1

WALL STREET, THE FIRST DOMINO

ON A DAY IN EARLY 1987, a man who worked for the Nasdaq stock market—let's call him Jones—showed up in the lobby of the World Trade Center. He found the appropriate elevator bank for his floor and pressed the up button. He was making a routine visit to one of the Nasdaq's fastest-growing customers. Jones knew what to expect. One Wall Street stock-swapping crew is the same as the next: a small lake of white male faces backed by Ivy League educations and appetites for profit. Nothing to see, really.

As he walked down the hallway toward the office suite's front door, he braced himself for the testosterone and chaos that awaited him. Trading floors aren't anomalous from game shows that stuff a person in a glass box full of blowing money—except that in the case of a trading floor some of the fluttering bills are losers. The deft players can discern winning bills from losing ones while maintaining a frenzied pace.

A receptionist greeted him and retreated to another room to fetch his host. When she returned, a short, dapper man with a full head of

silvering hair accompanied her. Thomas Peterffy's blues eyes warmly greeted Jones. He spoke with an accent.

Jones couldn't have known that Peterffy would later become a man worth more than $5 billion, one of the richest people in America. He was still at that point a Wall Street upstart. But his trading volume had been streaming upward, and so had his profits. Jones was always curious as to how people like Peterffy figured out ways to beat the market so consistently. Had he hired the sharpest people? Did he have a better research department? Was he taking giant risks and getting lucky?

What Jones didn't know was that Peterffy wasn't a trader at all. He was a computer programmer. He didn't make trades by measuring the feelings of faces in the pit, the momentum of the market, or where he thought economic trends were leading stocks. He wrote code, thousands of lines of computer language—Fortran, C, and Lisp—all of it building algorithms that made Peterffy's trading operation one of the best on the Street, albeit still small. He was chief among a new breed on Wall Street.

As Peterffy led the way onto his trading floor, Jones grew confused. The more he saw—and there wasn't much to see—the more flummoxed he became. He had expected a room bursting with commotion: phones ringing, printers cranking, and traders shouting to one another as they entered buy and sell orders into their Nasdaq terminals. But Jones saw none of this. In fact, he saw only one Nasdaq terminal. He knew the volumes that Peterffy did—and they were big. How was this possible? Who was making all those trades?

"Where is the rest of the operation?" Jones demanded. "Where are your traders?"

"This is it, it's all right here," Peterffy said, pointing at an IBM computer squatting next to the sole Nasdaq terminal in the room. "We do it all from this." A tangle of wires ran between the Nasdaq machine and the IBM, which hosted code that dictated what, when, and how much to trade. The Nasdaq employee didn't realize it, but he had walked in on the first fully automated algorithmic trading system in the world.

Peterffy's setup didn't merely suggest what to trade, as other systems had in the past. It didn't simply pump out trades that humans would later carry out. The computer, by way of a surreptitious hack into the trading terminal, made all of the decisions and executed all of the trades. No humans necessary. Its trading partners, though, were 100 percent human—and they were getting drubbed.

With the hacked data feed coming from the Nasdaq terminal, Peterffy's code was able to survey the market and issue bids and asks that could easily capture the difference between the prevailing price at which buyers would buy and sellers would sell. That difference, called the spread, could grow past 25 cents a share on some Nasdaq stocks at that time, so executing a pair of 1,000-share orders—one to buy at $19.75 and one to sell at $20.00—resulted in a near-riskless $250 profit.

The trades were even less risky for Peterffy because he utilized machines to execute them. One of the main dangers at that time to market makers, who constantly maintain offers to buy or sell a stock, was leaving stale quotes up after a market shift. Most market makers could only be as fast as their traders, who had to read new prices on a computer screen, assimilate that information, make a decision on how to change their prices, and then cancel orders and type new prices into their Nasdaq keyboards. A trader could fall a few steps behind the market just by taking too many bites of a tuna sandwich or having a chuckle with a colleague. Peterffy's computer didn't need a lunch. It stepped in tandem with the market's zigs and zags, mitigating a high percentage of his market risk, something a human simply couldn't do.

Peterffy's operation marked a new dawn on Wall Street, as programmers, engineers, and mathematicians mounted a two-decade invasion in which algorithms and automation, sometimes incredibly complex and almost intelligent, would supplant humans as the dominant force in our financial markets.

Jones stood agape. Where Peterffy saw innovation, Jones saw somebody breaking the rules with a jury-rigged terminal.

"You can't do this," Jones said.

The Nasdaq had no trading floor; all of its trades took place over the phone or on its computer network that took users' orders as they entered them on the keyboard of a dedicated Nasdaq terminal. Peterffy had taken the incoming data wire meant for the terminal and spliced it, soldering the split end into a circuit board that his team of programmers and physicists had built from scratch and embedded into the motherboard of an IBM PC. The IBM ran software that Peterffy wrote himself. As the PC got data from the Nasdaq wire splice, its algorithms analyzed the market and made quick trading decisions, firing these trades back through a tangle of wires that wound their way into the innards of the Nasdaq terminal. Peterffy, unbeknownst to anybody until that moment, had hacked the Nasdaq.

The Nasdaq didn't need word of this contraption, this mad scientist's laboratory, reaching the market. Would other traders be comfortable knowing they were matching wits with algorithms powered by an IBM rather than other gut-following gamblers? The Nasdaq didn't want to find out.

"The terminal needs to be disconnected from this IBM and all orders need to go through the keyboard, typed one by one—just like the rest of our customers," Jones said.

Jones left. Peterffy stood in his office contemplating what might be the end of his business. The Nasdaq had given him a week to comply with the inspector's edict. The thought of dismantling his machine wrenched Peterffy. He had little interest in going out and finding traders, even young and cheap ones, to sit in chairs and punch orders into Nasdaq terminals. It had taken him years to wring the human element and its capricious whims out of his operation. It would be difficult to reinject people, their errors, their laziness, and, most important in this case, their slow typing back into the process and expect the same results. His operation was going to lose most of its efficiency overnight. There had to be a better option.

Before he went to sleep that night in his Upper East Side apartment, a solution came together in his head. It wouldn't be easy, but it offered

possibilities. Peterffy thought he could pull information from the Nasdaq terminal without touching the machine. No spliced wires, no attached circuit boards, none of that. But how to do it? He asked his crew of engineers and physicists if they could build something that read data straight off the screen, like a camera, and then translated that information into electronic bits and sent it to the waiting IBM PC. The answer was yes.

But the data feed was only half the problem. How would Peterffy execute his trades without having a team of people sit at Nasdaq terminals? He could not send a wire back into the machines as he had done before. No, the trades had to go through the keyboard, just as the Nasdaq had ordered. Peterffy had an idea, a crazy idea. But could such a thing work?

During a frantic week, Peterffy and his best engineers welded metal, wrote code, and soldered wires. They affixed a large Fresnel lens to the face of the Nasdaq terminal to enlarge the screen's text. A camera was placed a foot from the lens. From the camera, a wire led to a computer sitting adjacent to the apparatus. In just a few days, Peterffy and his programmers wrote software that would decode the visual data streaming in from the camera. From there, the data could be plugged into Peterffy's existing algorithms that once used the direct wire from the Nasdaq terminal.

A new wire now came out of the IBM and, instead of slithering into the case of the Nasdaq terminal, ran into a nest of metal rods, pistons, and levers hovering above the terminal's keyboard. If the camera and screen-reading rig appeared odd, this piece of the system was downright bizarre. It evoked the intricate mechanical looms of the Industrial Revolution. The device was an automated typing machine, built from scratch. As orders came from the computer, the machine's rods rapped the terminal's keys in staccato bursts. Orders flew out one after another, with dozens logged in under thirty seconds.

The Nasdaq said trades had to be typed, but they didn't specify who had to type them. Peterffy's team had created a trading—and

typing—cyborg. And it had taken them six days. He had obeyed the letter of the law, but had, by any definition, violated its spirit. But that didn't worry him much. Wall Street is nothing if not a den of loopholes, work-arounds, and back doors that favor the most inventive of finaglers.

The Nasdaq inspector returned a week later, as promised. Peterffy met him at the elevator and led him down the hallway to his trading room. A steady clinking emanated from the door. Where once had been silence, there now arose a racket, just as it should be on a trading floor. Peterffy led Jones through the door and, with a flourish, gestured to his creation. The Nasdaq man drank in a scene that could have been conjured by Jules Verne.

"What is this?" the man said.

Peterffy explained that his machine put in the trades just like the Nasdaq requested—by keyboard input, one at a time. Just at that moment, the market came to life, as did the machine. Peterffy's program began trading so rapidly that the typing apparatus fired like a machine gun. The continuous stream of orders caused the machine to mash the keyboard furiously, creating a chaotic din that made conversation impossible. Each time it seemed a lull had set in, the machine would fire out more orders, refilling the fleeting silence. The whole operation was yet another marvelous rule bypass brought to the world by the flexible minds on Wall Street.

"He did not like this one bit," Peterffy recalls.

Feeling he had nothing to lose at this point, Peterffy offered to build a mannequin into the contraption and make the doll strike the keys. He was half joking, but he would have done it. Jones's face remained tight.

As the man shook his head, Peterffy grimaced. He had built the fastest trading machine in the world and he now fully expected to have to take it apart. After stewing for several minutes, the Nasdaq man stalked out of Peterffy's offices wordlessly. Peterffy prepared for the worst: a fiat from the Nasdaq that would ban his technology from the market. But Jones never came back, and the phone call Peterffy feared

never came. His operation left intact, Peterffy, who had begun with less than $100,000 several years before, made $50 million in 1987.

Peterffy was still a Wall Street minnow in 1987, but he was one of the lead fish in a new pack of market players who were as adept writing complex code, soldering semiconductor chips, and employing math as they were negotiating labyrinthine market structures. What Peterffy had done was simple in theory and complicated in execution: he had taken the brains of the smartest traders and found a way to express those smarts in a series of algorithms. His programming included all the elements that a crack human trader weighed in making a decision. But the computer took far less time to do the math, check the prices, and pull the trigger.

There would be others to wield software, code, and swift computers to beat the market, but Peterffy's innovations, from keyboard-hammering pistons to hacked data feeds, sparked this revolution. Today, 60 percent of all trades are executed by computers with little or no real-time oversight from humans. The story Peterffy weaved is unique on Wall Street. He wasn't a big-shot trader who presciently hired programmers to further his dominance. Nor was he a Wall Street player who taught himself coding to gain an advantage over the rest of the field. What made Peterffy unique was that he was a programmer—and a good one—long before he ever understood how a stock option worked or how shares of different companies often move in tandem.

Using his programming skills, his understanding of math, and his mastery of writing complex code, Peterffy created layered algorithms to disrupt a field new to him: the trading floors of Wall Street. This disruptive hacker paradigm has played out across varying parts of our world during the latter years of the twentieth century and opening of the twenty-first: a deft engineer of computer code and algorithms takes an interest in a new field, develops expertise, and, by applying computer science and clips of code that mimic their human forerunners, topples industries, companies, standards, and the old guard. The ability to create algorithms that imitate, better, and eventually replace humans

is the paramount skill of the next one hundred years. As the people who can do this multiply, jobs will disappear, lives will change, and industries will be reborn. It's already happened, and it will continue. And as with any trend, this one follows the money. That's why it began on Wall Street, in no small part thanks to a Hungarian immigrant.

THE MAKING OF A HACKER, THE HARD WAY

Thomas Peterffy may have become one of the most important figures in this thirty-year tale of creeping algorithmic takeovers, but he was born not into a world of access but into the sounds of the bloodiest war in human history. Delivered in the basement of a Budapest hospital during a 1944 bombing raid, Peterffy was raised by his mother and grandparents after his father fled the Soviet-backed communists who took over Hungary following World War II. He remembers a childhood of fear, of relatives disappearing, of moves in the middle of the night, and of the constant threat of starvation, freezing, or worse.

Peterffy discovered capitalism in high school, when he sold smuggled sticks of Juicy Fruit gum to students at a 500 percent markup. At thirteen, he organized several crews of boys who would raid abandoned buildings and rubble heaps for any metal that could be scavenged. He bartered with men three or four times his age and found the best prices for his scrap, splitting the proceeds among his crews. He later turned his industrious focus to stamp buying, selling, and trading. The irregular market, in which some stamps sold for more in one place than they did in another, enthralled him. He had discovered arbitrage, where one takes advantage of similar asset markets with disparate prices. An arbitrageur buys where the price is lower and sells where the price is higher—a strategy that, in far faster form, comprises the backbone of many modern high-speed trading operations.

After graduating high school, Peterffy studied advanced geometry in a technical school for surveyors, with a long-term goal of college and

a degree in civil engineering. But his education was derailed in 1965 when, at twenty-one, he got a short-term visa to visit some distant relatives in West Germany. He seized this opportunity in Americanized Germany to apply for a U.S. immigration permit, which he eventually received. Boarding a plane to New York, the young Hungarian had little concept of Wall Street, let alone the computers and algorithms with which he'd conquer it.

He found lodging in a two-room apartment on the Upper East Side with a monk who had been excommunicated by the church for drinking and womanizing. The monk brought Peterffy into his business for a time as an unofficial notary public for Hungarian immigrants. Through the growing Hungarian immigrant network in New York City, Peterffy eventually found a new apartment and a job drafting plans at a civil engineering firm.

By the mid-1960s, computers had just begun to fall within reach of small businesses. The boxy machines soon flooded the offices of well-intentioned business owners who believed harnessing computing power would bring them more clients and more efficiency. But the grand arrival of computers in these places was met with a dearth of people who actually knew how to program them. Many computer buyers felt stymied when they discovered that, for all the fanfare, using a computer was hardly liberating. It was difficult. For that reason, many of the machines purchased during this era collected dust, unused and relegated to closets and back rooms.

When Peterffy's firm bought its first computer in 1966, nobody at the engineering company knew how to program it. Peterffy volunteered. He pored over the English manuals and began to pick up coding. He created simple algorithms executing the Pythagorean theorem, ones that determined angles using sine and cosine functions, and others that helped engineers prescribe the radii and slopes of joining roads. By the end of 1966, he had built the firm a library of programs while collecting sixty-five dollars a week in salary. Picking up programming was easier for him than learning how to converse in English. He excelled.

Just as is the case now, good computer programmers in the late 1960s didn't want for jobs. Writing code offered Peterffy a clear path to more money and better work. His first opportunity came in 1967 when he left the engineering company for a position at Aranyi Associates, a firm that helped its Wall Street clients set up computer systems. The job, again, came through native networking; the firm's owner, Janos Aranyi, was a Hungarian immigrant.

On Wall Street, Peterffy confronted what we'll call phase zero of the algorithm story, which is to say that algorithmic bots had no place in this era of people's lives or on Wall Street. It was a world of human choices and human strategy executed by humans. A trader made a decision on the floor based on where he believed the market was headed, the securities he already had in his pocket, or, in many cases, an ambiguous gut feeling. He signaled his trade to another human, who took note of the transaction in a notebook. This was the world.

In his first finance job, Peterffy built algorithms allowing investors and traders to easily compare securities' different characteristics and values all at once. Bearing down with an intensity that came from being an immigrant with little else on which to focus, he made himself into a formidable programmer at a time when there existed few—and almost none of them on Wall Street.

After two years with Aranyi, Peterffy's computer skills landed him an interesting job offer with one of the best-known players in New York's markets: Dr. Henry Jarecki, a psychiatrist who had taken a fancy to trading commodities and during the 1960s built a large precious metals trading company that took the name of Mocatta Group, after Mocatta & Goldsmid, a three-hundred-year-old London firm with which Jarecki had originally partnered.[1] Jarecki started Peterffy with a $20,000 salary and a $4,000 bonus—about the equivalent of $145,000 in 2012 and good money for somebody a few years removed from sharing an unheated apartment with an excommunicated monk. Peterffy found the metals market intuitive and moved up quickly at Mocatta as his programming skill became indispensable.

THE ALGORITHM THAT CHANGED WALL STREET

With Jarecki in 1969, Peterffy introduced one of Wall Street's first so-called black boxes, which inhale market data, chew on it, then issue an instruction to their user, in this case whether to buy or sell. The calculus of an algorithm making trading decisions—really, any decisions—is built out of models, functions, and decision trees that at first are largely based on how humans make similar decisions. If Mocatta's traders usually dumped gold on Friday because they noticed that other traders got bullish before the weekend, then such preferences were written directly into the program. But it was also possible that Mocatta traders ignored their Friday selling rule when gold had been down the previous four days in a row. This condition too would be written into the computer program through a series of linked algorithms.

In 1969, Mocatta traders dialing on phones or shouting in pits made the actual trades, but the decision to buy or sell came straight from code Peterffy wrote. As good as Peterffy had become, there was one black box that had eluded him. Jarecki had asked him to come up with an algorithm that could peg exactly the correct price for options, whose prices, like anything else, obeyed no particular set of rules other than the vacillating whims of traders in the pit. Peterffy had spent months on the problem and produced little of use.

An option confers the right to buy or sell a given security at a set price before an expiration date. If IBM is trading at $100 and a trader is convinced it will shoot up during the next month, he might buy a call option that gives him the right to buy the stock at $100 during the next two months. The call option might only cost $10, so it's quite a bit cheaper than buying shares of IBM; a call option's downside is also limited—the most a trader might lose is simply the price of the option, or $10. The trader who sells the call option usually holds some IBM himself and is hedging against a dip by selling the call and pocketing that cash. He will have to surrender his shares for $100 if, say, the price

shoots up to $110. Put options, conversely, give one the right to sell a stock at a set price in the future. So buying a put to sell IBM at $100 is a bearish bet, because it only succeeds if the price of IBM falls. Buying a call is bullish.

In the early 1970s, options had just begun to change hands with frequency. Mocatta was one of the firms leading the way. Jarecki and Peterffy had come to the conclusion that there were three main ingredients to pricing an option: the price that the option allowed one to buy or sell the stock for—called the strike price; the expiration date; and the volatility of the stock or metal. For instance, the options for a security whose price can swing wildly should be more expensive, because it's more likely that extreme strike prices will be hit. Other ingredients matter too, such as the prevailing risk-free interest rate, which forces the price of call options up and the price of put options down. Peterffy needed a way to express all of this in one elegant algorithm that rightly weighted each factor. It was a complicated math problem that he found nearly impossible to solve. He cycled through spurts of dejection and inspiration.

After working on the problem for more than a year, Peterffy devised an algorithm of differential equations that cleverly weighted all of the ingredients. He back-tested the algorithm to see if it would have made money in the past, but the data sets for commodities options at that point in history were limited. This was before computers handled such things adeptly and, more important, before the options market had much history. So Mocatta did the only thing it could: it started trading with the algorithm. It made money. The options markets weren't the giant realms they are today, so the algorithm wasn't able to harvest billions of dollars, but it gave Mocatta's traders a big edge. Most of the company's pit people didn't know where their trade orders came from; they knew only that their trades almost always worked. This is phase one of an algorithmic takeover: a computer, equipped with human-composed algorithms, analyzes inputs and issues marching orders to humans.

About a year after the men had put their algorithm to work, a thunderclap sounded above Wall Street. In 1973 Fischer Black and Myron Scholes, both professors at the University of Chicago, published a paper that included what would become known as the Black-Scholes formula, which told its users exactly how much an option was worth. Algorithms based on Black-Scholes would over the course of decades reshape Wall Street and bring a flock of like-minded men—mathematicians and engineers—to the front lines of the financial world. The Black-Scholes solution, quite similar to Peterffy's, earned Myron Scholes a Nobel Prize in 1997 (Black had died in 1995).

Change didn't happen overnight. The Black-Scholes formula, a partial differential equation, was brilliant. But most traders didn't peruse academic journals. Even if they did, employing the formula wasn't simple; it took significant math skills to wield. As few people as there were who understood Black-Scholes, even fewer knew that a Hungarian had written a similar algorithm that made money on almost every trade. Peterffy and Jarecki kept it quiet.

At a 2010 black-tie banquet in Chicago, a spry Jarecki spotted Scholes across the room nursing a cocktail and lightly conversing. Jarecki made his way over to the Nobel laureate. "You know, you still have our Nobel Prize," Jarecki said to Scholes. The remark elicited a dry grimace. "He was not amused," Jarecki says.

For traders who understood it, Black-Scholes gave them a way to calculate the exact price at which options should be traded. It was like having a cheat sheet for the market. There was money to be made by anybody who could accurately calculate each factor within the Black-Scholes formula and apply it to options prices in real time. Traders using the formula would sell options that were priced higher than the formula stipulated and buy ones that were priced lower than their fair price. Do this enough times with enough securities and a healthy profit was virtually guaranteed.

TO BE A WALL STREET HACKER IN 1980: PERFECT PLACE, PERFECT TIME

The late 1970s marked the faint dawn of the hacker era on Wall Street, when algorithms began to step in front of humans, a trend that has come to dominate all financial markets in every corner of the world. Wall Street began to peel away an increasing share of the best math and science minds in the United States and put them to work programming and conceiving trading algorithms. Before Black-Scholes got hold of the market, there had always been a slow trickle of engineers and mathematicians into lower Manhattan, but they were rare.

The engineering and science halls at MIT, Harvard, and other elite universities became places where recruiters wrestled for leverage. Wall Street would always be there, around the corner, skulking about with its promises of cash, glamour, and bonuses. The financial industry would eventually succeed not only in pulling away promising young talent from research universities and tech companies but also in luring accomplished and veteran engineers and scientists from cushy positions of prominence in tech and academia.

Why did Wall Street want all of this talent? For speed. Those who are first in to a good trade win—and algorithms running on computers will always beat a human looking for the same kinds of trades. Being able to express algorithms in the form of code in the late 1970s was not a common skill. This is why Peterffy, an outlier with his fifteen years of coding experience and ten years of plying the markets, found himself in as perfect a position as anybody in the world to lead the coming changes on Wall Street.

Having written the options algorithm, Peterffy began to build his programming department, bringing on more coders as their utility expanded in the market. Mocatta, through Jarecki's trade smarts and Peterffy's mastery of algorithms, began to make millions of dollars and became one of the most powerful commodities traders in the world. As

Mocatta grew, so did Peterffy's hacker army. By 1975, they employed fifty programmers, making the company one of the few mainstays of programming knowledge on Wall Street.

What were all of these programmers doing? Most of them were helping Peterffy put trading algorithms, conceived by himself and Jarecki, into code that could be executed by a computer. As the algorithms grew more complicated, better code and more programmers were needed.

Algorithms can start as simple things. Take one for, say, doing the laundry. The inputs could be as simple as (1) the weight of the laundry and (2) the type of fabric. The algorithm would take the weight input and, if it were below one pound, set the washing machine's water level to low. It would then take the fabric input of "cotton" and set the machine's water temperature to hot for the wash and cold for the rinse. Different weights and fabrics would elicit different washing programs from the algorithm. But what if the algorithm had to also pick the exact right wash according to the laundry's colors, stains, presoak needs, drying time, and detergent types? Composing such an algorithm is well within the reach of any sophomore-year computer science student, but is still multitudes more difficult and layered than the first algorithm whose only inputs are weight and fabric. Humans can easily dispatch a load of laundry with multiple washes and needs without stretching their brains; writing a computer algorithm with the same capabilities, though, takes skill. All of a sudden, there are hundreds of possible solutions based on inputs. Each one has to be accounted for and rightly categorized for the algorithm to work correctly.

In this way, algorithms can be looked at as giant decision trees composed of one binary decision after another. Almost everything we do, from driving a car to trading a stock to picking a spouse, can be broken down to a string of binary decisions based on binary input. Is there a red item in the laundry? No. Are there black items? Yes. Are they nylon? No. Are they cotton? No. Are they silk? Yes. Do these black silk items have an existing stain? Yes. Is it a stain from coffee? No. Is it a

stain from mayonnaise? No. Is it a stain from cheese sauce? Yes. And so on. These binary decision trees can grow to millions or even billions of nodes for complicated subjects. The algorithm's tree may take inputs and run them through equations and formulas, then take those answers as further inputs, creating long strings with repetitive layers and mind-boggling detail. The German mathematician Gottfried Leibniz theorized on this exact subject three hundred years ago—that life could be broken down into a long series of binary decisions—long before there existed semiconductors to facilitate machines that could run algorithms.

Peterffy's algorithms grew to be spidery matrices with hundreds of inputs, variables, and dependent differential equations and integrals. Putting such things into computer code took a true master and a large team. At Mocatta's headquarters in Manhattan, Peterffy's programmers worked at computer screens and read market data as it came in on Teletype machines. The programmers then typed the data by hand into their computers, whose algorithms issued prices for Mocatta to quote on the New York Commodities Exchange floor. The programmers, speaking to clerks near the floor action downtown, would bark out quotes as fast as the algorithm issued them, and Mocatta's clerks would signal the prices to their pit traders with hand gestures. It was hardly high-speed trading, but it was the first time markets were consistently dictated by an algorithm. And the best part for Peterffy: the rest of the market had little idea where he got his numbers from.

He might have entered Wall Street as a hacker with little market sense, but Peterffy's trading instincts—born while chopping up chewing gum sticks, chasing scrap metal, and pawning stamps—became sharpened. Jarecki noticed. He came to lean on Peterffy for advice on any significant decisions or trades that Mocatta made. One coworker remembers Jarecki never entering an important meeting without Peterffy at his side.[2]

By 1976, Peterffy's hacker force had grown to eighty. It was the largest financial programming operation in the world. Peterffy had proven

himself not only a nimble writer of code but also a capable manager of disparate and sometimes brilliant scientific personalities—a rare and nuanced skill.

Even as Mocatta grew, its business remained mostly in commodities. Peterffy wanted to bring his algorithms to the stock options pits, but Jarecki wanted to remain focused on metals. The markets for stock options were dominated by traders who had come from the stock exchanges, where a company's value was determined by men in the pits—and rightly so. There are a number of nonquantifiable elements affecting stock prices, such as goodwill, growth prospects, looming lawsuits, and competition; for that reason, there's no magic formula for determining the price of a stock. Option prices, however, should be pure reflections of probability and statistics. Only a very select few, including Peterffy, knew this. For those who understood the math, opportunity ran like a river.

When the Chicago Board Options Exchange became well established by the late 1970s, Peterffy took it as a sign that the stock options market was about to explode. In 1976, he traveled to Chicago to check out the CBOE. The bid-ask spreads on some of the options were as much as two and three dollars. "The traders just made these prices up and threw them out there," he says.

With the burgeoning possibilities of stock options, Peterffy wasn't satisfied sticking to commodities. Volume on the gold and silver markets and their related options, Peterffy knew, weren't sufficient to build a true Wall Street fortune. He was also thwarted in his desire for a piece of ownership at Mocatta, which he says Jarecki had promised him. Jarecki denies ever making any such agreement.

In 1977, Peterffy spent $2,000 on his first home computer, an Olivetti. After putting in days at Mocatta, he spent nights programming his Italian machine with algorithms, preparing for the day he would storm the market for stock options.

THE ORIGINAL ALGORITHMIC TRADER

With no possibility of becoming a part owner at Mocatta, Peterffy decided he had squeezed all he could from his tenure there. So in 1977, with $200,000 in savings, he left the stability of employment and bought a seat on the American Stock Exchange, which had just begun to trade options. The seat cost him $36,000, leaving him $164,000 to trade with.

Leading up to his first day at the AMEX, Peterffy toiled at his computer for eighteen hours a day, tweaking his algorithms and producing sheets to guide his buying and selling of options on the floor. He homed in on a few dozen companies whose options he believed were more often mispriced than others. For each company, he made a series of sheets listing option values for different prices of the company's stock. As stock prices fluctuated throughout the day, Peterffy planned to quickly consult his sheets, determine the fair price of the stock's options, and buy or sell accordingly. The sheets were the paper manifestation of his algorithms.

Peterffy packaged all of his papers together into a three-ring binder that would serve as his portable cheat sheet in the trading pits. He found preparing for the AMEX difficult, not because he wasn't confident in his calculus—his methodology was his rock—but because he was scared of working alone, being utterly independent. He was worried about his accent and having to jostle, bounce, and shout with throngs of demonstrative and sweaty men in the pits. He fretted about clubby groups of traders ganging up on him, ending his experiment prematurely and unfairly. Most of all, he worried about failing, about having to return, defeated, to Mocatta.

Determined to not let that happen, Peterffy showed up on the AMEX floor, binder in hand. He quickly discovered that the binder, when held out in front of him, effectively made him the size of two traders in the packed pits. Other traders did not appreciate surrendering space so that he could crack open his magic book. And just what

the hell was in the book, anyway? the other traders asked. Trading, they preached, was about your wits, your guts, and your balls, not some goofy clutch of papers.

"People thought I was absolutely ridiculous working out of this binder," Peterffy says.

So to fit in, and to make life generally easier for himself in the pits, Peterffy boiled his most important notes down to a series of double-sided sheets that he could easily fold and stuff into his back pocket. When he thought the price was right, he would dip into his pocket and consult his sheet. As he stood there reading the tiny print that came from his algorithms, the tide of the pits shoved him to and fro. But he carried on, oblivious to the jostling, until he could shoot his head up, raise his hand, and catch the eye of another trader or market maker, barking out his order in a heavily accented burst of words. The accent, in fact, was a problem; so too was his peculiar habit of consulting grungy folded sheets of paper from his pocket. The other traders, Peterffy says, "thought I was quite mad."

Peterffy would sometimes spend hours in the pits without uttering a word or making a single trade. He religiously consulted his sheets. If an option didn't fit his very conservative profit guidelines, he didn't buy it. "I was very careful," he says.

Despite his caution, Peterffy couldn't avoid the market's mandatory beatings for neophytes. Early in his trading career, he spent a morning swapping options on DuPont. In the middle of the session, he noticed an out-of-the-money call option selling for $31. According to his sheets, the option was actually worth $22. He planned to go short. "That was a big profit for a little Hungarian guy," he says.

Peterffy actually had three hundred of the options contracts that he had picked up for $18, so he sold those at $31 and then sold two hundred more. He had sold two hundred call options without covering his call—he hadn't bought a corresponding number of shares or hedged his bet with put options in the other direction. A move against his bet could crush him. But how could he pass up such a deal?

Just after Peterffy sold the calls, DuPont stopped trading. News trickled in. The company announced earnings much larger than expected and a two-for-one split of the stock, whose price soared. Peterffy's two hundred options contracts, each representative of one hundred shares of stock, left him on the hook for a $5 loss per share, or $500 per contract. He had just blown $100,000, more than half of his trading capital. He blames the incident on people trading with insider knowledge. Whatever the reason, the $100,000 loss was a calamity. "I didn't know if I should throw up or cry," he says. He went home that night devastated, unsure of his methods. "I had thought I was so clever."

Smoking a cigarette, staring at his small kitchen table in his Upper East Side rental, Peterffy thought he needed to dedicate even more of his life, his money, and his attention to trading, although by most standards he was already maniacally focused. The only way to dig out of this hole, he decided, was to become a machine bent on one thing: trading, saving, and winning. Nothing else mattered. Peterffy got up from the table and threw his pack of cigarettes into the kitchen garbage. He would never smoke again. The cash he spent on cigarettes would be better utilized on the trading floor, he reasoned. "I instantly calculated how much money I could save in twenty years by no longer smoking," he explains. "I needed everything."

Peterffy returned to the pits with a renewed focus. He stuck to his sheets, as always, but with DuPont haunting him, he didn't make what he called "cowboy bets."

He slowly rebuilt his capital, one grinding day at a time. Sticking to his algorithmic system, he rarely experienced days with substantial losses. Even though the Black-Scholes formula had been published seven years before, it wasn't moving the markets enough to bother Peterffy or others who were cashing in on its genius.

As effective as his algorithms and sheets were, Peterffy was only one man. He needed more people in the pits. So he slowly hired more traders. To prevent losses and keep control of how his traders operated, he

trained them to bid and offer only off of values on his sheets, which he would update with fresh numbers from his algorithm every night. As he expanded his operation on the AMEX, Peterffy renamed his trading operation Timber Hill, after a road in rural New York where he vacationed. He bought more trading seats and began dabbling in other strategies such as pairs trading and arbitrage, both of which he was familiar with from his time developing tactics for Mocatta.

Even with additional traders jostling in the pits for him, Peterffy spent hours ruminating on ways he could drop all of his floor-trading theories into a computer that could execute his algorithms far better than people on a trading floor. But there was no avenue to do such a thing, not yet. The nature of the pits bedeviled him. The ceilings of the trading floor were more than forty feet high and the pits themselves were lined by railings where clerks would stand, far above, and signal to their traders below what to buy or sell. "Everybody knew everybody's signals," Peterffy says, so that much of the pits knew what was coming from some traders before they ever lifted their arms, resulting in their trades being ambushed or stolen. "It was ridiculous."

Peterffy circulated an idea that bids and offers could be entered by all traders on handheld devices tethered to a central computer that would automatically track price-time priorities and spread the deals out fairly. The idea didn't last long, as those in control—the specialists—quashed it.

Rather than changing how the market worked for the better with technology, Peterffy decided to join in a larger capacity and become a market maker in some options on the AMEX, thinking the higher volumes would lower his risk and raise his profits so long as he was able to keep trading in bands he knew to be fair according to his algorithms. But first he had to find a way to have his bids and offers instantly and consistently recognized by the specialists who controlled trading. Because he didn't traffic in the normal scuttlebutt and sports chatter that most traders did, he was something of an outsider. The specialists didn't always call out his trades from the crowd because they simply didn't

enjoy dealing with him. So the Hungarian decided to hire people whom he knew the specialists would like.

The financial industry, as is the case with most high-paying fields, tends to be dominated by men who are wont to hire more men. So when Peterffy hired the tallest, prettiest, most buxom women he could find, the plan was more than a bit novel. The tactic worked miracles for his order flow. Suddenly, the specialists always took his trades. They put their arms around his traders, chitchatted, and recognized the blondes' orders as fast as they were issued. "The specialists were thinking, 'These dumb blondes, what do they know, right?'" Peterffy says.

It's true that the women Peterffy hired didn't know much about trading, let alone algorithms. But none of his traders at that time were any good out on their own. And none of them were using the sheets for guidance anymore. Peterffy had devised a new system that empowered anybody to make smart trades.

Like many innovations, the system was conceived by accident. In the middle of 1982, Peterffy tore several ligaments in his knee. During his rehab, the knee became infected and he was unable to stand on the floor for long periods, let alone wrestle with the meatheads in the pits. Relegated to his office upstairs at the AMEX, he called trades downstairs and was left by himself to tinker. His attention eventually settled on his Quotron machine, which gave users one stock or option price at a time. The data for the Quotron came in on a dedicated phone line. Peterffy had asked Quotron, which dominated the data industry at the time, if they would sell him the feed they sent to their machines. The answer, every time, was a curt no.

Cooped up in his office, Peterffy took to the Quotron feed with a pair of wire snippers, a move that would later inspire his Nasdaq hack. "So, of course," he says, "we stole the data."

Upstairs, having severed the wire to his Quotron machine, Peterffy wielded the old-school tools of an electrical engineer. He used an oscilloscope to measure the electric pulses in the wire and, matching the pulses to data, decoded what the wire's signals meant. Once he knew

that, he wrote a program for his PC that would inhale the Quotron data as it was issued and store it within its memory. The program would then scan the warrens of stock and option data and route it through Peterffy's algorithms. First and foremost, the algorithms searched for options that were egregiously mispriced.

What Peterffy was especially interested in—and what he wrote his algorithms to search for—were what's known as delta neutral trades. In these trades, an overpriced call option, which Peterffy would sell, could be coupled with buying an underpriced put option to create a position that wouldn't be adversely affected by a spike or a dip in the market.

For example, say shares of IBM were trading hands at $75. A delta neutral trade for Peterffy could look something like this: He would sell 10,000 call options (the right to buy IBM at a strike price of $75 during the next sixty days) for $1 each (the overpriced option), taking in the $10,000. Almost simultaneously, another Peterffy trader would buy 10,000 put options (the right to sell IBM at a strike price of $75 during the next sixty days) for 85 cents each (the underpriced option), for $8,500. The result of the trade: a near-riskless $1,500 profit.

Because options on stocks of big companies such as IBM traded at dozens of different strike prices as well as multitudes of diverse expirations, the 1980s options market was rife with delta neutral trades for those who could find them. Some floor traders had caught on to the tactic—they scanned the tapes and tickers for mispriced options that could easily be hedged for riskless profits. But the power of a few men searching out trades in the pits was no match for Peterffy's indefatigable machine.

The computer would put together trades that made for delta neutral plays and print them out immediately. Peterffy, confined to a chair with a bum knee, would then place a call to his floor clerk, who would get the trades to his corps of women. And on it went. Four months after hacking the Quotron link and getting his computer system operational, Peterffy was making more money than ever. The key to it all was a dependable flow of pure data that few others had. And data, as so many

hot companies of today have demonstrated, can be the difference between domination of an industry and failure. Peterffy's operation pioneered the automated compilation and employment of vast data stores on Wall Street, where the mining of such things got its start.

THE ALGORITHM GOES HOLLYWOOD

After installing a trading system that leveraged a hacked Quotron machine along with attractive female traders fresh to the pits, Peterffy felt he had built the perfect profit engine. "Anybody," he told friends, "can make money trading with me. Anybody."

Wall Street men being Wall Street men, many called Peterffy on his assertions. How ridiculous his bragging must have sounded—to claim that anybody in his system could wade into a pit full of veritable experts, people who had spent entire careers honing their instincts and trading prowess, and take money from them. Peterffy stood his ground, and to prove it, he brought on Melvin Van Peebles, who was friends with Peterffy's old boss, Jarecki, and as unlikely a person as any to end up in the trading pits. In 1971, Van Peebles wrote, directed, produced, and starred in *Sweet Sweetback's Baadasssss Song* in a furious nineteen days. He needed a $50,000 loan from Bill Cosby to get it done, but the film eventually became a hit, grossing $10 million and launching Van Peebles's career as a producer, director, and actor.

Despite his celebrity status and an already busy life (at the time, Van Peebles was busy producing Broadway musicals), the writer, intrigued by the nature of Wall Street, went to work for Peterffy's Timber Hill alongside the firm's other traders, all women, in November 1982. He remained on the floor for Timber Hill an entire year, surprising almost everybody except Peterffy and himself. "I'm doing just what I've always done—making deals," Van Peebles told *New York* magazine.[3]

Van Peebles also made money, a lot of it. He explained his success: "You gotta be able to calculate doo-boop-be-deeliyaboop—deal! I can

do that."[4] He had learned math, he said, studying astronomy in the Netherlands and in the air force, but it's most likely any math being done for his trades came straight out of Peterffy's algorithm, which was gnawing on raw data from the hijacked Quotron line.

Just as with Peterffy's other traders, Van Peebles frequently ran sorties to a large bank of phones on the trading floor to communicate with Timber Hill's headquarters. On the phone, he scribbled down a jumble of letters, numbers, and fractions—his instructions. From there, he careened back into one of the roiling pits and put up his hands, ordering fresh delta neutral trades. Van Peebles's story accentuated the success of the most improbable trading squad roaming the pits of New York, perhaps to this day: three blonde women and one highly acclaimed black writer, director, and actor, all of them well-disguised proxies of an algorithm that dwelled inside a machine.

THE IPAD'S FORERUNNER

Peterffy's strategy to play to the pits' infamous chauvinism paid off as the options specialists continued to take his women's orders above most others. But after six months of his generating easy profits, the specialists began to notice the uncanny market sense that Peterffy's traders seemed to possess.

One of the specialists came to Peterffy and said, "Look, we know these trades are no good. We're getting killed on every single one. What are you doing?"

Keen observers assumed Peterffy had figured something out, but they couldn't be sure what it was. What they were certain of, though, was that they wanted little to do with the trades Peterffy's women were bringing to them—as much as they might have liked the attention. Sometime before this, Peterffy had been designated a market maker by the specialists, which gave him first crack at new orders in the pits. Technically, a market maker is required to keep both bids and offers up

at all times, no matter where the market goes. But Peterffy had been bending the rules, as a lot of market makers did, cherry-picking the trades he wanted according to the instructions of his algorithm. At no point was he maintaining constant bids and offers.

The specialists, sick of getting beaten by Peterffy on nearly every trade they did with him, told the Hungarian that he would have to maintain open bids and offers on a minimum number of options or else they would pull his market-maker status. He quibbled with the demands as much as prudence would allow, while his brain searched for a solution that would keep profits flowing and pacify those who might scuttle him.

Because he was required to keep constant bids and offers up on certain securities, Peterffy couldn't ask his traders to duck into the phone bank for every directive. Keeping quotes open at all times meant sticking to the pits and paying attention to market movements with vigilance. How could he expect his traders, who largely took their directions straight from an algorithm housed in the guts of a personal computer, to truly make markets without courting disaster?

The answer was buried in one of his past suggestions to the exchange: handheld computers. Peterffy had previously pushed to outfit the whole floor with the devices to do away with the anachronistic methods of the specialists, but he had made this proposal without a specific device in mind (they didn't exist) and without properly considering the dogmatic ways of the exchanges and who truly held power: the exact people he had suggested be displaced.

Peterffy's new plan wasn't to equip the entire exchange with handheld computers—just his traders. But would such things even be allowed? Peterffy hoped so; if he could succeed with his devices on the AMEX, he planned to take his game—and his algorithms, computers, and pit machines—to the Chicago Board Options Exchange, the largest options trading floor in the United States.

The AMEX governors weren't crazy for Peterffy's pitch; some members were hysterical about the matter. Machines, on the floor, trading!

Most objectors claimed the machines would get in the way of the jostling traders and perhaps even issue reckless orders that Peterffy wouldn't be able to cover if the market soured on him.

In spite of the protests, the AMEX agreed to allow Peterffy's traders to bring small tablet computers into the pits. Peterffy now had a new problem: he had no tablet computer of any kind. Nor did anybody else, thirty years before the advent of the iPad. The devices would have to be built from scratch.

With a vague idea of what he wanted, Peterffy brought in physics PhD candidates from NYU who helped him construct small rectangular boxes out of Mylar, a black plastic. The boxes measured roughly eight inches by twelve and were two inches deep. Inside were packed transistors and circuit boards that gave way to a top panel that included a series of gold wires. The wires detected when users pressed them with a finger, creating a touchscreen. Peterffy could then drop different sets of thin plastic templates on the boxes to serve as keypads. Different kinds of options required different keypads and different programs. Each overlay was similar to an app. This way, Peterffy could make just one type of box and then program each with the algorithm for what its user would be trading.[5]

In the morning before the market bell rang, Peterffy would crack open each device and pluck a small wire harness from inside, plugging it into the PC that had been collecting data from the Quotron line. From the computer, the handheld device would download the latest market prices and data, enabling it to instruct its pit-bound user on where to quote stock and options prices. Users punched in current market prices, and lights on the tablet's display indicated whether the trade was worth making. Now when specialists called on Peterffy's women for a bid and offer, the women could quickly give prices, knowing they were aligned with Petertffy's algorithm.

At this point, Peterffy was making more than $1 million a year. The question that faced him now was, how big could this become? Having tamed the AMEX with algorithms, he looked for new challenges. He

felt confident he could dominate any market to which he could apply his code. He set his sights on the Chicago Board Options Exchange, where volumes were biggest. The governors' board there fought him and refused to allow his handheld devices on the floor, claiming the boxes were too big and wouldn't fit inside the crowded trading pits. Peterffy accepted this and went back to his workbench, fashioning new, smaller boxes that measured seven inches square, a big reduction on the original design. Presented with the new boxes that could be easily held tight to a trader's chest, the CBOE cut straight to the heart of the matter: members of the exchange would tolerate absolutely no computers of any kind of the floor, clearly afraid of what kind of edge the devices might afford their users. Benefits to investors and the market in the form of efficiency and perhaps tighter spreads wasn't a consideration.

"Of course the exchanges fought me," Peterffy said. "They always fought everything."

So Peterffy turned to the New York Stock Exchange, which wanted to bolster its position as the dominant equity exchange with an options floor. Normally a kingpin that dictated terms, the NYSE was eager to court Peterffy's volume. To further assist his traders, who were already armed with pit computers, Peterffy constructed a set of light bars he mounted high above his clerk's post on the floor. The bars were broken up into a series of different-colored bulbs. He then wrote a system in which he could signal new trades to the pit using the colored bars.

Everything still relied on his computers' programming, which had recently been overhauled and rewritten to operate in C, a more modern and efficient programming language than the Fortran that Peterffy had used for most of his shop's code. As always, the computers combed incoming data for ripe trades. When the computer struck opportunity, it would immediately send a series of electric pulses to the colored bars on the NYSE floor, which a set of Timber Hill's traders watched from opening bell to closing. Before long, Peterffy became one of the major market makers at the NYSE.

Since buying his original seat on the AMEX for $36,000 in 1977, Peterffy had kept his main offices at that exchange. With further expansion on his mind, he needed more room than the AMEX could give him. So in 1986 he moved his headquarters to the World Trade Center, where he had more room to command traders at multiple exchanges.

Moving operations to the Trade Center, which was several blocks from the trading floors, made it harder to keep the tablets updated with fresh data, because the PCs that supplied the data had been moved as well. Peterffy's simple solution to this problem gave an unwitting nod to Wall Street's past, when runners used to broadcast word of what was happening on the markets to people uptown before the news could spread otherwise. He hired a couple of swift workers whose main purpose, outside of sundry office work, was to sprint from the World Trade Center to the exchanges with updated handheld devices under their arms.

"If you were ever downtown and you saw some crazy guy running as fast as he could down the street with a black box," said Peterffy, "then you saw our guys."

The running men eventually lost their jobs to dedicated phone lines carrying data, which were beginning to find homes in some of the tech-savvy trading houses by the mid-1980s. Peterffy was at the head of the line, leasing phone lines that fired data back and forth between his Trade Center offices and his exchange outposts, where computers would consume data from headquarters and dump it into the handhelds. Even with this update, traders still had to run the devices from the pit up to the computers at the exchanges several times a day. To eliminate this step, Peterffy and his engineering team built mini radio transmitters into the handhelds as well as Timber Hill's computers at the exchange. With that task completed, data now flowed effortlessly to the handhelds on the trading floor.

By 1986, the pits had become cash machines for Peterffy's trader corps. The algorithms' orders flowed out, money flowed in. The radio-enabled devices gave Peterffy the freedom to move more volume with-

out the fear of posting a quote that was out of line with his algorithms. Timber Hill started 1986 with $1 million in capital. It ended the year with $5 million in the bank, a 400 percent return. The successes, now piling up, allowed Peterffy to think expansion.

As technology advanced, so did Peterffy's most adroit opponents, who copied his methods. Joe Ritchie's Chicago Research and Trading Group had become a power in Chicago, and Blair Hull's Hull Trading charged up the ladder quickly after being founded in 1985. O'Connor & Associates, also in Chicago, was employing very similar tactics to Peterffy's, outfitting its traders with cheat sheets for valuing options and supplementing that information with computers that constantly crunched data upstairs while piping new numbers down to the pits. O'Connor was so secretive about its methods that when it bought two hundred Symbolics computers in the mid-1980s, executives shredded the packaging so Dumpster-diving competitors couldn't determine what technology the firm used.[6]

THE ALGORITHMS SPREAD COAST TO COAST

By 1987, index funds, which tracked groups of stocks such as the S&P 500, had grown popular not only with the public but also with professional traders. But certain indexes, the S&P 500 included, could only be licensed for trade in one market. In the case of the S&P 500, the license belonged to the Chicago Mercantile Exchange. So other exchanges employed indexes that were not exactly the same, but close. The Chicago Board Options Exchange traded the OEX, which was the same as the S&P 100; the New York Stock Exchange traded the NYSE composite, which tracked the entire NYSE; the AMEX traded the Major Market Index, which tracked the thirty biggest stocks; and the Pacific Exchange had what it called the PSE, which was based on technology companies, a growing share of the market.

All of these indexes contained different things, but their core hold-

ings were similar. The S&P 500 index, although only five hundred companies, comprised 90 percent of the weight of the NYSE index, which contained every company traded on the Big Board. Because the five hundred largest stocks on the Big Board were so disproportionately larger than the rest of the market, the NYSE index basically tracked the S&P 500 index and vice versa. The same could be said for the S&P 100, the Major Market Index, and the rest.

If the indexes more or less followed the same path, Peterffy reasoned, then their volatilities were the same and so should be the price of their options and futures. In reality, however, the prices of these instruments could vary greatly from exchange to exchange. A November call option on the NYSE index might be trading for $2 in New York, while a similar call might be trading for $3 on the OEX index in Chicago, and a third one for $2.25 on the Pacific Exchange in San Francisco. "So it was fairly obvious, at least to us, what people should be doing," Peterffy said. This was child's play: sell the expensive index derivatives and buy the cheap ones. "It was a wonderful thing," he recalls fondly.

To take advantage of all these easy trades, Peterffy needed people on the floor in San Francisco, the two Chicago exchanges, and the two New York exchanges. He and his team of tinkerers manufactured new sets of handheld devices for the waves of trading recruits who would establish Timber Hill beachheads on the country's other trading floors. Peterffy bought dozens of new computers and leased cross-country phone lines that would stay open for data at all times, allowing his computer network to maintain real-time contact and adjust his team's prices on the fly across the entire country. Radio transmitters were fitted and installed at the new exchanges, giving Peterffy's Chicago pit traders the same information available to those in San Francisco and New York. Now a sale in New York could be instantly hedged with buys in Chicago.

When the values of the derivatives converged back to their expected ranges, Peterffy's computers would tell his traders to dump both the long and the short positions, locking in profits. Because the index de-

rivatives were heavily traded in all markets, there were hundreds—if not thousands—of arbitrage opportunities every day. Few, if any, traders were taking advantage of technology the way Peterffy did. Some trading houses kept open phone lines between New York and Chicago so that clerks could bark prices back and forth and pounce on large pricing discrepancies. Peterffy's automated system allowed his traders to harvest not only large mispricings but also smaller ones—and they almost always got to them before others. Peterffy had created the first algorithmic trading operation working from coast to coast.

All trading activity from the handhelds was radioed to waiting terminals Peterffy had installed at each exchange. The computers there would then wire the data across the leased phone lines straight to Timber Hill's offices in the World Trade Center, where it would be received by a large master algorithm called simply the Correlator, which ran phalanxes of code to dissect markets and pinpoint their weaknesses, while dispatching Timber Hill traders in each city to hammer them. The Correlator analyzed real-time prices across a dozen equity and derivative markets and issued salvos of trades almost guaranteed to generate easy profit. As completed trades came in through the data lines, the Correlator swallowed Timber Hill's positions and spit out trades to hedge them. Some of the Correlator's trades were 100 percent automated—they were shipped directly over to Peterffy's hacked Nasdaq terminal, which rapped the keyboard automatically.

A trade that began with the Correlator and ended with an automated execution through Peterffy's co-opted Nasdaq terminal constitutes phase two of algorithmic takeover. Here algorithms comb the data, read the market, and issue an order that is no longer carried out by humans but by another machine. What Peterffy ultimately helped create was a Wall Street whose most important communications travel back and forth between machines, not humans. It would be more than a decade before this second-degree takeover spread across the entire U.S. market system, but it all started with Peterffy and the Nasdaq. After Peterffy's trick here, there remained only phase three—wherein

algorithms adjust independently of their human masters, and in some cases write algorithms of their own—to complete a total bot takeover.

Peterffy often sat in his World Trade Center office watching his traders' work pour into the Correlator. The screen listed completed trades and how those trades should be hedged, sending word to Timber Hill's people in the relevant markets. Once the hedging trades had been made, they too would be posted on the Correlator's screen. Peterffy had never been a gambler. His game was to make easy bets where profit, albeit sometimes small, was assured, while keeping the downside as close to zero as possible. When large trades popped up on the Correlator's screen, Peterffy would focus intently on the monochrome pixels, watching for his traders to hedge the bet. But even the mighty Correlator had its weaknesses—as do all algorithms left on their own with no human supervision.

One morning in early 1987, as Peterffy watched trades stream in, he noticed a whale. One of his traders sold 100,000 NYSE index puts, giving somebody in the crowd the right to sell 100,000 shares of the index at a guaranteed price in the future. If the index were to crash, as it would eventually do later in the year, such a position could be ruinous for Timber Hill. Seeing the trade, Peterffy's brow arched as he wondered who would be making such a large and bearish speculation. His mind, as it often did, wandered back to his disastrous DuPont trade. He had failed to hedge his DuPont play with a bet on the opposite side, which was why it had proved so calamitous. But now Timber Hill hedged everything.

Peterffy sat up in his chair and waited for what he knew was coming: the hedging trades. Just like it was supposed to do, the computer surveyed the markets and determined the cheapest way to shed the trade's risk and dispatched orders to do so. Because selling the puts was a bullish trade, the Correlator ordered traders to buy similar, cheaper puts on other exchanges as well as selling indexes similar to the NYSE short. His system worked exactly as he had programmed it. Peterffy eased back into his chair as the hedged trades were confirmed.

But then two minutes later the large trade popped up again: a trader sold 100,000 NYSE index puts. Ghosts of DuPont were poking Peterffy now. He whirled and picked up the phone, dialing his traders' desk at the NYSE.

"Who are you selling these puts to?" Peterffy said.

"What puts?" came the response. Timber Hill had six traders on the NYSE floor, so it was perfectly understandable that the trader who answered the phone didn't know about the sale. Peterffy explained the trade. "Go find out who *is doing this*," he said, hanging up.

Now ruffled, Peterffy sat back down. He watched the Correlator mete out more hedging moves, which his traders duly carried out. Then his stomach turned. For the third time, the Correlator screen read, SOLD: 100,000 NYSE INDEX PUTS.

"What is this shit?!" Peterffy yelled. He scrambled back to the phone and dialed the NYSE floor. A trader picked up.

"What the hell is going on—who is selling these puts?" Peterffy said.

"I don't know anything!" the trader responded.

Peterffy yelled, "Pull out all of the cords, just pull them out!"

The trader immediately turned around and pulled out all of the power and data cords going into the exchange computers, shutting down Timber Hill's operations on the NYSE. Their handhelds not receiving any information, Timber Hill's remaining NYSE traders, confused, wandered back to the office.

Peterffy rushed out of the World Trade Center and into the New York Stock Exchange. Scaling the stairs at the neoclassical NYSE headquarters at 11 Wall Street, he swung open the door to Timber Hill's small office. He interrogated all of his traders. "How is it that nobody has any idea where these trades came from?" he asked.

His mind jumping, Peterffy decided to count all of his handheld devices in the building. Each trader quickly produced their tablet. They were all safe and accounted for. But then Peterffy remembered there was a spare device kept in the office in case another broke, something that happened fairly often. Peterffy quickly spotted the small rectangle,

which sat on a desk near the door. Just as he went to retrieve it, one of his traders, who had been in the bathroom, came back into the office. A noticeable whoosh of air accompanied him as he opened the door to the office. Peterffy looked at the device, whose plastic overlay riffled as the air passed over it.

The door to the office closed and the air grew still. But then the door, forced by the air outside the office, cracked open again, sending another burst of air across the tablet, making its touchscreen overlay crinkle out loud.

"Turn on the computer," Peterffy, now intrigued, said to one of his traders.

The door cracked again, and the computer, now on and registering the tablet's entries, showed a sale for 100,000 NYSE index puts. The small blast of air from the door applied enough force to the device's face that it registered sales as if somebody were entering them with their fingertips. The order kept coming through because the office door was being continuously bumped open by air rushing in from the trading floor to the hallway. For a trade to be registered as legitimate, a trader had to not only enter it but also follow up with a confirmation. When the tablet blinked for the confirmation, the air feathered the yes button on the tablet and the Correlator was notified of the trade.

None of these big trades had ever happened. But the Correlator, working as it was designed, didn't know that. All of the hedging trades it ordered up weren't hedging at all. They were straight trades, pure and simple. When the market closed that day, Timber Hill was sitting on more than $3 million worth of naked directional bets. Peterffy had just become what he worked so hard to avoid—a high-stakes betting cowboy. He would have to wait until the next morning to unwind his positions; he simply had to hope the market didn't move against him before the opening.

That night, Peterffy couldn't sleep. He stared at the ceiling all night long until it was finally time to go back to the office.

Luckily, the market hadn't moved much and Timber Hill was able

to dump its positions with little bloodshed. Had this been a later day in 1987—October 19's Black Monday—these erroneous big bets could have ended Peterffy's career.

A HACKER RISES TO ROYALTY ON WALL STREET

In 1986 and 1987, Peterffy made a total of $75 million, an astonishing amount of money to him and a sum that marked his arrival to the big time. From his lead vantage point—few people knew what he was up to—he sprinted out ahead of the pack and continued to dominate stock and options markets with bots that consistently outdueled their human adversaries. At some point, however, the rest of Wall Street began to catch up—and that's when quant mania took hold of lower Manhattan and began to beckon scientists and engineers to careers in finance.

In 1999, Goldman Sachs offered Peterffy $900 million for his business. He wanted $3 billion. Goldman instead bought Blair Hull's automated trading operation in Chicago for $500 million. Hull's shop was far smaller than Peterffy's, but Hull had made waves when, more than six years after Peterffy started the trend, he began using bots to trade on the Cincinnati Stock Exchange in the early 1990s.

It was only a matter of time before the investment banks and Wall Street's blue-chip players started to catch up with Peterffy and the other programmers who had been getting the better of human traders for years. The monsters of finance hired their own hackers and engineers and moved into the space as quickly as they could. Hull ducked out of the game when he sold to Goldman, later losing a U.S. Senate primary race to Barack Obama in Illinois. Other algorithmic pioneers left even earlier. O'Connor & Associates, the shredder of computer boxes, sold to Swiss Bank in 1992, and Joe Ritchie's Chicago Research and Trading Group sold out to NationsBank, which would later become Bank of America, a year later. Peterffy, the original algorithmic trader, remained to face off against the self-appointed masters of the

universe. The Hungarian's operation, which he eventually renamed Interactive Brokers while moving the company's headquarters to Greenwich, Connecticut, continued to pace Wall Street in the 1990s, as it does to this day.

Part of the reason for this was that Peterffy's organization was, and will remain, he asserts, one of engineers and programmers. Goldman and the others on Wall Street seek out engineering talent to stock their quant departments, but at Interactive Brokers, the engineers *are* the company—making Peterffy's firm something akin to Wall Street's version of Google, a place where engineers make the product and the big decisions. Interactive Brokers, in fact, works to ensure that 75 percent of its employees are programmers and engineers. "Most Wall Street firms concentrate on what they do best," Peterffy says. "And that means they sell. But we write code. That's what we do."

Nobody at Interactive Brokers has a business degree, Peterffy points out, making the firm flagrantly out of place among its peers. Peterffy insists he won't have an MBA at his company—ever.

During the 1990s and into the 2000s, Interactive Brokers expanded, bringing its algorithms to European markets as he continued gaining more share in the United States. On Friday, May 4, 2007, Peterffy prepared for a day that all companies, tech and finance alike, dream of having. It was IPO day for Interactive Brokers. He wore a beige suit with a subtle check pattern paired with a pressed white shirt and a tie so blue it nearly looked purple. He arrived at work early, sipped green tea, and peered out the corner windows of his office at the bubbling traffic of Greenwich.

By 7:30 a.m., Interactive Brokers was humming. Peterffy headed out of his office and greeted visitors. At 9:29 a.m., several dozen people all grouped into one place, Peterffy at their center. As the clock hit 9:30, he raised his hands, clapped, yelled, and brought his hand quickly down on a large orange button as applause erupted all around him. Twenty years after the Nasdaq had tried to dismantle his automated trading operation that subsisted on spliced wires, hacked data lines, and custom-

written code, Peterffy rang the Nasdaq's opening bell. The market valued his company at $12 billion.

Peterffy retained an 85 percent ownership share of Interactive Brokers and only put 10 percent of its stock up for sale in the offering. Even so, the deal put $1.18 billion directly into his pocket and was the second-largest IPO in the United States that year. Not a bad outcome for a Hungarian immigrant who, lacking a full engineering degree, decided to pick up programming by reading computer manuals in the 1960s.

THE UNKNOWN FINANCIAL FRONTIER

The speed and volume of trading continue to tick up on Wall Street as fresh code and newer and faster hardware flood the game. As the arms race played out on Wall Street in the late 1990s and into the 2000s, some of its methods and talents began to leak into other fields. Wall Street may have cribbed some of the science, but no other industry has so perfected the development of endlessly complex algorithms and automated bots.

In today's stock market, humans have largely been reduced to interested observers. The algorithms own the market now. Dow Jones and Bloomberg offer news services that are written specifically for the trading bots. These stories would be incomprehensible to a human, but make perfect sense to a bot. The news affects the markets, and just as Wall Street traders once skimmed *Barron's* on their train ride in from Greenwich, now algorithms read the paper too. They just read it a lot faster.

When machines are at the controls, we can never be sure exactly what the market will do. The disappearance of $1 trillion in wealth on May 6, 2010, is a case in point. And the aftershocks continue. Six months later, Progress Energy, a utility in North Carolina, saw its shares shed 90 percent of their value in minutes for no apparent reason. Apple shares, which rode wild price swings on May 6, inexplicably dropped 4

percent several months later, wiping out $16 billion of market cap before rebounding. Michael Kearns, a professor at the University of Pennsylvania who has written algorithms for traders and studied this new, machine-ruled market, says there's no way to understand the implications of giving algorithms the full control that they now have.[7]

The competition between Wall Street algorithms has become so bizarre that there are days when 40 percent of the trades on all U.S. exchanges, from the Nasdaq to the NYSE, are made by just two midwestern companies that most people, even those who work in finance, have never heard of. One of them, Getco, is located in Chicago; the other, Tradebot, is in Kansas City. Both firms employ world-class hackers and engineers who are focused on clearing profits of often less than one cent per share. Getco and Tradebot deploy thousands of algorithms to scour the markets for the tiniest of opportunities. And there are thousands of other companies, some big, some small, that exist only to do the same thing—to make money on the market with bots. All in all, this means that algorithms *are* the stock market, as they now carry out 60 percent of all trades in the United States; European and Asian markets aren't far behind. What once was determined by biting, swarming, and barking hordes of men is now decided by battling algorithms that are constantly testing each other, grappling for an edge, feigning their intentions, and learning as they trade.

There's plenty of good that has arisen from algorithms' role in our markets—the normal man's ability to trade stock for $7 from the laptop screen in his kitchen being chief among them. As the market shifted from one where each order had to pass through pits of humans to one that's facilitated by algorithms and exchanges hosted on computer servers, the costs of trading have plummeted. But we've blown by the utility of cheaper traders to a strange Star Wars–like battle that features fewer human inputs and more algorithmic autonomy. The speed at which something can go wrong is frightening.

Our stock markets have become such specialized battlegrounds that some algorithms sit silently for months, waiting to ambush enemy al-

gorithms that display design flaws, dated code, or a discernible pattern to their trading. Many of the algorithms plying our stock markets are built to mimic randomness. What's random can't be gamed, planned upon, or hijacked. For example, some of the most important algorithms on Wall Street trade stocks that belong to normal people—people who may own mutual fund shares in their 401(k) plans or IRAs. When a mutual fund company, be it Fidelity, Vanguard, or T. Rowe Price, makes a trade to add to a position or subtract from one, it's inevitably a very large order. Trading a million shares of a stock, even a heavily traded one such as Apple or ExxonMobil, can move the market against the large seller or buyer. If other traders know that an order to buy a million shares is coming through the pipe, they will do whatever they can to get in front of it and buy up available shares. That way, they can repost their newly acquired shares for sale at a higher price knowing that they'll get sucked into the mutual fund order.

When a mutual fund has to pay more for its shares, it costs the owners of that fund—normal people saving for retirement—money. To combat traders prowling for big orders to abuse, mutual funds and other institutional traders hired hackers to develop algorithms that randomly disguise their large trades by breaking them up into smaller ones. The idea is a bit like stealth technology. Instead of appearing as a giant chunk of metal in the sky, the design and coverings on a stealth plane show radar hundreds of smaller objects, which could be cloud cover, birds, or other detritus. Dispatching sorties to intercept every bird pack across a continent is futile, which is why stealth worked. But the Russians eventually developed ways that could sometimes discern true packs of birds from eighty tons of American steel. The same thing happened on Wall Street. Traders who were at first defeated by algorithms disguising big institutional orders soon developed complex scheming algorithms of their own that could sniff the market for large trades that had been disguised.

Mutual funds and institutions dealing in giant blocks of stock reacted by building better algorithms of disguise—bots that issued decoy

trades and would easily shift strategies if they suspected detection. The hunters, again, responded in kind, leading us to the current state of the stock market wherein algorithms are the gladiators and normal people, just like in the days of the Colosseum, stand by and watch. It's a fantastic game, although it has little to do with the base mission of the stock market: allowing growing companies an easy path to raising capital while giving the public a chance to invest in something that can build wealth in a meaningful way.

Peterffy thinks things have gone too far. He has already stepped back his company's participation in making markets. The man who was one of the most powerful forces behind the algorithms that have taken over Wall Street—and are now headed everywhere else—has second thoughts. "I only saw the good sides at the time," he says.

At the time, of course, Peterffy was building up one of the largest fortunes in America, so this might seem like an easy thing for him to say in hindsight. Peterffy thinks that in this age of light-speed trading, bids and offers on stocks should be held up for a minimum amount of time, still far less than a second, but enough to eliminate the head fakes, parries, and trickery that comprise the contemporary market and that lead us to clifflike falls and rocketlike spikes.

His ultimate fear is that a rogue series of algorithms sparks a string of colossal losses that their owners can't cover. Because some high-speed trading algorithms are able to trade on margin with leverage, it's conceivable that a series of bad trades, all conducted in seconds, could lead to a liquidity crisis, bankrupting a trader's broker and the clients he trades for. Such incidents have nearly happened before. In late 2009, Chicago's Infinium Capital Management, one of the more secretive and powerful trading houses in the United States, twice lost control of an algorithm that began selling S&P 500 futures as fast as it could, dropping the market. It happened again to Infinium in February 2010, when a new algorithm meant to capture small profits on crude oil trades tore up the commodities market as it traded wildly, losing more than $1 million in three seconds. The firm was fined $850,000 by the Chicago

Mercantile Exchange for "failing to diligently supervise its systems." The CME said that by unleashing such a flawed algorithm "to operate in a live trading environment, Infinium committed an act detrimental to the welfare of the exchange."[8] It was reported that Infinium, rather than testing the algorithm for six to eight weeks, as was its standard, set it loose after only two hours of checks.[9]

This virtual world of warring algorithms is what has become of Wall Street and our money. It doesn't stop there. The bot saga on Wall Street offers clues to what's in store for much of our future world.