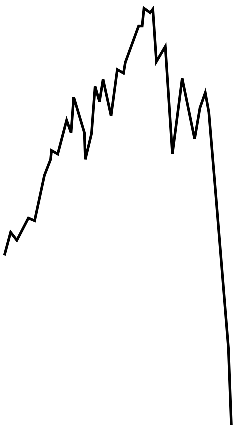

Why Stock Markets Crash

Critical Events in Complex Financial Systems

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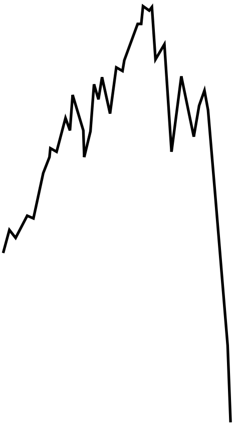

CHAPTER 1

FINANCIAL CRASHES: WHAT, HOW, WHY, AND WHEN?

WHAT ARE CRASHES, AND WHY DO WE CARE?

Stock market crashes are momentous financial events that are fascinating to academics and practitioners alike. According to the academic world view that markets are efficient, only the revelation of a dramatic piece of information can cause a crash, yet in reality even the most thorough post-mortem analyses are typically inconclusive as to what this piece of information might have been. For traders and investors, the fear of a crash is a perpetual source of stress, and the onset of the event itself always ruins the lives of some of them.

Most approaches to explaining crashes search for possible mechanisms or effects that operate at very short time scales (hours, days, or weeks at most). This book proposes a radically different view: the underlying cause of the crash will be found in the preceding months and years, in the progressively increasing build-up of market cooperativity, or effective interactions between investors, often translated into accelerating ascent of the market price (the bubble). According to this “critical” point of view, the specific manner by which prices collapsed is not the most important problem: a crash occurs because the market has entered an unstable phase and any small disturbance or process may have triggered the instability. Think of a ruler held up vertically on your finger: this very unstable position will lead eventually to its collapse, as a result of a small (or an absence of adequate) motion of your hand or due to any tiny whiff of air. The collapse is fundamentally due to the unstable position; the instantaneous cause of the collapse is secondary. In the same vein, the growth of the sensitivity and the growing instability of the market close to such a critical point might explain why attempts to unravel the local origin of the crash have been so diverse. Essentially, anything would work once the system is ripe. This book explores the concept that a crash has fundamentally an endogenous, or internal, origin and that exogenous, or external, shocks only serve as triggering factors. As a consequence, the origin of crashes is much more subtle than often thought, as it is constructed progressively by the market as a whole, as a self-organizing process. In this sense, the true cause of a crash could be termed a systemic instability.

Systemic instabilities are of great concern to governments, central banks, and regulatory agencies [103]. The question that often arose in the 1990s was whether the new, globalized, information technology–driven economy had advanced to the point of outgrowing the set of rules dating from the 1950s, in effect creating the need for a new rule set for the "New Economy." Those who make this call basically point to the systemic instabilities since 1997 (or even back to Mexico's peso crisis of 1994) as evidence that the old post–World War II rule set is now antiquated, thus condemning this second great period of globalization to the same fate as the first. With the global economy appearing so fragile sometimes, how big a disruption would be needed to throw a wrench into the world's financial machinery? One of the leading moral authorities, the Basle Committee on Banking Supervision, advised [32] that, "in handling systemic issues, it will be necessary to address, on the one hand, risks to confidence in the financial system and contagion to otherwise sound institutions, and, on the other hand, the need to minimise the distortion to market signals and discipline."

The dynamics of confidence and of contagion and decision making based on imperfect information are indeed at the core of the book and will lead us to examine the following questions. What are the mechanisms underlying crashes? Can we forecast crashes? Could we control them? Or, at least, could we have some influence on them? Do crashes point to the existence of a fundamental instability in the world financial structure? What could be changed to modify or suppress these instabilities?

THE CRASH OF OCTOBER 1987

From the market opening on October 14, 1987 through the market close on October 19, major indexes of market valuation in the United States declined by 30% or more. Furthermore, all major world markets declined substantially that month, which is itself an exceptional fact that contrasts with the usual modest correlations of returns across countries and the fact that stock markets around the world are amazingly diverse in their organization [30].

In local currency units, the minimum decline was in Austria (−11.4%) and the maximum was in Hong Kong (−45.8%). Out of 23 major industrial countries (Autralia, Austria, Belgium, Canada, Denmark, France, Germany, Hong Kong, Ireland, Italy, Japan, Malaysia, Mexico, the Netherlands, New Zealand, Norway, Singapore, South Africa, Spain, Sweden, Switzerland, United Kingdom, United States), 19 had a decline greater than 20%. Contrary to common belief, the United States was not the first to decline sharply. Non-Japanese Asian markets began a severe decline on October 19, 1987, their time, and this decline was echoed first on a number of European markets, then in North American, and finally in Japan. However, most of the same markets had experienced significant but less severe declines in the latter part of the previous week. With the exception of the United States and Canada, other markets continued downward through the end of October, and some of these declines were as large as the great crash on October 19.

A lot of work has been carried out to unravel the origin(s) of the crash, notably in the properties of trading and the structure of markets; however, no clear cause has been singled out. It is noteworthy that the strong market decline during October 1987 followed what for many countries had been an unprecedented market increase during the first nine months of the year and even before. In the U.S. market, for instance, stock prices advanced 31.4% over those nine months. Some commentators have suggested that the real cause of October's decline was that overinflated prices generated a speculative bubble during the earlier period.

The main explanations people have come up with are the following.

1. **Computer trading**. In computer trading, also known as program trading, computers were programmed to automatically order large stock trades when certain market trends prevailed, in particular sell orders after losses. However, during the 1987 U.S. crash, other stock markets

that did not use program trading also crashed, some with losses even more severe than the U.S. market.

2. **Derivative securities**. Index futures and derivative securities have been claimed to increase the variability, risk, and uncertainty of the U.S. stock markets. Nevertheless, none of these techniques or practices existed in previous large, sudden market declines in 1914, 1929, and 1962.
3. **Illiquidity**. During the crash, the large flow of sell orders could not be digested by the trading mechanisms of existing financial markets. Many common stocks in the New York Stock Exchange were not traded until late in the morning of October 19 because the specialists could not find enough buyers to purchase the amount of stocks that sellers wanted to get rid of at certain prices. This insufficient liquidity may have had a significant effect on the size of the price drop, since investors had overestimated the amount of liquidity. However, negative news about the liquidity of stock markets cannot explain why so many people decided to sell stock at the same time.
4. **Trade and budget deficits**. The third quarter of 1987 had the largest U.S. trade deficit since 1960, which together with the budget deficit, led investors into thinking that these deficits would cause a fall of the U.S. stocks compared with foreign securities. However, if the large U.S. budget deficit was the cause, why did stock markets in other countries crash as well? Presumably, if unexpected changes in the trade deficit are bad news for one country, they should be good news for its trading partner.
5. **Overvaluation**. Many analysts agree that stock prices were overvalued in September 1987. While the price/earning ratio and the price/dividend ratio were at historically high levels, similar price/earning and price/dividends values had been seen for most of the 1960–72 period over which no crash occurred. Overvaluation does not seem to trigger crashes every time.

Other cited potential causes involve the auction system itself, the presence or absence of limits on price movements, regulated margin requirements, off-market and off-hours trading (continuous auction and automated quotations), the presence or absence of floor brokers who conduct trades but are not permitted to invest on their own account, the extent of trading in the cash market versus the forward market, the identity of traders (i.e., institutions such as banks or specialized trading firms), the significance of transaction taxes, and other factors.

More rigorous and systematic analyses on univariate associations and multiple regressions of these various factors conclude that it is not at all clear what caused the crash [30]. The most precise statement, albeit somewhat self-referencial, is that the most statistically significant explanatory variable in the October crash can be ascribed to the normal response of each country's stock market to a worldwide market motion. A world market index was thus constructed [30] by equally weighting the local currency indexes of the 23 major industrial countries mentioned above and normalized to 100 on September 30. It fell to 73.6 by October 30. The important result is that it was found to be statistically related to monthly returns in every country during the period from the beginning of 1981 until the month before the crash, albeit with a wildly varying magnitude of the responses across countries [30]. This correlation was found to swamp the influence of the institutional market characteristics. This signals the possible existence of a subtle but nonetheless influential worldwide cooperativity at times preceding crashes.

HISTORICAL CRASHES

In the financial world, risk, reward, and catastrophe come in irregular cycles witnessed by every generation. Greed, hubris, and systemic fluctuations have given us the tulip mania, the South Sea bubble, the land booms in the 1920s and 1980s, the U.S. stock market and great crash in 1929, and the October 1987 crash, to name just a few of the hundreds of ready examples [454].

The Tulip Mania

The years of tulip speculation fell within a period of great prosperity in the republic of the Netherlands. Between 1585 and 1650, Amsterdam became the chief commercial emporium, the center of the trade of the northwestern part of Europe, owing to the growing commercial activity in newly discovered America. The tulip as a cultivated flower was imported into western Europe from Turkey and it is first mentioned around 1554. The scarcity of tulips and their beautiful colors made them a must for members of the upper classes of society (see Figure 1.1).

During the build-up of the tulip market, the participants were not making money through the actual process of production. Tulips acted

FIG. 1.1. A variety of tulip (the Viceroy) whose bulb was one of the most expensive at the time of the tulip mania in Amsterdam, from *The Tulip Book* of P. Cos, including weights and prices from the years of speculative tulip mania (1637); Wageningen UR Library, Special Collections.

as the medium of speculation and their price determined the wealth of participants in the tulip business. It is not clear whether the build-up attracted new investment or new investment fueled the build-up, or both. What is known is that as the build-up continued, more and more people were roped into investing their hard-won earnings. The price of the tulip lost all correlation to its comparative value with other goods or services.

What we now call the “tulip mania” of the seventeenth century was the “sure thing” investment during the period from the mid-1500s to 1636. Before its devastating end in 1637, those who bought tulips rarely lost money. People became too confident that this “sure thing” would always make them money and, at the period’s peak, the participants mortgaged their houses and businesses to trade tulips. The craze was so overwhelming that some tulip bulbs of a rare variety sold for the equivalent of a few tens of thousands of dollars. Before the crash, any suggestion that the price of tulips was irrational was dismissed by all the participants.

The conditions now generally associated with the first period of a boom were all present: an increasing currency, a new economy with novel colonial possibilities, and an increasingly prosperous country together had created the optimistic atmosphere in which booms are said to grow.

The crisis came unexpectedly. On February 4, 1637, the possibility of the tulips becoming definitely unsalable was mentioned for the first time. From then until the end of May 1637, all attempts at coordination among florists, bulbgrowers, and the Netherlands were met with failure. Bulbs worth tens of thousands of U.S. dollars (in present value) in early 1637 became valueless a few months later. This remarkable event is often discussed by present-day commentators, and parallels are drawn with modern speculation mania. The question is asked, Do the tulip market’s build-up and its subsequent crash have any relevance for today’s markets?

The South Sea Bubble

The South Sea bubble is the name given to the enthusiatic speculative fervor that ended in the first great stock market crash in England, in 1720 [454]. The South Sea bubble is a fascinating story of mass hysteria, political corruption, and public upheaval. (See Figure 1.2.) It is really a collection of thousands of stories, tracing the personal fortunes of countless individuals who rode the wave of stock speculation for a furious six months in 1720. The “bubble year,” as it is called, actually involves several individual bubbles, as all kinds of fraudulent joint-stock companies sought to take advantage of the mania for speculation. The following account borrows from "The Bubble Project" [60].

In 1711, the South Sea Company was given a monopoly of all trade to the South Sea ports. The real prize was the anticipated trade that would open up with the rich Spanish colonies in South America. In return for this monopoly, the South Sea Company would assume a portion of the national debt that England had incurred during the War of the Spanish Succession. When Britain and Spain officially went to war again in 1718, the immediate prospects for any benefits from trade to South America

FIG. 1.2. An emblematical print of the South Sea scene (etching and engraving), by the artist William Hogarth in 1722 (now located at The Charles Deering McCormick Library of Special Collections, Northwestern University). With this scene, Hogarth satirizes crowds consumed by political speculation on the verge of the stock market collapse of 1720. The "merry-go-round" was set in motion by the South Sea Company, who held a monopoly on trade between South America, the Pacific Islands, and England. The Company tempted vast numbers of middle-class investors to make quick money through absurd speculations. The wheel of fortune in the center of the print is broken, symbolizing the abandonment of values for quick money, while "Trade" lies starving to death. On the right, the original inscription on the London Fire Monument—erected in memory of the destruction of the City by the Great Fire in 1666—has been altered to read: "This monument was erected in memory of the destruction of the city by the South Sea in 1720." Reproduced by permission from McCormick Library of Special Collections, Northwestern University Library.

were nil. What mattered to speculators, however, were future prospects, and here it could always be argued that incredible prosperity lay ahead and would be realized when open hostilities came to an end.

The early 1700s was also a time of international finance. By 1719 the South Sea directors wished, in a sense, to imitate the manipulation of public credit that John Law had achieved in France with the Mississippi Company, which was given a monopoly of French trade to North America. Law had connived to drive the price of its stock up, and the South Sea directors hoped to do the same. In 1719 the South Sea directors made a proposal to assume the entire public debt of the British government. On April 12, 1720 this offer was accepted. The company immediately started to drive the price of the stock up through artificial means; these largely took the form of new subscriptions combined with the circulation of pro-trade-with-Spain stories designed to give the impression that the stock could only go higher. Not only did capital stay in England, but many Dutch investors bought South Sea stock, thus increasing the inflationary pressure.

South Sea stock rose steadily from January through the spring. As every apparent success would soon attract its imitators, all kinds of joint-stock companies suddenly appeared, hoping to cash in on the speculation mania. Some of these companies were legitimate, but the bulk were bogus schemes designed to take advantage of the credulity of the people. Several of the bubbles, both large and small, had some overseas trade or "New World" aspect. In addition to the South Sea and Mississippi ventures, there was a project for improving the Greenland fishery and another for importing walnut trees from Virginia. Raising capital by selling stock in these enterprises was apparently easy work. The projects mentioned so far all have a tangible specificity at least on paper, if not in practice; others were rather vague on details but big on promise. The most remarkable was "a company for carrying on an undertaking of great advantage, but nobody to know what it is." The prospectus stated that "the required capital was half a million, in five thousand shares of 100 pounds each, deposit 2 pounds per share. Each subscriber, paying his [or her] desposit, was entitled to 100 pounds per annum per share. How this immense profit was to be obtained, [the proposer] did not condescend to inform [the buyers] at that time" [60]. As T. J. Dunning [114] wrote:

> Capital eschews no profit, or very small profit.... With adequate profit, capital is very bold. A certain 1 percent will ensure its employment anywhere; 20 percent certain will produce eagerness; 50 percent, positive

> audacity; 100 percent will make it ready to trample on all human laws; 300 percent and there is not a crime at which it will scruple, nor a risk it will not run, even to the chance of its owner being hanged.

Next morning, at nine o'clock, this great man opened an office in Cornhill. Crowds of people beset his door, and when he shut up at three o'clock, he found that no less than one thousand shares had been subscribed for, and the deposits paid. He was thus, in five hours, the winner of £2,000. He was philosophical enough to be contented with his venture, and set off the same evening for the Continent. He was never heard of again.

Such scams were bad for the speculation business and so, largely through the pressure of the South Sea directors, the so-called "Bubble Act" was passed on June 11, 1720 requiring all joint-stock companies to have a royal charter. For a moment, the confidence of the people was given an extra boost, and they responded accordingly. South Sea stock had been at £175 at the end of February, 380 at the end of March, and around 520 by May 29. It peaked at the end of June at over £1,000 (a psychological barrier in that four-digit number).

With credulity now stretched to the limit and rumors of more and more people (including the directors themselves) selling off, the bubble then burst according to a slow but steady deflation (not unlike the 60% drop of the Japanese Nikkei index after its all-time peak at the end of December 1989). By mid-August, the bankruptcy listings in the *London Gazette* reached an all-time high, an indication that many people had bought on credit or margin. Thousands of fortunes were lost, both large and small. The directors attempted to pump up more speculation. They failed. The full collapse came by the end of September, when the stock stood at £135. The crash remained in the consciousness of the Western world for the rest of the eighteenth century, not unlike our cultural memory of the 1929 Wall Street Crash.

The Great Crash of October 1929

The Roaring 20s—a time of growth and prosperity on Wall Street and Main Street—ended with the Great Crash of October 1929 (for the most thorough and authoritative account and analysis, see [152]). (See Figure 1.3.) The Great Depression that followed put 13 million Americans out of work. Two thousand investment firms went under, and the American banking industry underwent the biggest structural changes


"All the News That's Fit to Print."

The New York Times.

STOCKS COLLAPSE IN 16,410,030-SHARE DAY, BUT RALLY AT CLOSE CHEERS BROKERS; BANKERS OPTIMISTIC, TO CONTINUE AID

GRUNDY FOR CURBING 'BACKWARD STATES' ON THE TARIFF BILL

KAHN REFUSES POST IN SENATE CAMPAIGN; CALLS CHOICE UNWISE

COALITION FIGHTING MOVE TO KILL TARIFF

MISSING AIRLINER BROUGHT IN SAFELY

LEADERS SEE FEAR WANING

U. S. STEEL TO PAY $1 EXTRA DIVIDEND

RESERVE BOARD FINDS ACTION UNNECESSARY

Fig. 1.3. The front page of the October 30, 1929 *New York Times* exclaimed the massive loss on Wall Street. It worked hard to ease fear among panicked investors—without success, as history has shown.

of its history, as a new era of government regulation began. Roosevelt's New Deal politics would follow.

The October 1929 crash is a vivid illustration of several remarkable features often associated with crashes. First, stock market crashes are often unforeseen for most people, especially economists. "In a few months, I expect to see the stock market much higher than today." Those words were pronounced by Irving Fisher, America's distinguished and famous economist and professor of economics at Yale University, 14 days before Wall Street crashed on Black Tuesday, October 29, 1929.

"A severe depression such as 1920–21 is outside the range of probability. We are not facing a protracted liquidation." This was the analysis offered days after the crash by the Harvard Economic Society to its subscribers. After continuous and erroneous optimistic forecasts, the society closed its doors in 1932. Thus, the two most renowned economic forecasting institutes in America at the time failed to predict that crash and depression were forthcoming and continued with their optimistic views, even as the Great Depression took hold of America. The reason is simple: the prediction of trend-reversals constitutes by far the most difficult challenge posed to forecasters and is very unreliable, especially within the linear framework of standard (auto-regressive) economic models.

A second general feature exemplified by the October 1929 event is that a financial collapse has never happened when things look bad. On the contrary, macroeconomic flows look good before crashes. Before every collapse, economists say the economy is in the best of all worlds. Everything looks rosy, stock markets go up and up, and macroeconomic flows (output, employment, etc.) appear to be improving further and further. This explains why a crash catches most people, especially economists, totally by surprise. The good times are invariably extrapolated linearly into the future. Is it not perceived as senseless by most people in a time of general euphoria to talk about crash and depression?

During the build-up phase of a bubble such as the one preceding the October 1929 crash, there is a growing interest in the public for the commodity in question, whether it consists of stocks, diamonds, or coins. That interest can be estimated through different indicators: an increase in the number of books published on the topic (see Figure 1.4) and in the subscriptions to specialized journals. Moreover, the well-known empirical rule according to which the volume of sales is growing during a bull market, as shown in Figure 1.5, finds a natural interpretation: sales increases in fact reveal and pinpoint the progress of the bubble's diffusion throughout society. These features have been recently reexamined for evidence of a bubble, a "fad" or "herding" behavior, by studying individual stock returns [455]. One story often advanced for the boom of 1928 and 1929 is that it was driven by the entry into the market of largely uninformed investors, who followed the fortunes of and invested in "favorite" stocks. The result of this behavior would be a tendency for the favorite stocks' prices to move together more than would be predicted by their shared fundamental economic values. The co-movement indeed increased significantly during the boom and was a signal characteristic of the tumultuous market of the early 1930s. These results are

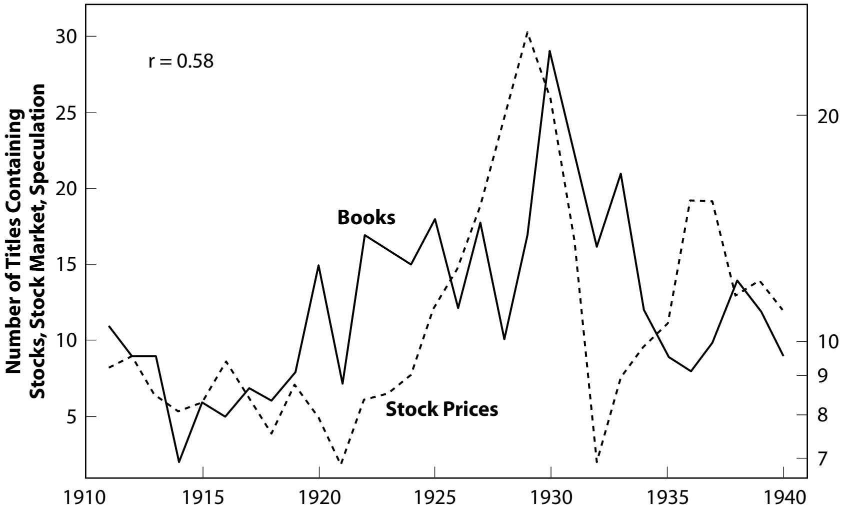

FIG. 1.4. Comparison between the number of yearly published books about stock market speculation and the level of stock prices (1911–1940). Solid line: Books at Harvard's library whose titles contain one of the words "stocks," "stock market," or "speculation". Broken line: Standard and Poor's index of common stocks. The curve of published books lags behind the price curve with a time-lag of about 1.5 years, which can be explained by the time needed for a book to get published. Source: The stock price index is taken from the Historical Abstract of the United States. Reproduced from [349].

thus consistent with the possibility that a fad or crowd psychology played a role in the rise of the market, its crash, and subsequent volatility [455].

The political mood before the October 1929 crash was also optimistic. In November 1928, Herbert Hoover was elected president of the United States in a landslide, and his election set off the greatest increase in stock buying to that date. Less than a year after the election, Wall Street crashed.

EXTREME EVENTS IN COMPLEX SYSTEMS

Financial markets are not the only systems with extreme events. Financial markets constitute one among many other systems exhibiting a complex organization and dynamics with similar behavior. Systems with a large number of mutually interacting parts, often open to their environment, self-organize their internal structure and their dynamics with novel and sometimes surprising macroscopic ("emergent") properties. The complex

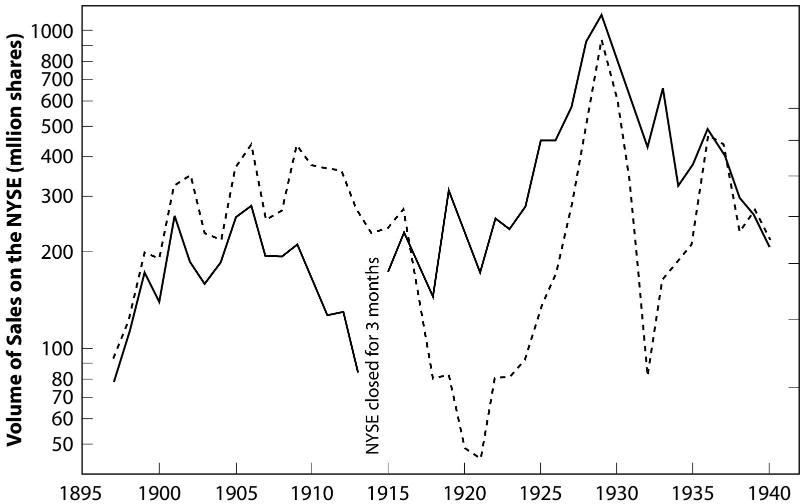

FIG. 1.5. Comparison between the number of shares traded on the NYSE and the level of stock prices (1897–1940). Solid line: Number of shares traded. Broken line: Deflated Standard and Poor's index of common stocks. Source: Historical Statistics of the United States. Reproduced from [349].

system approach, which involves "seeing" interconnections and relationships, that is, the whole picture as well as the component parts, is nowadays pervasive in modern control of engineering devices and business management. It also plays an increasing role in most of the scientific disciplines, including biology (biological networks, ecology, evolution, origin of life, immunology, neurobiology, molecular biology, etc.), geology (plate-tectonics, earthquakes and volcanoes, erosion and landscapes, climate and weather, environment, etc.), and the economic and social sciences (cognition, distributed learning, interacting agents, etc.). There is a growing recognition that progress in most of these disciplines, in many of the pressing issues for our future welfare as well as for the management of our everyday life, will need such a systemic complex system and multidisciplinary approach. This view tends to replace the previous "analytical" approach, consisting of decomposing a system in components, such that the detailed understanding of each component was believed to bring understanding of the functioning of the whole.

A central property of a complex system is the possible occurrence of coherent large-scale collective behaviors with a very rich structure, resulting from the repeated nonlinear interactions among its constituents: the whole turns out to be much more than the sum of its parts. It is widely believed that most complex systems are not amenable to mathematical, analytic descriptions and can be explored only by means of "numerical experiments." In the context of the mathematics of algorithmic complexity [73], many complex systems are said to be computationally irreducible; that is, the only way to decide about their evolution is to actually let them evolve in time. Accordingly, the "dynamical" future time evolution of complex systems would be inherently unpredictable. This unpredictability does not, however, prevent the application of the scientific method to the prediction of novel phenomena as exemplified by many famous cases (the prediction of the planet Neptune by Leverrier from calculations of perturbations in the orbit of Uranus, the prediction by Einstein of the deviation of light by the sun's gravitation field, the prediction of the helical structure of the DNA molecule by Watson and Crick based on earlier predictions by Pauling and Bragg, etc.). In contrast, it refers to the impossibility of satisfying the quest for the knowledge of what tomorrow will be made of, often filled by the vision of "prophets" who have historically inspired or terrified the masses.

The view that complex systems are unpredictable has recently been defended persuasively in concrete prediction applications, such as the socially important issue of earthquake prediction (see the contributions in [312]). In addition to the persistent failures at reaching a reliable earthquake predictive scheme, this view is rooted theoretically in the analogy between earthquakes and self-organized criticality [26]. In this "fractal" framework (see chapter 6), there is no characteristic scale, and the power-law distribution of earthquake sizes reflects the fact that the large earthquakes are nothing but small earthquakes that did not stop. They are thus unpredictable because their nucleation is not different from that of the multitude of small earthquakes, which obviously cannot all be predicted.

Does this really hold for all features of complex systems? Take our personal life. We are not really interested in knowing in advance at what time we will go to a given store or drive to a highway. We are much more interested in forecasting the major bifurcations ahead of us, involving the few important things, like health, love, and work, that count for our happiness. Similarly, predicting the detailed evolution of complex systems has no real value, and the fact that we are taught that it is out of reach from a fundamental point of view does not exclude the more interesting possibility of predicting phases of evolutions of complex systems that really count, like the extreme events.

It turns out that most complex systems in natural and social sciences do exhibit rare and sudden transitions that occur over time intervals that are short compared to the characteristic time scales of their posterior evolution. Such extreme events express more than anything else the underlying "forces" usually hidden by almost perfect balance and thus provide the potential for a better scientific understanding of complex systems.

These crises have fundamental societal impacts and range from large natural catastrophes, such as earthquakes, volcanic eruptions, hurricanes and tornadoes, landslides, avalanches, lightning strikes, meteorite/asteroid impacts (see Figure 1.6), and catastrophic events of environmental degradation, to the failure of engineering structures, crashes in the stock market, social unrest leading to large-scale strikes and upheaval, economic drawdowns on national and global scales, regional power blackouts, traffic gridlock, and diseases and epidemics. It is essential to realize

FIG. 1.6. One of the most fearsome possible catastrophic events, but one with very low probability of occurring. A collision with a meteorite with a diameter of 15 km with impact velocity of 14 km/s (releasing about the same energy, equal to 100 Megatons of equivalent TNT, as what is thought to be the dinosaur killer) occurs roughly once every 100 million years. A collision with a meteorite with a diameter of the order of 1,000 km as shown in this figure occurred only early in the solar system's history. (Creation of the space artist Don Davis.)

that the long-term behavior of these complex systems is often controlled in large part by these rare catastrophic events: the universe was probably born during an extreme explosion (the "big bang"); the nucleosynthesis of all important heavy atomic elements constituting our matter results from the colossal explosion of supernovae (stars more heavy than our sun whose internal nuclear combustion diverges at the end of their life); the largest earthquake in California, repeating about once every two centuries, accounts for a significant fraction of the total tectonic deformation; landscapes are more shaped by the "millenium" flood that moves large boulders than by the action of all other eroding agents; the largest volcanic eruptions lead to major topographic changes as well as severe climatic disruptions; according to some contemporary views, evolution is probably characterized by phases of quasi-stasis interrupted by episodic bursts of activity and destruction [168, 169]; financial crashes, which can destroy in an instant trillions of dollars, loom over and shape the psychological state of investors; political crises and revolutions shape the long-term geopolitical landscape; even our personal life is shaped in the long run by a few key decisions or happenings.

The outstanding scientific question is thus how such large-scale patterns of catastrophic nature might evolve from a series of interactions on the smallest and increasingly larger scales. In complex systems, it has been found that the organization of spatial and temporal correlations do not stem, in general, from a nucleation phase diffusing across the system. It results rather from a progressive and more global cooperative process occurring over the whole system by repetitive interactions. For instance, scientific and technical discoveries are often quasi-simultaneous in several laboratories in different parts of the world, signaling the global nature of the maturing process.

Standard models and simulations of scenarios of extreme events are subject to numerous sources of error, each of which may have a negative impact on the validity of the predictions [232]. Some of the uncertainties are under control in the modeling process; they usually involve trade-offs between a more faithful description and manageable calculations. Other sources of error are beyond control, as they are inherent in the modeling methodology of the specific disciplines. The two known strategies for modeling are both limited in this respect: analytical theoretical predictions are out of reach for most complex problems. Brute force numerical resolution of the equations (when they are known) or of scenarios is reliable in the "center of the distribution," that is, in the regime far from the extremes where good statistics can be accumulated. Crises are extreme events that occur rarely, albeit with extraordinary impact, and are thus completely undersampled and poorly constrained. Even the introduction of "teraflop" supercomputers does not qualitatively change this fundamental limitation.

Notwithstanding these limitations, I believe that the progress of science and of its multidisciplinary enterprises makes the time ripe for a full-fledged effort toward the prediction of complex systems. In particular, novel approaches are possible for modeling and predicting certain catastrophic events or "ruptures," that is, sudden transitions from a quiescent state to a crisis or catastrophic event [393]. Such ruptures involve interactions between structures at many different scales. In the present book, I apply these ideas to one of the most dramatic events in social sciences, financial crashes. The approach described in this book combines ideas and tools from mathematics, physics, engineering, and the social sciences to identify and classify possible universal structures that occur at different scales and to develop application-specific methodologies for using these structures for the prediction of the financial "crises." Of special interest will be the study of the premonitory processes before financial crashes or "bubble" corrections in the stock market.

For this purpose, I shall describe a new set of computational methods that are capable of searching and comparing patterns, simultaneously and iteratively, at multiple scales in hierarchical systems. I shall use these patterns to improve the understanding of the dynamical state before and after a financial crash and to enhance the statistical modeling of social hierarchical systems with the goal of developing reliable forecasting skills for these large-scale financial crashes.

IS PREDICTION POSSIBLE? A WORKING HYPOTHESIS

With the low of 3227 on April 17, 2000, identified as the end of the "crash," the Nasdaq Composite index lost in five weeks over 37% of its all-time high of 5133 reached on March 10, 2000. This crash has not been followed by a recovery, as occurred from the October 1987 crash. At the time of writing, the Nasdaq Composite index bottomed at 1395.8 on September 21, 2001, in a succession of descending waves. The Nasdaq Composite consists mainly of stock related to the so-called "New Economy," that is, the Internet, software, computer hardware, telecommunications, and similar sectors. A main characteristic of these companies is that their price–earning ratios (P/Es), and even more so their price–dividend ratios, often come in three digits. Some, such as VA LINUX, actually have a *negative* earning/share (of −1.68). Yet they are traded at around $40 per share, which is close to the price of a share of Ford in early March 2000. In constrast, so-called "Old Economy" companies, such as Ford, General Motors, and DaimlerChrysler, have P/E $\approx$ 10. The difference between Old Economy and New Economy stocks is thus the expectation of *future earnings* as discussed in [282] (see also [395] for a new view on speculative pricing): investors expect an enormous increase in, for example, the sale of Internet and computer-related products rather than of cars and are hence more willing to invest in Cisco rather than in Ford, notwithstanding the fact that the earning per share of the former is much smaller than for the latter. For a similar price per share (approximately $60 for Cisco and $55 for Ford), the earning per share in 1999 was $0.37 for Cisco compared with $6.00 for Ford. Close to its apex on April 14, 2000, Cisco had a total market capitalization of $395 billion compared with $63 billion for Ford. Cisco has since bottomed at about $11 in September 2001 and traded at around $20 at the end of 2001.

In the standard fundamental valuation formula, in which the expected return of a company is the sum of the dividend return and of the growth rate, New Economy companies are supposed to compensate for their lack of present earnings by a fantastic potential growth. In essence, this means that the bull market observed in the Nasdaq in 1997–2000 is fueled by expectations of increasing future earnings rather than economic fundamentals: the price-to-dividend ratio for a company such as Lucent Technologies (LU) with a capitalization of over $300 billion prior to its crash on January 5, 2000 (see Figure 1.7) is over 900, which means that you get a higher return on your checking account (!) unless the price of the stock increases. In constrast, an Old Economy company such as DaimlerChrysler gives a return that is more than 30 times higher. Nevertheless, the shares of Lucent Technologies rose by more than 40% during 1999, whereas the share of DaimlerChrysler declined by more than 40% in the same period. Recent crashes of IBM, LU, and Procter & Gamble (P&G), shown in Figures 1.7–1.9 correspond to a loss equivalent to the national budget of many countries! And this is usually attributed to a "business-as-usual" corporate statement of a slightly revised smaller-than-expected earnings!

These considerations suggest that the *expectation* of future earnings (and its perception by others), rather than present economic reality, is an important motivation for the average investor. The inflated price may be a speculative bubble if the growth expectations are unrealistic (which is, of course, easy to tell in hindsight but not obvious at all in the heat of the action!). As already alluded to, history provides many examples of

FIG. 1.7. Top panel: Time series of daily closes and volume of the IBM stock over a one-year period around the large drop of October 21, 1999. The time of the crash can be seen clearly as coinciding with the peak in volume (bottom panel). Taken from http://finance.yahoo.com/.

bubbles driven by unrealistic expectations of future earnings followed by crashes [454]. The same basic ingredients are found repeatedly: fueled by initially well-founded economic fundamentals, investors develop a self-fulfilling enthusiasm from an imitative process or crowd behavior that leads to the building of "castles in the air," to paraphrase Burton Malkiel [282]. Furthermore, the causes of the crashes on the U.S. markets in October 1929, October 1987, August 1998, and April 2000 belong to the same category, the difference being mainly in which sector the bubble was created. In 1929, it was utilities; in 1987, the bubble was supported by a general deregulation of the market, with many new private investors entering the market with very high expectations about the profit they would make; in 1998, it was an enormous expectation for the investment opportunities in Russia that collapsed; until early 2000, it was the extremely high expectations for the Internet, telecommunications, and similar sectors that fueled the bubble. The IPOs (initial public offerings) of many Internet and software companies have been followed by a mad frenzy, where the share price has soared during the first few hours of trading. An excellent example is VA LINUX SYSTEMS whose $30 IPO price increased a record 697% to close at $239.25 on its

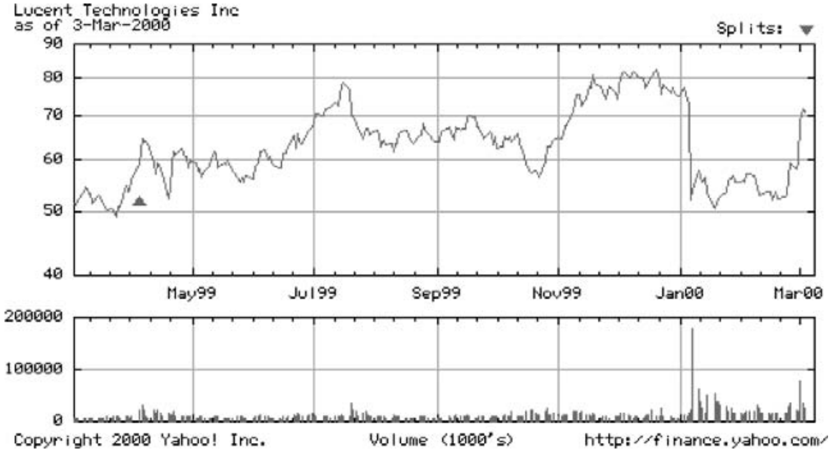

FIG. 1.8. Top panel: Time series of daily closes and volume of the Lucent Technology stock over a one-year period around the large drop of January 6, 2000. The time of the crash can be seen clearly as coinciding with the peak in volume (bottom panel). Taken from http://finance.yahoo.com/.

opening day December 9, 1999, only to decline to $28.94 on April 14, 2000.

Building on these insights, our hypothesis is that stock market crashes are caused by the slow build-up of long-range correlations leading to a global cooperative behavior of the market and eventually ending in a collapse in a short, critical time interval. The use of the word "critical" is not purely literary here: in mathematical terms, complex dynamical systems can go through so-called critical points, defined as the explosion to infinity of a normally well-behaved quantity. As a matter of fact, as far as nonlinear dynamical systems go, the existence of critical points is more the rule than the exception. Given the puzzling and violent nature of stock market crashes, it is worth investigating whether there could possibly be a link between stock market crashes and critical points.

- Our key assumption is that a crash may be caused by *local* self-reinforcing imitation between traders. This self-reinforcing imitation process leads to the blossoming of a bubble. If the tendency for traders to "imitate" their "friends" increases up to a certain point called the "critical" point, many traders may place the same order (sell) at the same time, thus causing a crash. The interplay between the progressive strengthening of imitation and the ubiquity of noise requires a probabilistic description: a crash is *not* a certain outcome of the bubble but

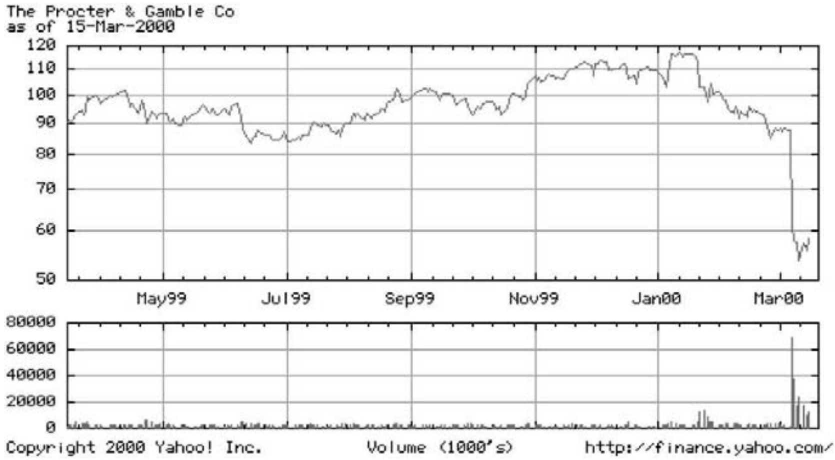

FIG. 1.9. Top panel: Time series of daily closes and volume of the Procter & Gamble stock over a one-year period ending after the large drop of March 7, 2000. The time of the crash can be seen clearly as coinciding with the peak in volume (bottom panel). Taken from http://finance.yahoo.com/.

can be characterized by its hazard rate, that is, the probability per unit time that the crash will happen in the next instant, provided it has not happened yet.

- Since the crash is not a certain deterministic outcome of the bubble, it remains rational for investors to remain in the market provided they are compensated by a higher rate of growth of the bubble for taking the risk of a crash, because there is a finite probability of "landing smoothly," that is, of attaining the end of the bubble without crash.

In a series of research articles performed in collaboration with several colleagues and mainly with Anders Johansen, we have shown extensive evidence that the build-up of bubbles manifests itself as an overall super-exponential power-law acceleration in the price decorated by log-periodic precursors, a concept related to fractals, as will become clear later (see chapter 6). In telling this story, this book will address the following questions: Why and how do these precursors occur? What do they mean? What do they imply with respect to prediction?

My colleagues and I claim that there is a degree of predictive skill associated with these patterns, which has already been used in practice and has been investigated by us as well as many others, academics and, most-of-all, practitioners. The evidence I discuss in what follows arises from many crashes, including

- the October 1929 Wall Street crash, the October 1987 World crash, the October 1987 Hong Kong crash, the August 1998 World crash, and the April 2000 Nasdaq crash;
- the 1985 foreign exchange event on the U.S. dollar and the correction of the U.S. dollar against the Canadian dollar and the Japanese Yen starting in August 1998;
- the bubble on the Russian market and its ensuing collapse in 1997–98;
- 22 significant bubbles followed by large crashes or by severe corrections in the Argentinian, Brazilian, Chilean, Mexican, Peruvian, Venezuelan, Hong-Kong, Indonesian, Korean, Malaysian, Philippine, and Thai stock markets.

In all these cases, it has been found that, with very few exceptions, log-periodic power-laws adequately describe speculative bubbles on the Western markets as well as on the emerging markets.

Notwithstanding the drastic differences in epochs and contexts, I shall show that these financial crashes share a common underlying background as well as structure. The rationale for this rather surprising result is probably rooted in the fact that humans are endowed with basically the same emotional and rational qualities in the twenty-first century as they were in the seventeenth century (or at any other epoch). Humans are still essentially driven by at least a modicum of greed and fear in their quest for well-being. The "universal" structures I am going to uncover in this book may be understood as the robust emergent properties of the market resulting from some characteristic "rules" of interaction between investors. These interactions can change in details due, for instance, to computers and electronic communications. They have not changed at a qualitative level. As we shall see, complex system theory allows us to account for this robustness.