s by a factor of 400 million, a truly remarkable number. Think of it as 4 trillion basis points. **Figure 1** is a graph of the performance/dollar change. On this scale, the line hugs the horizontal axis until the mid-1980s, but the improvement in the figure of merit was roughly a factor of 10 every 18 months. Nothing like this growth has ever happened in the history of technology.

Another way of looking at this 400 million factor in technological growth is to consider what would happen if the same rate of progress had occurred in the world of automobiles during the same period. Because consumers like their cars fast, fuel efficient, and cheap, a suitable figure of merit for cars is to multiply the first two (good) numbers and divide by the cost. Thus, the figure of merit for cars is (Mileage × Speed)/Cost.

A typical 1960s car—say, a Ford Edsel—got

**Figure 1. Growth in Information Technology**



Note: The growth factor is the change in the figure of merit for a midlevel business computer available in each year.

Source: D.J. Leinweber.

about 10 miles to the gallon, cruised at about 80 miles an hour, and cost about \$2,500; so the figure of merit is 0.32. If this figure is scaled up by a factor of 400 million, today's car would be a model land rocket tooling along at a brisk 10,000 miles an hour, going 1,200 miles on a gallon of gas, and costing 12 cents.

Think how this car would change the world! Oil companies would not be much of a factor in investment portfolios or the world economy. People could drive coast to coast in 20 minutes, so airline stocks would probably sell a little lower than they do. The practice of getting three estimates for body work would be history; it wouldn't pay to put money in the parking meter, let alone worry about fixing the thing. It would still get stuck in traffic, however, on the Santa Monica Freeway.

This utterly extravagant explosive growth in technological capability poses the challenge facing the securities industry today: If you had everything, computationally, what would you do with it? Clearly, the general answer is: use it to improve the investment management process. The big question is: how. The rest of this presentation will take a look back and a look ahead at the role of technology in finance and investing. The hope is to generate some new ideas about how "The Machine That Changed the World" changes investment management.

## Looking Back: Technology in Investing and Trading

Technology and finance have been joined at the hip almost since the beginning. The first market data system in the United States was shouting under the Buttonwood Tree near 68 Wall Street in 1792. The first technological advance was moving indoors, still shouting, followed shortly thereafter by hand signals and chalk boards.

Computers at the time were nonexistent, although Charles Babbage in London designed what he called a "calculating engine" and even built some

partial prototypes in the 1820s. Babbage made a career out of petitioning the British government to pay for a machine that would automatically calculate compound interest. He was considered something of a crank, however, and his machines were not built in his lifetime. When the Royal Museum of Technology in London put together a working version from his drawings to commemorate his 200th birthday, the machine worked fine so long as they remembered to change the oil.

The development of telegraphy was very important to investors and traders. Prior to that point, markets were localized. Whether shouting or using hand signals or chalk boards, traders all had to be in the same place to communicate prices.

In country after country, the first use of telegraphy was by the military, but the second use was to disseminate financial information. The third use, by the way, was to perpetuate some kind of financial fraud.

Early telegraph systems were semaphores, signals conveyed by people waving flags around. Later, mechanical "flag-wavers" were used, which is why so many places called "telegraph hill" exist. Hills are not needed for wire telegraphy, but they are needed to relay messages visually over any distance. Flag waving is also why fraud was so easy. Anyone could hang out near the hill with flags and run up there when the legitimate flag waver went to lunch.

Next came electrostatic telegraphs. One early version had a separate wire for each letter and number. These machines had serious range problems. From one room to another was about as far as a message could be sent. Soon, people got the idea of adding a battery, which led to various attempts to develop an electric telegraph. Some still had 40 wires. A particularly snappy model used a receiver made of 40 little metal balls in a glass tank filled with salt water; the electric current caused a stream of little bubbles to rise from the ball corresponding to the character being sent.

Finally, in 1844, the modern single-key telegraph was invented. Its arrival brought about what is probably the biggest single change in the way financial markets operate. For the first time, people did not have to be physically present at the market to participate in it.

The next big advance came in 1867 with Thomas Edison's invention of the ticker tape. Ticker tape is important because it allowed people to get in on the market's minute-by-minute activity without having to know Morse code. Ticker tape was also the enabling technology for the first information explosion. The NYSE archives are full of pictures of well-dressed gents up to their eyebrows in ticker tape. By its very nature, ticker tape recorded data; thus, it

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spawned the art/science of technical analysis. And it produced some great parades.

Telegraphy and ticker-tape machines caught on in a major way. By the late 1890s, overhead wires had proliferated so rapidly that the light of day was barely visible on Wall Street, which led to burying wires and that technological marvel, the manhole.

The 1930s brought electronic quote boards, but they were unwieldy, Rube Goldberg machines with lots of hard-working kids from Queens standing on ladders behind the boards flipping widgets with sticks. On the computing front, the 1940s brought the first electronic computers. An ENIAC weighed in at 30,000 pounds, had an 800-bit memory, and ran at about a few thousand instructions per second, when it ran at all. Its capacity was a small fraction of the capacity of the Hewlett-Packard programmable calculators many people carry around in their pockets today. The calculators sell for \$60; ENIAC cost about \$5 million in 1940 dollars. The computer was built with tubes, and one tube burned out about every 40 minutes. It required a crew of engineers who did nothing but replace tubes. The first computer bug was found in the ENIAC—a large dead roach that shorted out the circuitry and earned a permanent place in the technical lexicon.

Computers were not really practical devices until the invention of the transistor. This invention, at Bell Labs in the late 1950s, won a Nobel prize for the inventors. By the 1960s, transistors could be manufactured in sufficient quantities for people to build computers with them.

The early machines produced only pictures of data; actually doing anything with the information was difficult. Computers are now everywhere in the financial markets, doing almost everything: trading, arbitrage, market making, and portfolio construction. Electronic execution systems such as DOT, POSIT, Instinet, CINCI, AZX, and Lattice now fill over two-thirds of the orders in U.S. equities. In some markets, such as London and Toronto, computers have entirely replaced the traditional trading floor. The nature and pace of the securities industry has been permanently altered by the phenomenal rise of information technology.

The machine that changed the financial world continues to change it. The previously impossible, impractical, and ridiculous is now on the investment manager's desk. Last year's vaporware (software that exists only in someone's imagination) is this year's investment and trading system and tomorrow's clearance sale.

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## Today's Applications

The pace of technological progress means that in-

vestment professionals can implement more and more of their ideas. Unlimited computational resources are like dynamite, however. Used properly, they can move mountains; used improperly, they can blow your legs off. Managers have more technology than they know how to use, more ways to fool themselves than ever before—at ever-increasing speeds. Applying “wetware,” the grey stuff between your ears, before you go charging up some computational hill is more important than ever. Otherwise, the hill may turn out to be a cliff.

An important use of information technology in finance is to instantiate, extend, amplify, and inspire quantitative ideas. A substantial base of knowledge and theory in finance can be made real with the use of technology, and many computational models exist that suggest new ways of looking at finance.

Technology has transformed portfolio management and optimization. Peter Bernstein's *Capital Ideas* contains a marvelous story about Bill Sharpe wandering around Wall Street in the 1960s trying to shake loose enough computer time to test his capital asset pricing model.<sup>1</sup> A mainframe computer needed about 32 minutes to run a 100-stock optimization program and cost about \$350 in computer time. A realistic portfolio optimization—using, say, the Wilshire 5000—would have taken weeks and cost (at least) many hundreds of thousands of dollars. Today, analysts run such stock-optimization programs during their coffee breaks.

Technology has also changed the way quantitative and technically oriented traders do their work. Back in the bad old days, they looked at one chart at a time. Now, software like Quantex or Instinet Analytics can look at thousands of charts at a time and ring a bell to call a trader's attention to the important things that are going on. Having this software is like having a whole battalion of trading assistants who never go to lunch. First Quadrant manages billions of dollars using models developed by analysts working with traditional econometric tools amplified by the machine-learning technique called the genetic algorithm. The genetic algorithm has, on occasion, improved the models overnight by as much as was achieved in years of conventional statistical work.

Two distinct, but not exclusive, paths exist for using the power of information technology in quantitative money management. One is to exploit the statistical tools already in use, exploit the capacity of the machine to expand the reach, robustness, and scope of the statistical methods that constitute the foundation of quantitative management. The second is to exploit newer, less widely known approaches in forecasting, modeling, and machine

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<sup>1</sup>*Capital Ideas: The Improbable Origins of Modern Wall Street* (New York: Free Press, 1992).

learning.

Many innovative ideas using computer power are relevant to finance and trading. One is the use of technology for presenting information visually in a way that allows the manager to see what could not previously be seen. Other examples involve artificial intelligence and genetic algorithms. Another innovation is the building of adaptive trading behavior using ideas from robotics.

## Visualization

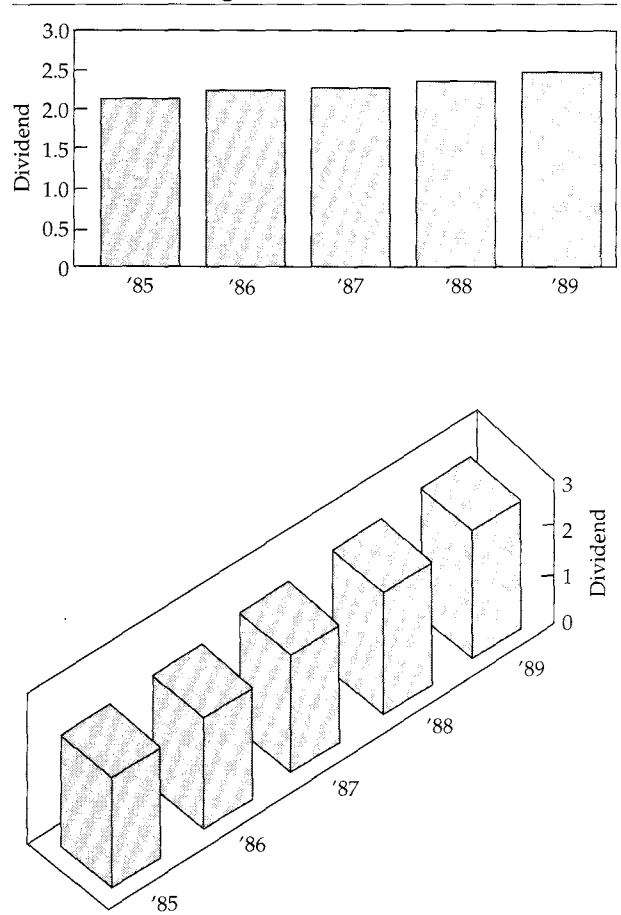
Anywhere a lot of data are found is fertile ground for using visualization—making pictures of data to understand it—and the field of finance is no exception. Modern computers can digest vast amounts of data and convey the information in pictures—from simple charts and graphs to truly innovative, interactive, animated displays.

Visible Decisions, Inc. (VDI), a small company in Toronto, Canada, is an example of innovative producers of the kinds of graphics that are used by some of the larger equity market makers in North America. The people at VDI came from the entertainment side of the computer graphics business. They used to do computer-animated sharks and snakes, and now they do computer-animated stocks and bonds. VDI produces animated displays of equity trading and the order book on the Toronto Stock Exchange that gives traders access to a real-time animation showing bid and ask prices, sizes, trade prices and volume over time, and various other data pertaining to the stocks on the exchange. The VDI staff can slice or dice the data any way they want.

VDI produces a five-dimensional graphic being used to visualize and manage one of the largest bond portfolios in Canada. The five dimensions are the usual three plus motion and interactivity. Analysts can picture the bond portfolio by maturity, issuer, or client. The sizes of short and long positions are immediately apparent. This product replaces reams of printouts. The portfolio manager does “what if” analyses to see the sensitivity of bond holdings to changes in the yield curve. The yield curve is also in the graphic. Managers can adjust it any way they want simply by using their mouse and can call up any kind of projection or simulation. They can “drill down” through the graphic levels to see the details of each position.

As with any technology, a manager can go wrong with graphics. Remember the adage about “lies, damn lies, and statistics”? Statistical graphics take it one more step. Charts abound with curves soaring from the bottom off toward the ceiling. A close look, however, may show a scale starting at 113.7 and ending at 113.9. Other charts, including the famous example shown in **Figure 2** from an

**Figure 2. Lackluster Dividend Growth Given a Flattering Tilt**



Source: *The Globe and Mail*.

actual 1989 annual report, make a major trend out of absolutely nothing using only three-dimensional rotation.

## Artificial Intelligence

Some kind of artificial intelligence (AI) shows up in the financial press as “this year’s breakthrough of the century” every few years. The last breakthrough was expert systems; now, neural networks are in favor. Neural nets have inspired some hyperbolic overselling and lots of truly unreasonable expectations. Plenty of AI research and development is being written off in lower Manhattan.

AI is not, however, some bogus idea dreamed up by a software salesperson. Plenty of AI successes exist. The most famous is Alan Turing, the British mathematician and AI pioneer, breaking the German Enigma code. The result was Hitler losing World War II. Other remarkable, if less historically weighty, achievements can be cited. The world backgammon champion, for example, is a machine; also in checkers, the human champ is a prodigious talent who has

only lost twice in the past ten years—both times, to a computer. AI can beat all but the very top chess players. Computers using AI do symbolic math well enough that they rewrote tables of integrals that were in their 42nd edition. They detect patterns well enough to have prompted a major revision of the National Aeronautics and Space Administration astronomical catalog. They can steer a missile up a tail-pipe from 3,000 miles away.

The biggest AI success is one investment managers use without even thinking about it. Back in the early 1970s, a couple of nerds were working in the Massachusetts Institute of Technology AI lab on something called visual programming. It used mouse actions and a CRT screen to describe an example of the program the user wanted to solve. The user did not need to worry about the usual details of telling the machine how to solve the problem step by step; do it once, and the program could learn the example. Change the data on the screen, and the answers changed. It was a wonderful idea, and it turned up a couple of years later as Visicalc, the first computer spreadsheet. AI had turned half the corporate world into programmers, and they hardly noticed.

### Genetic Algorithms

Of the many alternatives among the new technologies, the most worthwhile are probably found in machine learning, particularly learning based on genetic algorithms. Genetic algorithms are a tool for learning and discovery modeled on the time-tested process of Darwinian evolution (Holland 1992). Potential forecasting models and trading rules are modeled as “chromosomes” containing all of their salient characteristics. Each individual solution’s fitness is then calculated explicitly as a payoff—for example, predictive ability or excess return beyond a benchmark. A population of the fittest solutions is then allowed to “evolve” by being favored for inclusion in subsequent generations. Solutions with the lowest fitness become extinct in a few generations.

Genetic algorithms have been used successfully in many contexts, including meteorology, structural engineering, robotics, econometrics, and computer science. The genetic algorithm is particularly well suited for financial applications because of its robust nature and the importance of the payoff in guiding the process. It is robust in the sense that its use places few restrictions on the form of the financial model to be optimized. Almost any form of constraint can be applied to the algorithm.

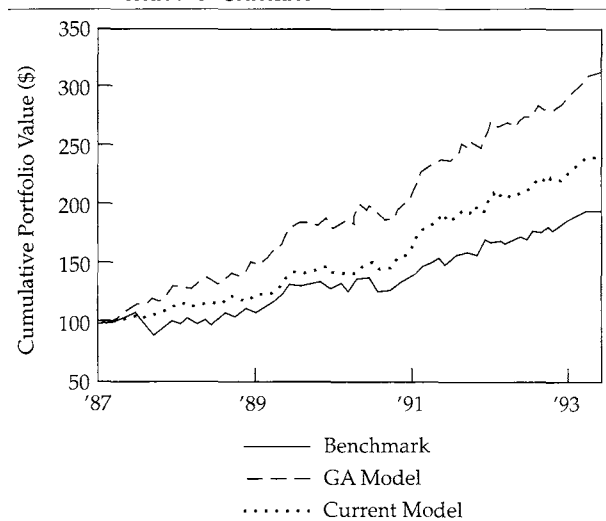
Small problems can run on PCs, but genetic algorithms can use tremendous amounts of computational technology. Depending on the complexity of the fitness function and the population size, they can

quickly require a large supercomputer or a network of high-powered workstation computers working in parallel. This kind of parallel network can exceed the power of the top-of-the-line Cray supercomputers of a few years ago.

The genetic algorithm is highly parallel. The raw fitness of one member of a generation is unaffected by any other member of the same generation. Therefore, entire generations can be partitioned over a parallel network for evaluation. Only the creation of subsequent generations, a small piece of the computation, is not inherently parallel. Thus, a moderate number of workstations organized as a parallel computer can usually be as effective as the largest supercomputers. At First Quadrant, we configure our whole office as a big parallel computer on most nights.

A typical project was First Quadrant’s use of a genetic algorithm to improve our global tactical asset allocation (GTAA) models (Arnott and Hendriksson 1989). As of mid-1992, we were managing more than \$4 billion using GTAA models that had been in use for ten years. At that time, we decided to use the genetic algorithm to “breed” a better set of GTAA models, the GA models. **Figure 3** shows the out-of-sample performance of a GA model and the model that was current at the time relative to the benchmark. The GA model adds about 50 basis points a year for a typical moderate implementation (i.e., with no leverage). First Quadrant now uses the GA in quantitative currency and international equity work as well as in global tactical asset allocation, and it continues to add value (Leinweber 1993).

**Figure 3. Out-of-Sample Performance: Comparison of GA Model and Model Current in 1992 with Benchmark**



Note: Benchmark is 60 percent U.S. stocks/40 percent U.S. bonds; moderate implementation.

Source: D.J. Leinweber.

## Trading Robots

With the use of concepts from robotics, traders can use the information produced by the trading process to improve the process and to bring a wide variety of quantitative notions to bear directly on real-time trading. Robots and traders have more in common than the traders may believe. Both have to integrate many kinds of information from diverse sources. The robot's sensors are cameras, range finders, and feelers. Traders look at price and volume, changes in quoted prices and sizes, and activity in the options and in related securities. Both have a variety of means available to change their environments. Robots move around, pick up auto parts or Mars rocks, and use tools. They monitor the effects of their actions to decide what to do next. Traders place market or limit orders using different execution channels. They monitor the effects (i.e., fills or the lack of fills) to decide what to do next. Both follow a decision process to go from observations to actions, and both may learn from their experiences.

For regular robots, the environment is the hallway, the road, the great outdoors, Mars, or some nasty volcano. Trading robots have the market as their environment. Both have sensors to get information about their environment and effectors to change it.

For regular robots, the sensors are TV cameras, range finders, microphones, feelers, and probes. For trading robots, the sensors are market real-time data feeds and data bases (including the patterns of fills for their own orders) and calculations made using them.

For regular robots, the effectors are wheels, legs, arms, and mechanical hands or tools attached to them. For trading robots, the effectors are the orders they place in the markets and the actions they take to change the type, size, or price of orders.

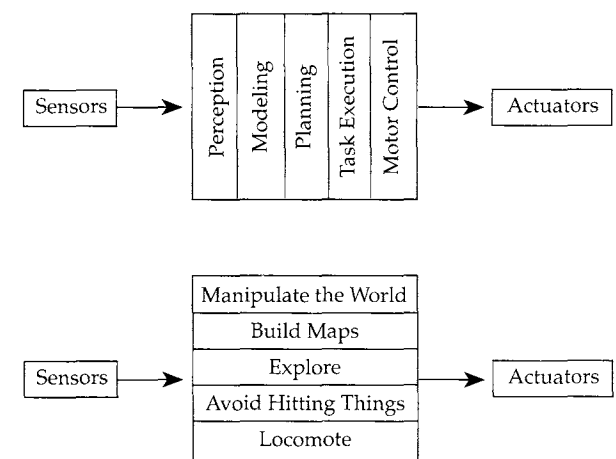
Robot traders are not some cute little beeping droids with flashing lights on their heads sitting in front of a screen and a telephone. Trading robots are simply computer programs with electronic sensors and effectors linking them to the market. Such a robot looks pretty much the same as any ordinary computer. What makes it a trading robot is the nature of the program connecting the sensors (market events) to the effectors (order streams).

Trading robots can use the same sort of "brain" that regular robots use. In both types, the sensors and effectors are simply gadgets until some kind of control process is put in between them to decide how the effectors are affected by what the sensors sense—that is, how the sensors will make the robots behave.

The challenge of building behaviors has been the subject of AI research for many years, and lately some true breakthroughs have been made in the way

people think about robot "brains." Old-fashioned robot brains were complex and not very flexible. The view of robots up to the early 1980s required a continuous, step-by-step flow from sensor information, which was used to build up a detailed model of the "world," to the decisions about actions. This approach to robotics is illustrated in the top portion of **Figure 4**. The robot control program's structure involved elaborate models of the environment and tended to break down in real conditions more complex than simplified, idealized problems. The result was multi-million-dollar robots that embodied dozens of doctoral dissertations but could barely roll down the hall.

**Figure 4. Traditional and Subsumption Architectures for Robot "Brains"**



Source: Brooks (1991).

Rodney Brooks, who worked on one of these disappointing robots, had a great idea for transforming the architecture of a robot "brain" that began with the thought: "An ant can do it." Ants do not build elaborate theories or world models; they carry out a number of low-level tasks and respond to stimuli. Brooks's idea for the architecture of a robot "brain," the bottom of Figure 4, started with very low-level behavioral rules, such as "don't fall over," and then introduced higher level behavioral rules, such as "move around," "explore the environment," and "make maps." The higher level rules, if they are applicable, take over (or subsume) the actions that would be caused by the lower rules. If they are not subsumed, the lower level rules produce the observed behaviors.

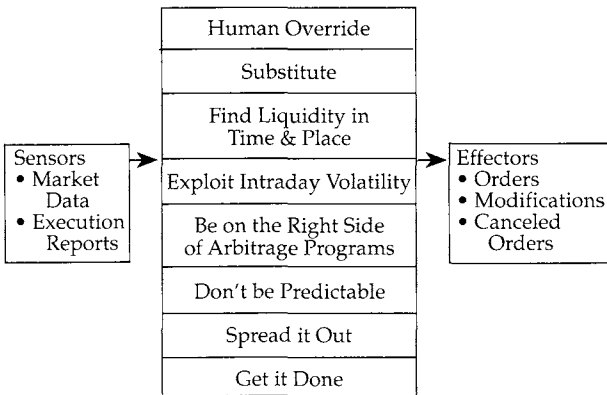
An equivalent hierarchy of rules in trading might be: "fill this order," "don't be predictable to the specialist," and "be on the right side of index arbitrage programs." This subsumption of simple, low-level behaviors by more elaborate ones has allowed Brooks and many other roboticists to build

machines that have capabilities far exceeding their recent predecessors. Brooks's robots and their kind do useful real work in real environments. Trading behavior modeled using a subsumption architecture looks much like real honest nickel-a-share trading.

For example, consider a simple set of subsumption principles for a precommitted equity trade as shown in **Figure 5**. The base level is "get it done" (fill the order). Next comes "spread it out"; then "don't be predictable"; then "be on the right side of index arbitrage programs"; then some higher level behaviors. What kind of trading behavior would a subsumption process running by these rules produce?

Suppose the trading robot has been handed a day order to buy 28,000 shares of a stock that trades an average of 50,000 shares a day. The effects of the

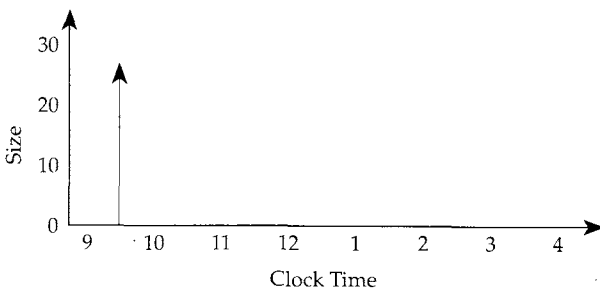
**Figure 5. A Subsumption Architecture for Precommitted Trading**



Source: D.J. Leinweber.

various levels of behavior are as follows: The first level, "get it done," results in the rather stupid trade shown in **Figure 6**—one big market order at the open. The result is one big market impact; buy the specialist a new boat. The next level, "spread it out," results in the pattern of orders shown in **Figure 7**. After awhile, the specialists see the trades coming; they can

**Figure 6. Trader Behavior: Get It Done**

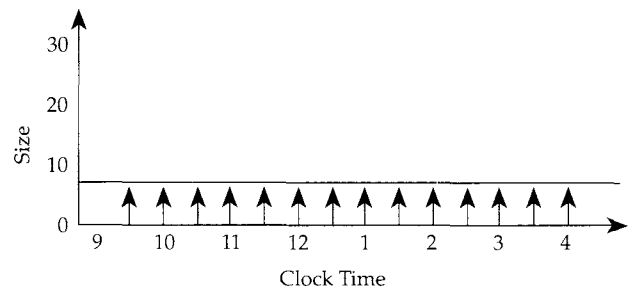


Note: 28,000-share buy; day order.

Source: D.J. Leinweber.

buy a slightly smaller boat than the first trade allowed. The next level up is "don't be so predictable," so orders are made random in size and in time, as shown in **Figure 8**. This trading pattern is more reasonable than the previous two but is still pretty mindless, and it uses no information from sensors at all. The trader could be buying right when the wave of index arbitrage programs is most disadvantageous.

**Figure 7. Trader Behavior: Spread It Out**

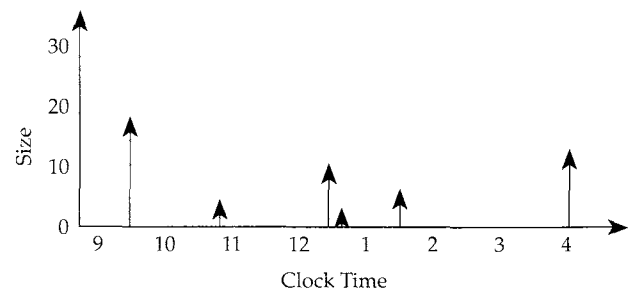


Note: 28,000-share buy; day order.

Source: D.J. Leinweber.

Now, the robot program starts to use sensor data, and the next level in the architecture, subsuming the randomized market orders generated by the level below, suppresses orders during buy programs and accelerates them when index arbitrage trading lowers prices, which is illustrated in **Figure 9**. The trading has now begun to look like nickel-a-share behavior, and limit orders, alternate liquidity channels, feedback from fills or lack of fills over time, or short-term predictive models have not even been engaged. Without going through the full system, you can see how the concept of subsumption architecture, which has been a huge success for regular robots, also applies to building programs that produce very reasonable trading behavior.

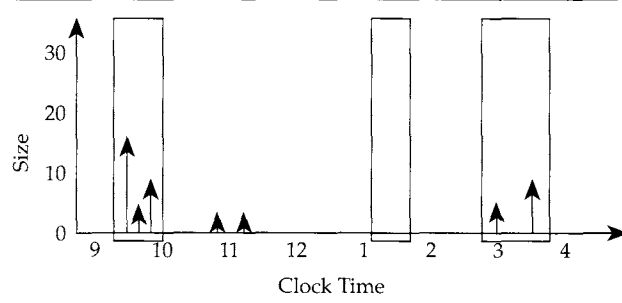
**Figure 8. Trader Behavior: Don't Be Predictable**



Note: 28,000-share buy; day order.

Source: D.J. Leinweber.

**Figure 9. Trader Behavior: Be on the Right Side of Arbitrage Programs**



Note: 28,000-share buy; day order.

Source: D.J. Leinweber.

## Conclusion

Technology is inextricably woven into the financial world. This was true 200 years ago, and it is even more true today. The computational riches that are available allow us to bring many outstanding new ideas to bear on financial problems and to amplify and extend outstanding old ideas. The prediction, therefore, is for more nerds in everyone's future.

Technological change has brought us to the point that we can do almost anything we think up. So, we had better be careful what we think up.