


Philip Ball

# Why Society is a Complex Matter

Meeting Twenty-first Century Challenges  
with a New Kind of Science

With a contribution by Dirk Helbing

 Springer

Philip Ball

## Why Society is a Complex Matter

Meeting Twenty-first Century Challenges with a New Kind of Science

Society is complicated. But this book argues that this does not place it beyond the reach of a science that can help to explain and perhaps even to predict social behaviour. As a system made up of many interacting agents – people, groups, institutions and governments, as well as physical and technological structures such as roads and computer networks – society can be regarded as a complex system. In recent years, scientists have made great progress in understanding how such complex systems operate, ranging from animal populations to earthquakes and weather. These systems show behaviours that cannot be predicted or intuited by focusing on the individual components, but which emerge spontaneously as a consequence of their interactions: they are said to be ‘self-organized’. Attempts to direct or manage such emergent properties generally reveal that ‘top-down’ approaches, which try to dictate a particular outcome, are ineffectual, and that what is needed instead is a ‘bottom-up’ approach that aims to guide self-organization towards desirable states.

This book shows how some of these ideas from the science of complexity can be applied to the study and management of social phenomena, including traffic flow, economic markets, opinion formation and the growth and structure of cities. Building on these successes, the book argues that the complex-systems view of the social sciences has now matured sufficiently for it to be possible, desirable and perhaps essential to attempt a grander objective: to integrate these efforts into a unified scheme for studying, understanding and ultimately predicting what happens in the world we have made. Such a scheme would require the mobilization and collaboration of many different research communities, and would allow society and its interactions with the physical environment to be explored through realistic models and large-scale data collection and analysis. It should enable us to find new and effective solutions to major global problems such as conflict, disease, financial instability, environmental despoliation and poverty, while avoiding unintended policy consequences. It could give us the foresight to anticipate and ameliorate crises, and to begin tackling some of the most intractable problems of the twenty-first century.

*The “science of complex systems” has been a buzzword for some time now, full of promise but mocked for its glib ambition to solve all the problems that the old science of “simple systems” had failed to master. In spite of this sarcasm, the field has developed in a strangely anarchic, uncoordinated way. Physicists, biologists, computer scientists, mathematicians, economists and sociologists all come up with ideas, methods and algorithms to deal with some of the collective phenomena that have such huge impacts on our lives: epidemics, avalanches, traffic jams, crowd panic, economic crises & financial crashes.*

*Why Society is a Complex Matter is a wonderful little book. It is not only an exciting, crystal-clear introduction to the multifarious achievements of the past decade. It also reveals how these disparate contributions have formed, over the years and without noticing it, a coherent scientific corpus that can be used and built upon by future generations. This book makes a convincing case that better models of our complex socioeconomic systems are becoming available. We should all take heed and roll up our sleeves.*

**Jean-Philippe Bouchaud** Professor at the Ecole Polytechnique and Chairman of Capital Fund Management

*Complex systems research on social and economic problems is a very rapidly growing area of scientific enquiry. Philip Ball has done an excellent job in demonstrating both the range and the power of this approach. He translates into clear and comprehensible English, the difficult maths which often lies behind these models. This book deserves a wide readership, and not just amongst social scientists. Anyone who takes an intelligent interest in public policy will benefit from reading it.*

**Paul Ormerod** Economist, and author of *Butterfly Economics* and *Why Most Things Fail*

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# Introduction

## Society: a Complex Problem |

It is becoming ever more clear that the twenty-first century is not a continuation of the twentieth, but something new. War is qualitatively different now from what it was half a century ago, and so is peace. So are consumerism, access to information, environmental change, health care, demography, and perhaps the very concept of democracy. It seems we are living not at the “end of history” after all but at the beginning of a new historical phase – one that demands new ways of thinking.

This is why it is time to escape the constraints of disciplinary thinking. The major challenges of the twenty-first century are not ones that can be understood, let alone solved, from a particular academic perspective. For example, if today’s patterns of consumption make global mean temperatures destined to rise by even 2 °C, the consequences for international relations, biodiversity, food and water security, and human migration are immense, and yet are at this stage little more than informed guesswork. Simply comprehending and forecasting such impending crises, let alone mitigating them, is not just a question of having more accurate models of global climate, but must involve the integration of a host of socioeconomic, technological and political factors.

The most important novelty in the changes that are currently being felt by our societies and our environment stems from the profound impact of globalization: the linkages and interconnections that transcend states and societies. The interdependence of economies, cultures and institutions has become deep and dense, in large part thanks to the pervasive nature of information and communication technologies (ICT). Nothing will work that fails to take this into account: not the economy, not policing, not international diplomacy, not governance. Bird flu pandemics, the Arab Spring revolutions, the financial crisis, terrorist networks and the spreading of cyber-crime are all manifestations of our ever more connected world. They all illustrate that the current pace of technological change, particularly in the area of ICT, is outstripping our capacity to manage it.



Our society is data-rich, but lacks the conceptual and technological tools to handle it. (Credit: worradirek/Shutterstock.)

The inter-connectedness of global phenomena, and in particular the roles of interactions between individuals, groups and institutions, give a new perspective to events that could look superficially like more of the same. For example, the fall of long-standing, dictatorial regimes in Tunisia, Egypt and Libya was unlike the dissolution of the Soviet Union, not least in terms of its bottom-up impetus. Alleged triggers of the ‘Arab Spring’, whether they be escalating food prices in North Africa or the self-immolation of a Tunisian street vendor in protest at official harassment, must be seen as catalysts that unleashed rather than created the phenomenon. While the importance of social networking media in these uprisings (which some have called Twitter revolutions) remains open to debate, the issue is not so much whether they ‘caused’ the revolutions but that their existence – and the concomitant potential for mobilizing a young, educated demographic – can alter the way things happen in North Africa, the Middle East and beyond. Similarly, while economic crashes have always been with us, the financial crisis that began in 2008 was evidently a product of the interconnections – strong ones, yet poorly known – within the institutions that instigated it. The crisis was partly about risk hidden so deeply as to cause

paralytic fear; it was also about instruments too complicated for users to understand, and about legal and financial systems labyrinthine enough to permit deception, selfishness and mendacity to thrive.



■ The Arab Spring of 2011: the product of a complex, deeply interconnected social system. (Credit: MOHPhoto/Shutterstock.)

What is qualitatively new about these events is the crucial role of interdependence and interaction and the almost instantaneous transmission of information through social, economic and political networks. That novelty does not by itself explain why they happened, much less help us to identify solutions or ameliorate the unwelcome consequences. But it points to an unavoidable truth: the world has changed, and it is not going to change back.

We are, for one thing, now living in a world that is data-rich, but with much of the important information highly dispersed so that it can be brought to light only by a smart process of aggregating and sifting. Intelligence may need to rely increasingly not on a few 'hard facts' but on diffuse 'sensing' of mood and opinion: on patterns normally invis-

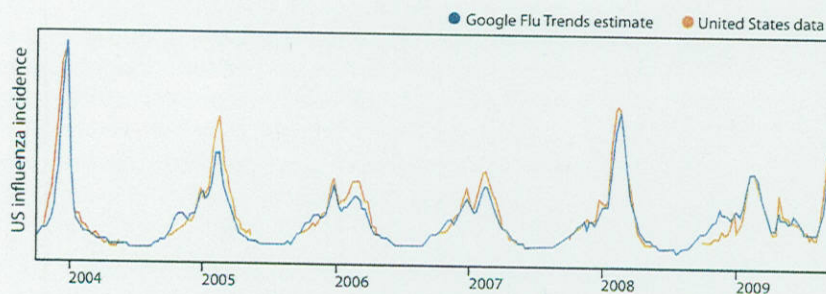
ible among the noise, such as the epidemiological data unearthed from Google searches by GoogleFluTrends.

Many political analysts today consider that the major challenges in the future will be examples of *discontinuous* change: not gradual shifts in the balance of power or the organization of societies and cultures, but sudden, perhaps catastrophic transformations. Such changes are extremely hard to predict, in terms not just of their magnitude, onset and occurrence but of their very nature – we don't know exactly *what* is going to break.

All this is uncharted territory for politicians, and they do not know how to navigate it. That makes for a dangerous situation, because if political leaders feel compelled to improvise solutions that fail entirely to acknowledge the nature of the problem, they stand a good chance of making things worse. As Lee C. Bollinger, president of Columbia University in New York, has said, "The forces affecting societies around the world are powerful and novel... Too many policy failures are fundamentally failures of knowledge."

This is why politicians and decision makers need new concepts and tools if they are not to lose the capacity to govern, to manage economies, to create stable societies, to keep the world worth living in. And they will need to learn the key lesson of the management of complex, interacting systems: solutions cannot be imposed, but must be coaxed out of the dynamic system itself. There is an analogy with earthquakes, which may never be exactly predictable, but might possibly be managed by mapping out in great detail the accumulating strains that give rise to them, and perhaps inducing controlled, small-scale release of pent-up energy (for example, by injecting groundwater into fault systems). This approach, rather than top-down imposition of laws and structures, might be the way to handle 'social earthquakes' too.

It is sometimes said that by their very nature no one can be expected to foresee radical departures from the



■ Patterns in the number of searches for influenza-related topics worldwide turn out to closely track flu outbreaks recorded by disease-monitoring centres, with the advantage that the data are available almost instantaneously. See <http://www.google.org/flutrends/>.

previous status quo. Yet social and political discontinuities are rarely if ever random in that sense, even if there is a certain arbitrary character to their immediate triggers. In the complex systems familiar to natural scientists from the physical and biological sciences, discontinuities don't reflect profound changes in the governing forces but instead derive from the interactions and feedbacks between the component parts. And they are not necessarily unpredictable: sometimes there are precursory signs, and sometimes we can foresee the circumstances in which they will occur, or at least in which they will be more likely to do so.

The notion of 'complex systems' is relatively new in the social sciences. But natural scientists have studied these systems with much success for several decades now. This book argues that the time is ripe – indeed, the need is urgent – to approach the social sciences from this perspective. It calls for a collaboration between natural and social scientists between, for example, computer scientists, physicists, mathematicians, biologists, technologists, psychologists, economists, sociologists, urban planners, political scientists, philosophers, historians and artists – to build a new picture of human social behaviour and its consequences. This is an immense task, but it is already beginning. It is one we can no longer afford to neglect.

### Is Society Predictable?

The idea that the social sciences can usefully employ concepts developed in the natural sciences is not new. It was evident at the very origin of modern political philosophy. In the seventeenth century, Thomas Hobbes based his theory of the state on the laws of motion recently deduced by Galileo, in particular the principle of inertia. The ascendancy of the mechanistic view of the natural world, for which the paradigm was Isaac Newton's gravitational model of the cosmos, gave rise in the eighteenth century to a belief that social behaviour also follows rigorous laws that can be expressed and understood along similar mechanistic lines. Adam Smith's notion of an 'invisible hand' that creates a stable and efficient economy from the self-interested behaviour of its many actors already embodied the image of social self-organization that required no over-arching guidance or authority. The operation of this invisible hand was deemed to be as dependable as the law of gravity, provided that the state did not interfere: a central tenet of the belief that markets must be free if they are to be efficient, which many economists and politicians still hold to some degree today.

And in the nineteenth century the cohesion of society as a collective result of the actions of its multitude of members was considered in statistical terms: what mattered was not the capriciousness of individual actions and

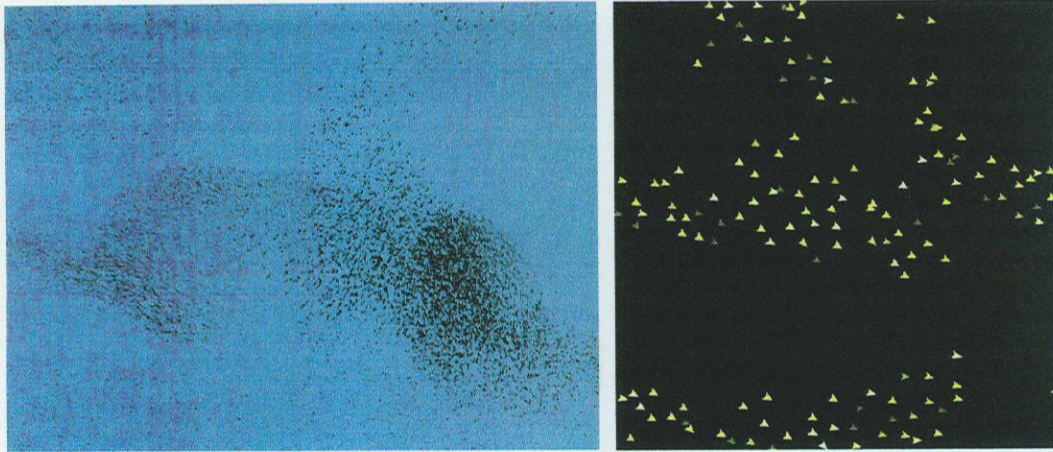
choices, but the predictable averages. This image both influenced and was influenced by the evolving physical theories of matter envisaged as a vast collection of atoms and molecules: the ideas that gave rise to the twentieth-century science of *statistical physics*. Just as the random, unpredictable movements of individual particles in a gas produce, en masse, the wholly reliable and mathematically simple 'gas laws' that relate its pressure, temperature and volume, so might society show predictable and regular behaviour when viewed as a whole. Thus, early sociology was largely constructed according to an unspoken faith that there was a kind of 'physics of society'.

### What is Complexity?

In retrospect, this idea remains valid but it often drew on the wrong analogies. Society does not run along the same predictable, 'clockwork' lines as the Newtonian universe. It is closer to the kind of complex systems that typically preoccupy statistical physicists today: avalanches and granular flows, flocks of birds and fish, networks of interaction in neurology, cell biology and technology. These systems differ from simple gases in that the component particles or agents interact strongly with one another, affecting and responding to one another's behaviour. That is true even for a non-living system like a pile of sand: tumbling grains can strike other grains, setting off cascades that can produce avalanches of all sizes, which are difficult to predict individually but which have characteristic statistical patterns.

This means that societies are more like the communities and ecosystems studied by biologists: food chains, ant and bee colonies, predators and their prey. At one level that seems hardly surprising, for what are societies but communities of a particular species of animal? But what is striking is that analogies between the group behaviour in these cases exist despite the supposedly much greater psychological and cultural sophistication of humans. Some features, such as collective movements and modes of organization, seem rather insensitive to the fine details of how individuals interact, and are determined by the very fact of those interactions, along with the *shape* of the networks they define. That's why descriptions of the resulting behaviour remain accessible to the kinds of theories of complex systems that physicists have developed. They do not necessarily need a great deal of biological or psychological realism to capture the essence of the emergent phenomena.

Thus, on the macroscopic level, social and economic systems have some features that seem to be similar to properties of certain physical or biological systems. For example, they tend to develop hierarchical organization. In social systems, individuals form groups, which establish organizations, companies, parties and so forth. These



■ Flocking of birds and fish (left) can be mimicked in a computer model (right) in which each individual reacts only to the motions of its near neighbours. (Credits: (left) Flickr photo by Jef Poskanzer, for free use under Creative Commons licence; (right) prepared using the NetLogo free software, <http://ccl.northwestern.edu/netlogo>.)

in turn make up states, which might develop alliances and build broader communities of states such as the United States, NATO or the European Union.

The field often called complexity science has evolved to describe systems of this sort. Definitions vary, but there is a general consensus that a complex system is one made up of many components (which might or might not be identical) that interact strongly with one another. When these components are autonomous entities that can make decisions – representing animals, people, institutions and so forth – they are often called agents.

That it has recently become possible (and popular) to study and model systems of this sort is due to several factors. One is the maturity of the discipline of statistical physics, which over the course of the twentieth century developed the theoretical tools and concepts needed to describe and explain the behaviour of increasingly complicated phenomena. But perhaps the most important factor has been the explosion in computer power over the past several decades, which has made it possible to conduct simulations of complex systems in cases where the traditional approach of writing down and solving mathematical equations is intractable.

There are some key concepts that have arisen from these studies, which we will encounter repeatedly in this book. Perhaps the most important is that *complex systems can display ordered, regular types of behaviour*. The apparent complexity of their fundamental nature, with many components interacting with many others, does not necessarily lead to chaos and unpredictability. Rather, there are commonly *emergent collective modes of behaviour*, such as the coherent motions seen in swarms of birds or fish. Here ‘emergence’ refers to the fact that it is usually impossible to predict this organized collective behaviour

by considering the details of the system: by looking at the rules of interaction between the constituent agents. The only way to find out what will emerge is to look and see: for example, to run a computer model. This ability of complex systems to adopt orderly patterns of behaviour is often called *self-organization*: it is not imposed from above, for example by agents all following a leader, but arises spontaneously from the bottom up.

These self-organized modes of behaviour typically appear suddenly – that’s to say, a very small change in the forces or properties governing the system, such as the density of particles, can induce an abrupt, profound *global* change in their behaviour. That’s something familiar from the early days of statistical physics, when physicists began to understand how it is that substances freeze or melt. These too are sudden changes that happen everywhere: just a tiny drop in temperature below zero degrees is enough to switch water from the liquid state to ice. It looks as if all the water molecules have somehow decided to stop moving at the same time. That’s because freezing is a collective property that depends on the interactions between molecules. Freezing and melting are examples of what scientists call *phase transitions*. Models of social behaviour often also exhibit jumps that look like phase transitions – indeed, these are precisely the ‘discontinuous changes’ mentioned above. They happen at certain *thresholds* in the magnitude of the influences driving the system’s behaviour – the density of traffic flow, say, or the proportions of different types of agent.

One of the most important characteristics of many real-world complex systems, especially those in the social sciences, is that they never settle down to a steady, unchanging state. Unlike, say, a block of ice, they are not in equilibrium: they are *non-equilibrium* systems. These are

the most challenging systems for statistical physics to describe, and it is only relatively recently that this has become possible. Yet many if not most real-world complex systems are like this. The weather system is one example: patterns recur, often with some predictability, and yet there will never be a state of unchanging weather everywhere.

What makes a system out of equilibrium is a constant input of energy or matter. Weather is never in equilibrium because it is fed by solar energy, which creates gradients of warmth and cold across the planet, driving movements of air and water. Human social systems are also perpetually fuelled in some way – literally so in the case of traffic flow. Lack of equilibrium does not preclude *dynamic* stability, where modes of behaviour or organization remain steady: traffic, for example, can keep flowing at a constant rate under certain conditions.

Commonly, however, non-equilibrium systems experience fluctuations and variations of many sorts and scales. The popular idealized model for this is the pile of sand. With no fresh input of material and energy, it settles into a static state. But if grains are continually dropped from above, the slopes are constantly growing and steepening, only to be relieved by avalanches of grains that might set just a few grains tumbling or might disrupt the whole slope. Each of these events is a *cascade*, where rolling grains collide with and dislodge others, which in turn collide with others, and so on. Cascades are very common in complex social and technological systems: they are manifested in panic selling in markets, or propagating breakdowns in power grids, or the epidemic spread of contagious diseases.

Fluctuations, phase transitions and cascades can make complex systems hard to predict, and still harder to control. But this isn't impossible, once we recognize that complex systems can't usually be *forced* to behave in a certain way by top-down measures. Instead, they must be guided towards one of the modes of behaviour available to them by 'bottom-up' control: by tweaking the conditions or the rules of interaction. It's like guiding the course of a river: you have to work with the flow, or it will just rearrange the banks.

For complex social systems this consideration carries an important message for governance. It does not imply that political interventions are doomed to fail, but just that they must sometimes take other forms from those often advanced today: ones that facilitate the emergence of desirable, self-organized modes of behaviour. Such interventions must happen at a deep level, and with scope for adaptation and flexibility. And they must acknowledge which states of the system are stable, and which are not. None of this is to deny the value of some state-led, top-down regulation – but when that is applied, we must recognize that the consequences may be non-intuitive and difficult to predict.

Despite the shared characteristics of physical and social/economic complex systems, we should not lose

sight of the important differences. In social systems, for example, the number of variables involved is typically much larger, the 'rules of the game' may change over time, and the timescales of these changes may overlap. Besides, when we are dealing with humans rather than inanimate particles, we have to consider the technical, financial, ethical and cultural dimensions (which also change over time), as well as the potential for changing behaviour merely by observing or predicting it. Human behaviour involves (among other things) memory, anticipation, emotion, creativity, and intention.

For such reasons, social systems are the most complex systems we know, and are certainly more complex than physical systems. It is scarcely surprising, then, that many social scientists are skeptical about the value of mathematical models. But while the challenges are greater than some natural scientists appreciate, that is no reason for pessimism. The dramatic progress in this field over the past two decades or so gives reason to believe that social complexity is not impossibly complicated. We already have reason to think that many of the qualitative features and behaviours familiar from experience with physical systems remain evident in social ones – and indeed, it would be rather surprising if they did not. This book offers a brief, selective survey of what we have learnt so far – and where the next steps might take us.

## Modeling Complex Systems

In the following chapters I describe some of the models that have been devised to study and explain social behaviour. We must then ask: how do we know if they are any good?

In the natural sciences there is, in principle, a clear procedure for answering that. The predictions of the model are tested against experimental results, and the degree to which they match is a fair indication of the degree to which the model is a valid description. If two rival models vie to explain the same phenomenon, that one is preferred which offers the best match to observations.

But in social sciences it's rarely so simple. Testing a model against observations in the real world is often hard enough in the first place, for various reasons. It is extremely difficult – practically, financially and ethically – to conduct experiments on human social systems. And even when this is possible, the number of parameters or variables describing the system is commonly very large, and some may be hard or impossible to quantify. How, for example, does one measure trust? Surveys of opinions are a common tool in social science, but are notoriously tricky to interpret or calibrate. And whereas in the physical sciences the usual experimental approach is to vary

one parameter while holding others constant, this might not be possible in social-science experiments.

The problem goes beyond these practical obstacles to experiment and validation. It is not unusual for one model or theory to appear to be supported by experience in one situation, but others in other circumstances. An example is the effect of incentives on productivity in economic theory: incentives seem to work in some cases but not in others.

This situation does not necessarily imply that the theories are inadequate or ambiguous, but may be simply a reflection of what the social world is like. Not only do outcomes often depend on a host of different contingencies, but sometimes there may be too much variability in the system – too sensitive a dependence on random factors – for outcomes to be repeatable. The converse is also true: a particular social phenomenon might be equally well ‘explained’ by two different models based on quite divergent assumptions.

In such cases, we need not despair of the value of models or theories. Rather, it might be necessary to accept that a particular phenomenon has no unique explanation, no ‘best’ model that accounts for it. In such cases, there might instead be a need for several complementary and overlapping models, some of which work well sometimes or for some aspects of a problem and others in other cases. This goes against the grain for many natural scientists, although in fact the situation is not unprecedented even for them: predictions of climate change, for example, draw on many different models, which include and exclude different aspects of the ‘living Earth’ system, and which have various strengths and weaknesses. The predictions are an amalgam of the results of all these models, expressed as a range of possibilities with an estimate of uncertainties and often with an acknowledgement of some outliers that exceed the limits of most model outcomes. A ‘majority view’ might not be philosophically very satisfactory (who is to say that the outlier might not include some vital factor that the other models neglect?), but it seems to work well enough in practice. It is very likely that a science of social complexity will need to embrace this position of ‘pluralistic modeling’.

### What this Book is for

The aim of this book is to show that it is possible and productive to try to understand social systems as complex systems, and in many cases to design and direct them with that in mind. That approach has already been found to work in some cases: to offer explanations for social phenomena, and to suggest solutions to social problems, where other, more conventional theories and approaches

have failed. The examples chosen here, both in terms of general topics and specific case studies within them, are by no means comprehensive, but are intended as an illustrative sample of what has been achieved.

As well as demonstrating the general validity of this approach, the book has a more specific agenda. It argues that the complex-systems view of social sciences has now matured sufficiently for it to be possible, desirable and perhaps essential to attempt a grander objective: to integrate these efforts into a unified scheme for studying, understanding and ultimately planning and predicting the world we have made. Such a scheme would not constitute a single ‘model of everything’, but rather, would allow society and its interactions with the physical environment to be explored through a combination of a suite of realistic models and large-scale data collection and analysis. It is a vision that should now be possible by mobilizing and coupling many different research communities, and it is one that might enable us to find new and effective solutions to major global problems that are impending or already with us, such as conflict, disease, financial instability, environmental despoliation and poverty, while avoiding unintended policy consequences. It could give us the foresight to anticipate and ameliorate crises, and at least to begin tackling some of the most intractable problems of the twenty-first century. The final section of the book outlines a project with these objectives.

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The idea that the social sciences can usefully employ concepts developed in the natural sciences is not new. It was evident at the very origin of modern political philosophy. In the seventeenth century, Thomas Hobbes based his theory of the state on the laws of motion recently deduced by Galileo, in particular the principle of inertia. The ascendancy of the mechanistic view of the natural world, for which the paradigm was Isaac Newton's gravitational model of the cosmos, gave rise in the eighteenth century to a belief that social behaviour also follows rigorous laws that can be expressed and understood along similar mechanistic lines. Adam Smith's notion of an 'invisible hand' that creates a stable and efficient economy from the self-interested behaviour of its many actors already embodied the image of social self-organization that required no over-arching guidance or authority. The operation of this invisible hand was deemed to be as dependable as the law of gravity, provided that the state did not interfere: a central tenet of the belief that markets must be free if they are to be efficient, which many economists and politicians still hold to some degree today.

And in the nineteenth century the cohesion of society as a collective result of the actions of its multitude of members was considered in statistical terms: what mattered was not the capriciousness of individual actions and

choices, but the predictable averages. This image both influenced and was influenced by the evolving physical theories of matter envisaged as a vast collection of atoms and molecules: the ideas that gave rise to the twentieth-century science of *statistical physics*. Just as the random, unpredictable movements of individual particles in a gas produce, en masse, the wholly reliable and mathematically simple 'gas laws' that relate its pressure, temperature and volume, so might society show predictable and regular behaviour when viewed as a whole. Thus, early sociology was largely constructed according to an unspoken faith that there was a kind of 'physics of society'.

## What is Complexity?

In retrospect, this idea remains valid but it often drew on the wrong analogies. Society does not run along the same predictable, 'clockwork' lines as the Newtonian universe. It is closer to the kind of complex systems that typically preoccupy statistical physicists today: avalanches and granular flows, flocks of birds and fish, networks of interaction in neurology, cell biology and technology. These systems differ from simple gases in that the component particles or agents interact strongly with one another, affecting and responding to one another's behaviour. That is true even for a non-living system like a pile of sand: tumbling grains can strike other grains, setting off cascades that can produce avalanches of all sizes, which are difficult to predict individually but which have characteristic statistical patterns.

This means that societies are more like the communities and ecosystems studied by biologists: food chains, ant and bee colonies, predators and their prey. At one level that seems hardly surprising, for what are societies but communities of a particular species of animal? But what is striking is that analogies between the group behaviour in these cases exist despite the supposedly much greater psychological and cultural sophistication of humans. Some features, such as collective movements and modes of organization, seem rather insensitive to the fine details of how individuals interact, and are determined by the very fact of those interactions, along with the *shape* of the networks they define. That's why descriptions of the resulting behaviour remain accessible to the kinds of theories of complex systems that physicists have developed. They do not necessarily need a great deal of biological or psychological realism to capture the essence of the emergent phenomena.

Thus, on the macroscopic level, social and economic systems have some features that seem to be similar to properties of certain physical or biological systems. For example, they tend to develop hierarchical organization. In social systems, individuals form groups, which establish organizations, companies, parties and so forth. These