AMBIO (2010) 39:600–607
DOI 10.1007/s13280-010-0075-7

REPORT

Requisite Simplicities to Help Negotiate Complex Problems

**Richard Stirzaker, Harry Biggs, Dirk Roux,
Paul Cilliers**

Received: 8 May 2009 / Revised: 1 April 2010 / Accepted: 15 April 2010 / Published online: 13 July 2010

Abstract Decision makers responsible for natural resource management often complain that science delivers fragmented information that is not useful at the scale of implementation. We offer a way of negotiating complex problems by putting forward a requisite simplicity. A requisite simplicity attempts to discard some detail, while retaining conceptual clarity and scientific rigor, and helps us move to a new position where we can benefit from new knowledge. We illustrate the above using three case studies: elephant densities and vegetation change in a national park, the use of rules of thumb to support decision making in agriculture, and the management of salt in irrigation. We identify potential requisite simplicities that can allow us to generate new understanding, lead to action and provide opportunities for structured learning.

Keywords Reductionism · Complexity · Adaptive learning · Decision support models · Natural resource management · Irrigation

INTRODUCTION

The experimental or reductionist approach to problem solving, which involves removing sub-systems from their wider context so that cause and effect can be inferred through controlled experiments, has been spectacularly effective. Yet, some argue that this success is confined to manipulating simpler systems and is inadequate for understanding complex ecological systems (Gadgil et al. 1993; Gunderson and Holding 2002; Berkes et al. 2003). Our knowledge of the sub-systems accumulates, but not our ability to predict system behavior as a whole, and the gap between what is known and our ability to apply new knowledge in real world situations remains (McCown 2001; Balmford and Cowling 2006; Roux 2006; van Kerkhoff and Lebel 2006).

In response to this dilemma, new approaches have been pioneered to what are commonly referred to as complex problems (Walters 1986; Holling 2001; Cilliers 1998; Cilliers 2005; Stankey et al. 2005; Walker and Salt 2006). Complexity, in this context, refers to the nature of the problem not the degree of difficulty. In short, complex problems comprise a number of components, and at least some of these components have non-linear relationships between them. Although the components may be well understood in themselves, non-linear interactions and feedbacks between components give the system a degree of unpredictability. Cause and effect can usually be resolved when looking backward, but one cannot be sure which of several logical outcomes will eventuate when looking forward (Cilliers 2005; Levin 1999). Complex systems have *emergent* properties. Emergence is a characteristic of the system as a whole, not of individual components. If one takes the system apart, i.e., reduce it to its components in isolation, the emergent properties disappear.

Those tasked with managing complex systems often complain that science delivers fragmented information that is not useful at the scale of implementation (Roux 2006). They need scientific knowledge to be translated into robust guidelines, and identifying a requisite simplicity may provide this: “there is a requisite level of simplicity behind the complexity that, if identified, can lead to an understanding that is rigorously developed but can be communicated lucidly” (Holling 2001). The idea of “requisite simplicity” is compelling because it holds together what are often competing interests. On the one hand, participating groups have to simplify sufficiently to get the cooperation from groups with different expertise and agendas—from those who are providing the financial resources to those who will be affected by the management intervention. At the same time we dare not simplify so far that we fall into the arena of the simplistic—which will ultimately lead to error.

When we deal with complex systems, some form of reduction is inevitable. At the same time, this reduction cannot be "perfect." We have to be explicit about the nature of the reduction and of its shortcomings. In this article, we argue for a requisite simplicity that enables us to structure our learning when dealing with inherently complex problems.

COMPLEX PROBLEMS

One way of understanding the nature of complex problems is to compare problems that are fully understood, on the one hand, with problems that appear unresolvable or chaotic, on the other (Snowden 2002). Since the scientific renaissance of the 1700s, scientists have viewed the natural world as "Knowable," residing in domain B of Fig. 1, where cause and effect are resolvable by experimentation. Experiments are carried out under controlled conditions to minimize the impact of extraneous variables and are then replicated to show that the variable being controlled contributes more to the outcome than other factors. In this way, theory is developed, challenged, and improved. The new knowledge is moved from the Knowable domain B to the Known domain A, where it can be used by the target audience.

As the scale of enquiry becomes wider or we are trying to understand multiple scales, it becomes more difficult to resolve cause and effect and the problem can be viewed as complex. Examples of Domain C problems include the phosphorus input into lakes and their trophic status (Folke et al. 2004), the relationship between land clearing and ground-water salinity (George et al. 1997), or the response of savannah vegetation to grazing pressure (Ludwig 1997). These systems may display alternate stable states into which parts of a system could be "attracted" for various periods of time. A transition between such states appears to occur relatively suddenly when thresholds are crossed, while returning to the previous state is more difficult than simply reversing one's positions along a continuum (Walker and Salt 2006; Walker 2004).

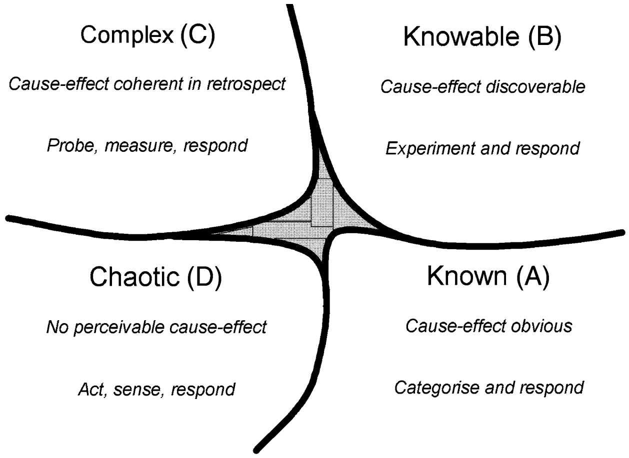

Fig. 1 The four problem domains and for each, the cause–effect relationships that typically apply and the appropriate management response [adapted from Snowden (2002)]

Domain D is the chaotic domain where there is no discernable link between cause and effect. Although the system behavior, such as the passage of an intense storm, appears to be random, some think it would be deterministic if we could take enough measurements. Although we do not deal further with the chaotic domain here, it serves as a useful comparison to complexity. Complex systems may change rapidly with the external environment, but parts of the system resist change or change slowly, giving the system memory. Complex systems can also retain the same emergent behavior even when there are substantial changes in some of the components, i.e., they have some enduring structure (Cilliers 2005).

UNDERSTANDING COMPLEX SYSTEMS

Complex systems usually consist of a large number of non-linear relationships. These relationships are multiple—any single component links to many others—and there are always feedbacks. Complex systems are also open systems which interact with their environments. Since the boundaries of such systems are often problematic (Cilliers 2005), we also have to include the broader environment in our description of the system. These environments are usually complex in their own right. In order to generate a perfect model of a complex system, one has to model everything.

In order to understand this claim, we have to remember the non-linear nature of the interactions in complex systems. This non-linearity has two important consequences. In the first place, when there are a lot of simultaneous, non-linear interactions, it soon becomes practically impossible to keep track of all the causal relationships between the components. Secondly, as a result of the non-linear nature of complex systems, they are incompressible. A set of linear relationships can be simplified by adding them together—the so-called "law of superposition." A set of non-linear relationships cannot be simplified in this way; each individual relationship has to be taken into consideration on its own. Moreover, complex systems have a memory. This means that present and future states of the system are co-determined by the history of the system, a history to which we may not have detailed access (Cilliers 1998; Walker and Salt 2006).

If we take these considerations into account, the problem should become clear: models have to reduce the complexity of the phenomena being described, so they have to leave something out. However, we have imperfect ways of predicting the importance of that which is not considered. In a non-linear world where we cannot track a clear causal chain, something that may appear to be unimportant now, may turn out to be vitally important later. Our models have to "frame" the problem in a certain way, and this framing will inevitably introduce distortions.

This is not an argument against the construction of models or a dismissal of reductionist methods. We have no choice but to make models if we want to understand the world. Our acts of simplification are necessary, but not perfect. We have to acknowledge the complexity of the problem and then make the best simplifications we can. These simplifications allow us to generate understanding, and they lead to action, but at the same time they have to be constantly revised and used with care. They provide opportunities for learning and lead to further exploration.

It could be argued that perhaps we can construct (e.g., computationally) a model which include *all* the relevant information. Although this cannot be precluded in principle, it does not solve our problem. If we have a model which is just as complex as the system it models, it will be just as difficult to understand as the system itself. We will also not be able to judge if the model actually tracks the system correctly in time and space. It is often therefore better to have a simpler model which we understand, and understand the limitations of, than a complex one we do not understand.

ATTEMPTS TO SIMPLIFY

The idea of simplification can be illustrated by showing the relationship between the increasing level of detail and the functional utility of an evolving understanding or product (Ward 2005). To develop something useful, we must engage the detail of the particular subject area. We start at position 1 in Fig. 2 and make our way to position 2. At position 2 we have a useful product, but decide it is not good enough. We add more detail, but find that additional detail provides less and less utility as we head for position 3. Our product has become overcomplicated and its utility has diminished. At this point, further progress comes not from adding more detail, but from taking it away—in other words, simplification (Ward 2005).

Figure 2 was originally illustrated using the example of an airplane, and the journey toward destination 3 was described as producing "gears that turn without reason or grind against other gears" (Ward 2005). This happens because experts with a narrow focus over-work the problem and give us unnecessarily complicated solutions. Simplification comes when someone adds a fresh new perspective that reduces the problem to its essential components and provides a more elegant way forward. Yet, the airplane example operates in the knowable domain – each component of an airplane has a known function and the addition and removal of each component can be evaluated. This is not so in the complex domain, because, as argued earlier, we have no way of gauging the importance of what we leave out. Simplification in the complex domain must therefore involve the identification of emergent properties of the system and simple ways to track them.

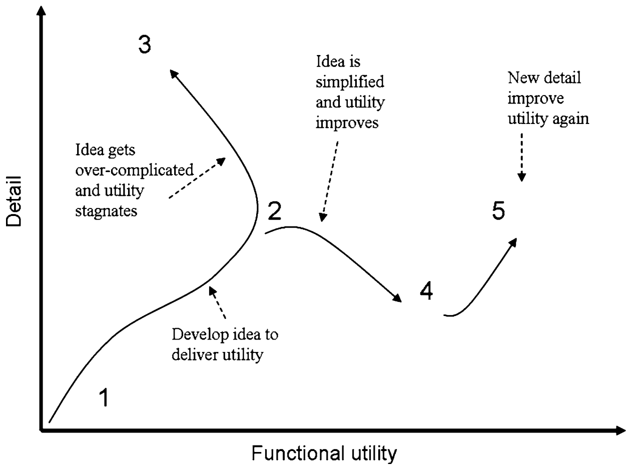

Fig. 2 The simplicity cycle [adapted from Ward (2005)]

Passioura's visual parable provides another way to think about detail and our ability to understand the system. He shows a picture of white dots of different sizes arranged in different ways against a black background (Passioura 1979). If we focus on the dots themselves we can form theories on their size and shape and their arrangement on the page. Yet, if we stand back and blur our eyes slightly, the different densities of dots merge to produce the illusion of light and shade. If we stand back further, the light and shade produce features we can recognize, the nose, eyes and mouth of a man smoking a pipe. We can only see the face when we abandon the details embodied in each of the little dots.

REQUISITE SIMPLICITIES

In this section, we draw on three examples to identify problems against the classification in Fig. 1 and how we might simplify by reframing the problem or identifying a requisite simplicity.

Elephants and Vegetation Change

Elephant numbers have increased in the Kruger National Park from an estimated 100 in 1925 to about 12,500 in 2006 (Whyte et al. 2003; Scholes and Mennell 2008). Many believe the population density of elephants is now impacting the structure of savanna vegetation and contributing to the loss of tall trees. This has spawned the difficult debate over if and how elephant numbers should be controlled, since vegetation change is believed to affect populations of other fauna in the Park. However, the relationship between elephant density and vegetation change turns out to be neither straightforward nor linear (Scholes and Mennell 2008), so the notion of an "optimum density" of elephants has come under close scrutiny.

Elephants do impact on trees, but under certain circumstances and relative to certain management objectives, high densities can also produce "good" outcomes, such as creation of additional types of habitat via the disturbance they produce. Moreover, the values held by humans about elephants are widely divergent, from the view that they should be hunted for community profit, to the belief elephants are sacrosanct (Scholes and Mennell 2008).

Hence the "elephant management issue" resides firmly in the complex domain of Fig. 1, not only because of varying social and economic values, but because the biophysical outcomes themselves depend not only on the elephant density, but also on the particular soil type, vegetation characteristics, rainfall, surface distribution of drinking water, and the amount and type of fire which occurs in each vegetation type. A large and complicated research program aimed at characterizing each of these biophysical combinations may help us to eventually predict which outcome is likely to occur at each locality at a certain time, but may equally take us on the journey to position 3 of Fig. 2.

All the various interest groups in South Africa have been brought together in a well-structured initiative, at the end of which the South African government was able to publish widely acceptable guidelines for elephant management, drawing also on the scientific evidence (Scholes and Mennell 2008). There are a plethora of circumstances to consider in different places, but in the Kruger Park, the requisite simplicity to help direct the thinking is based on its fundamental mandate, i.e., to maintain biodiversity in all its facets (Du Toit et al. 2003). A range of differing vegetation structures, which may also vary over time, is a useful surrogate for heterogeneity (variation over space), which in turn is considered a surrogate for biodiversity. Management of the park increasingly involves setting and monitoring thresholds for this variation, including bush thickening and loss of tall trees. These thresholds guide decisions as to any intervention and are themselves open to revision as knowledge is gained from new research and practical experience.

Decision Support Models in Agriculture

The development of scores of Decision Support System models (DSSs) over the last two decades, particularly in the agricultural sciences, represents the most concerted effort to bridge the gap between the knowable and known domains. Implicit in the DSS is that cause and effect are fundamentally resolvable, and therefore management decisions can lead to a predictable consequence, or at least a probability distribution subject to the vagaries of climate. Although DSS was developed to simplify the task of management, the lack of demand for these models by farmers has puzzled the model developers (McCown 2002).

Farm managers know that it is much harder to get the whole farm business to work satisfactorily than it is to do one part, aided by a DSS, extremely well. Clearly, managing a production system for profit resided in the complex domain of Fig. 1, whereas the DSS was operating in the knowable domain of one or more of the sub-systems which were amenable. Moreover, the relationship between more information and improved decision making is not proportional, there is a critical amount of information which is helpful for a farm manager, but after some point more information becomes unnecessary or confusing (Hayman 2004), much like the journey to destination 3 of Fig. 2.

Farmers often prefer their own simple rules of thumb to help them make decisions in the face of uncertainty (Tengö 2004). A well-known rule of thumb is the "French and Schultz equation," used to estimate the potential maximum yield of wheat as a function of seasonal rainfall in a Mediterranean environment (French and Schultz 1984a, b). Based on a large number of field trials, they showed that the maximum production of wheat per mm of water transpired was 20 kg ha^{-1} of grain. Farmers could estimate crop water use from rain and changes in soil moisture storage over the season and apply the 20 kg of grain per mm rule. If they reached the French and Schultz potential, they were doing as well as they could for that season. If not, the crop was limited by factors other than water, often factors within their control to manipulate.

Irrigation and Salt

All irrigation water contains some salt. Plants exclude unwanted salts at the root surface, and these salts accumulate in the soil. Extra water, above the requirement of the plants, is needed to leach these salts out of the root zone (Ayres and Westcot 1989). This leaching fraction must be kept to a minimum, because it contributes to groundwater, and rising saline groundwater is a serious threat to irrigation worldwide. Some irrigators deploy crop water use models or soil water monitoring equipment, but such techniques cannot in themselves ensure the leaching fraction is kept between reasonable limits.

The problem can be reframed by viewing salt as a passive tracer, and its accumulation as an integral of water applied, evapotranspiration and leaching below the root zone. In other words, irrigation is a salt concentrating business; salt is added to the root zone with the water, concentrated by evapotranspiration, and removed by leaching. We do not necessarily have to measure the ever changing upward and downward fluxes, which are difficult measurements to make. By monitoring the concentration of salt in the soil water near the bottom of the root zone, we can get a rough guide as to whether leaching is too high or too low.

The soil water content is a fast changing variable, as plants can deplete the store of soil water in a matter of days. Good irrigators need to manage this variable closely, to ensure the plants are not stressed. Changes in groundwater level, however, tend be very slow, responding adversely to poor irrigation practice years or decades earlier. The fast variable is linked to productivity and the slow variable to sustainability. Salt accumulation near the bottom of the root-zone varies over weeks to months, and as such is an intermediate scale variable. This is the scale variable that, when coupled with the fast and slow one on either side, helps us to learn how the whole system behaves (Lynam and Stafford Smith 2004).

The learning approach above is being followed by an entire district of irrigators using low quality water in South Australia.[1] They use a wetting front detector, a funnel-shaped instrument that is buried in the root zone, to capture some water after irrigation events so salt levels can be monitored (Stirzaker 2003). Instead of seeing salt as essentially "bad," we encourage irrigators to let the salt build up in the lower part of the root zone. This tells them that leaching is not excessive and so minimizes the amount of water reaching the groundwater and the loss of soluble nutrients. At the same time there needs to be a threshold which triggers leaching, so that crops are not damaged by too much salt in the root-zone.

REQUISITE SIMPLICITY AND LEARNING

If the above three examples qualify as requisite simplicities, then they need to fit Holling's definition of "an understanding that is rigorously developed but can be communicated lucidly (Holling 2001)." The French and Shultz equation has become fundamental in linking the research domain (what yield is possible) with the reality faced by farmers and their consultants in southern Australia wheat growing regions (Passioura 2002), and the original papers underpinning the equation have hundreds of citations. It certainly passes the test of lucid communication across the various interest groups.

The requisite simplicity concerning elephant impacts on vegetation is still gaining a constituency. It is not so much about finding a lucid way of communicating a complex problem, but a way of negotiating the tension between scientific rigor and political reality (Lee 1993). Up to the 1990s, the view of KNP managers was that the park had a maximum elephant carrying capacity which needed to be adhered to by culling or removal. Following the democratising of South Africa, many other voices wanted to be heard and culling on a large scale became politically unacceptable. The requisite simplicity of monitoring elephant impacts within a heterogeneity framework has now replaced the command and control culling framework, and give all sides of the debate space to negotiate an acceptable outcome. Similarly, the intermediate scale variable of salt in the root zone was envisaged to provide common ground between the exploiters of the resource (irrigators) and the health of the river and aquifers that their long term survival is dependant upon.

This leaves us with the other half of the definition of requisite simplicity, that of scientific rigor, so we avoid the pitfall of over-simplifying. The key elements of the requisite simplicity must be measureable. A requisite simplicity is not falsifiable in the same sense as an experimental hypothesis. Yet, the requisite simplicity does represent a conceptualization of the problem, and our measurements can show whether events are unfolding in a way that is consistent with this conceptualization. It provides a basis for our actions, although we expect that as context and values change, and knowledge is gained, that it will be superseded.

In addition to rigor and lucidity, we include a third component to a requisite simplicity. We must be able to show that the requisite simplicity helped us to learn something new. The single line relating seasonal water use to potential yield could be seen as simplistic, and ultimately leading to error, since the timing of water stress with crop growth stages could vary enormously for the same total seasonal water use. French and Schultz plotted farm yield data to this relationship and found that in most cases yield fell well short of the potential based on rainfall (French and Schultz 1984a). They also showed that better attention to weeds, disease, rotations, and nutrition could push many yields back toward the potential set by rainfall (Fig. 3).

When farmers and researchers saw that yield was rarely limited by rainfall in a dry Mediterranean environment, they could no longer point to the weather as the cause of

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[1] http://www.angasbremerwater.org.au/. Accessed 31 March 2010.

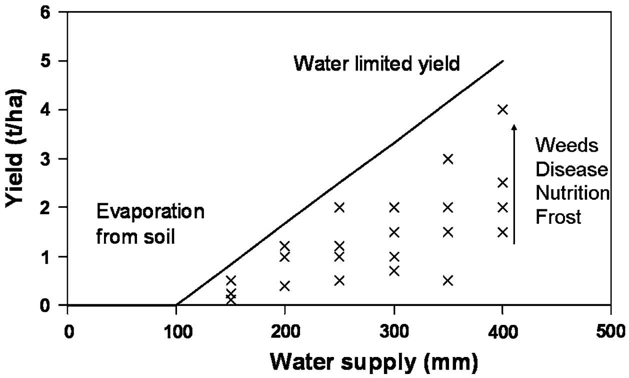

Fig. 3 A simple relationship showing total season water use demonstrated the upper limit to yield. On-farm yields (denoted by x) typically fell well below the potential, and it was largely factors within the farmer's management control that moved yield upwards toward the water-limited yield [adapted from Passioura (2002)]

their problems. This opened up new research fields, particularly around the role of soilborne root diseases and how to overcome them with strategic rotations. The result is reflected in national yield statistics (Passioura 2002). It remains to be seen whether the requisite simplicities postulated around elephants and irrigation will provide similar opportunities to learn.

The final consideration is how we go about finding a requisite simplicity. Here, we only offer some preliminary ideas. We must be prepared to move outside our specialist areas and form bridges between scientific disciplines and across the domains of science, management, and societal values (Max-Neef 2005). We will have to develop empathy for other knowledge forms such as culture and experience and spend time learning together (Senge 1990). We may have to give ground on some of our hard fought positions and find the humility to acknowledge error and embrace failure as we develop a more defensible shared rationale with other stakeholders.

CONCLUSION

The three case studies span the knowable and complex domains of Fig. 1. The interaction between elephants, vegetation, and biodiversity resides largely within the complex domain. The business of running a farm with decision support models crosses the boundary between complex and knowable. Many would see the salt and irrigation problem occupying the knowable domain, but in practice irrigators need approaches that integrate the components of the water balance, which are possible, but difficult, to measure.

We draw four guiding principles from above discussion in the context of practical management. First, our knowledge usually advances incrementally as we investigate more detail, and we will invariably overshoot position 2 and head for position 3 of Fig. 2. We recognize this overshoot when people representing different interests and disciplines lose a shared view on how to move forward. A requisite simplicity attempts to discard some detail, while retaining conceptual clarity and scientific rigor, and helps us move to a new position where we can more usefully benefit from new knowledge (detail)—the road to position 5.

Second, lack of certainty is no excuse for lack of action. In fact, it is the pursuit of a false certainty, the failure to recognize the complex elements of the problem, which ultimately slows progress. We encourage those who recognize they may be on the journey to position 3 to reframe the problem in a way that gives a place to stand and take action while we learn more about how the system is really operating.

Thirdly, we recognize that there are no simple answers to complex problems, but simplification is part of the journey of learning how to deal with them. Many of the problems we face comprise knowable and complex elements and we need to identify which are which. In the complex domain, this will generally involve the identification of a robust integral or emergent property of the system which we can practically monitor and learn from. However, there is no single correct variable to monitor, if we thought this we would drift back toward a command and control approach (Holling and Meffe 1996).

Fourthly, dealing with complex systems demands a degree of humility from scientists because our knowledge is limited and there will be surprises. It is better to take a modest position, which is not a weak position but a responsible one that "resists the arrogance of false certainty" (Cilliers 2005). In the domain of complexity, our focus should be to maintain structured learning, rather than producing blueprints.

Acknowledgments We thank Oonsie Biggs, Nicky Grigg, John Passioura, Fabio Boschetti, Ted Lefroy, and Stefanie Freitag-Ronaldson for their helpful comments on the manuscript.

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AUTHOR BIOGRAPHIES

Richard Stirzaker (✉) is a Principal Research Scientist at CSIRO Land and Water in Canberra, Australia. His main research interests include irrigation, salinity, agroforestry, participative learning, and technology transfer. He is an honorary professor in the Department of Natural and Agricultural Sciences of the University of Pretoria.
Address: CSIRO Land and Water, PO Box 1666, ACT 2601 Canberra, Australia.
e-mail: Richard.stirzaker@csiro.au

Harry Biggs leads the systems ecology research for SANParks, based in the Kruger National Park, South Africa. He has a particular interest in strategic adaptive management and is involved in the implementation of new biodiversity and protected area legislation in South Africa.
Address: Scientific Services, Kruger National Park, Private Bag X402, Skukuza 1350, South Africa.

Dirk Roux works in the field of freshwater ecosystems, spanning the fields of limnology, aquatic toxicology, environmental monitoring and reporting, systematic conservation planning, policy and strategy development, and institutional learning and knowledge processes. Before joining Monash South Africa, he worked for CSIR where he

was a Principal Researcher and Fellow of the Natural Resources and Environment Unit.
Address: IWC, Africa Water Research Node, Monash South Africa, Private Bag X60, Roodepoort 1725, South Africa.

Paul Cilliers is in the Philosophy Department of the University of Stellenbosch where he teaches cultural philosophy, deconstruction, ethics and logic for philosophy. After initially qualifying and then working as an electrical engineer, he completed a D. Phil in 1994 on complexity theory. Much of this work, together with post-doctoral research, was published in an internationally renowned book entitled Complexity and Postmodernism.
Address: Centre for Studies in Complexity, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa.