

# FROM FITNESS LANDSCAPES TO KNOWLEDGE LANDSCAPES

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## ABSTRACT

Based on the complexity theory concept of fitness landscapes, this article develops and discusses the concept of "knowledge landscapes." A knowledge landscape is metaphor of an ever-changing knowledge of each individual and organization. Each one of us is surrounded by *potential* knowledge landscape peaks and valleys.

Individuals, communities, and organizations move on their own knowledge landscapes by simultaneously climbing local peaks and exploring other visible peaks. The higher one climbs, the harder it is to climb still further. The ability to climb is also limited by the identity, who we are, which on an organizational level is linked to the tightness of organizational interconnectedness. Co-evolutionary struggles between individuals and organizations can lead us to climb potential knowledge peaks faster. Moreover, our knowledge landscapes exist on many levels of scale, meaning what appears to be one peak is actually a series of sub-peaks on a smaller level of scale.

## INTRODUCTION

The purpose of this article is to introduce and discuss the concept of “knowledge landscapes”- - analogous to the concept of fitness landscapes in complex adaptive systems theory--which we believe brings forth new insights in the organizational science realm. More precisely, viewing individuals and organizations through a lens of knowledge landscapes raises new research questions on what is the boundary of organizations (Scott, 1987), the role of managers (Thompson, 1967), co-operative strategies (Hamel, 1991), and organizational learning (Huber, 1991). Because it rests on a different set of assumptions than much organization theory, the concept of knowledge landscapes also raises important questions regarding research methodology (McKelvey, 1997).

Some scholars have pointed out that extending theories developed for natural sciences to social systems is fraught with potential pitfalls (e.g. Mingers, 1995). Johnson and Burton (1994) described the difficulty of using complexity theory in organization science research given: i) greater uncertainty in testing conclusions due to the generally smaller number of data points, ii) a perceived overdependence on metaphoric use of the theories, and iii) the wholesale abandonment of Newtonian principles thought to lie behind much complexity research by organizational researchers. While we acknowledge these concerns, we believe metaphors and analogies can allow cross-fertilization between complexity and other theories to improve our understanding of organizational phenomena. Johnson and Burton themselves concede that metaphors are “fair game” in the context of discovery processes. The value of analogies has similarly been highlighted by Holland: *analogy helps to generate new rules applicable to a novel target problem by transferring knowledge from a source domain that is better understood* (Holland, et al., 1986).

The current state of organization theory-building drawing on complex adaptive systems theory bears many similarities to the situation facing organizational learning in the early 1990s. A small but dramatically increasing number of people are conducting research in the area, and a number of conferences, seminars, Internet list servers, and journal special issues are drawing more and more attention to the topic. An inevitable “jockeying for position” is underway in complex adaptive systems theory development analogous to the process cited in Huber’s (1991) critique of organizational learning. However, some emergent order is becoming evident as the field seems to be dividing into two streams: those developing theory using computer modeling (e.g. Bruderer and Singh, 1996) and those using metaphors and narrative (e.g. Lissack, 1997).

This article follows the latter research stream. We use metaphors and analogies to relate the concept of fitness landscapes to organization theory. After a brief review of fitness landscapes, we discuss the importance of focusing on knowledge, or rather, *potential* knowledge. From here, we outline and discuss the concept of knowledge landscapes and their core properties. Finally, we discuss three implications for further research in the organization science realm.

## THE FITNESS LANDSCAPE

Although the fitness landscape concept has been around for over sixty years (Wright, 1932), more recent work by Kauffman (1987, 1993, 1995) has generated a great deal of interest

among management scholars. Using his NK model, Kauffman has developed simplified versions of fitness landscapes containing a series of peaks and valleys of varying heights and depths. He postulates that in the competition for survival, species use mutation and selection to take “adaptive walks” to reach higher viability “fitness points” in their “adjacent possible”.<sup>1</sup> Species who fail to move to higher points on their landscapes may be outpaced by competitors who are more successful in doing so, and thus face extinction through a process of natural selection. As species climb fitness peaks, further climbing becomes steadily more difficult. Co-evolutionary processes between the organism and others on its fitness landscape can affect the level of smoothness or landscape “correlation”.

The speed of such adaptive walks depends on the degree of “epistatis”<sup>2</sup> or interconnectedness among organisms’ genes, which decides how effectively the organism can adopt new genetic traits. Any particular location’s fitness on the landscape is therefore not an objective and identical value for every species. Geneticists describe the process of *epistatic coupling*, in which a new gene links or “couples” into the network of a species’ existing genes. Notably, the contribution a new gene can make to a species’ overall fitness depends on genes the species already has. For example, a long neck would be more useful to a giraffe, which already has long legs and can use such a neck to reach treetop leaves, than to a hippopotamus, whose short legs are designed to allow it to eat grass.<sup>3</sup> A high density of epistatic connections thus slows the speed with which the species can consider new variations and evolve.

Due to epistatis, the speed at which a species can climb peaks on its fitness landscape in nature appears limited. Darwinian evolution is a gradual process, with species accumulating useful variations over extended periods of time through the process of natural selection. If a species is unable to evolve gradually, i.e. if the pace of change exceeds the capacity of the species to adapt and mutate by reassembling its building blocks, it faces extinction. Error catastrophe<sup>4</sup> can lead a species to move *down* a peak if it occurs more quickly than the species can climb through natural selection processes. Useful traits acquired through natural selection can thus be lost, and the species drifts down its peak towards a valley on its fitness landscape.

Recently, Kauffman (1995) has begun to apply the concept of fitness landscapes to the evolution of technology in organizations. He asserts that firms embark on adaptive walks to develop new technologies, travelling up peaks on their landscapes. Each move up a local peak reduces the number of directions in which the technology can be improved by a constant fraction, so climbing becomes more difficult. His claim is supported by evidence that as technologies mature, each additional dollar invested yields a steadily declining marginal improvement. Kauffman concludes that while a technological innovation may be highly desirable for one part of an organization, as the number of epistatic connections increase, chances grow that the innovation will negatively affect other parts of the organization.

### **SHIFTING ATTENTION TO POTENTIAL KNOWLEDGE**

We are not the first authors to attempt to bring the fitness landscape concept into the organizational realm. Stacey (1996), Levinthal (1997), and Kane (1996) are some examples of scholars taking this route. Yet, these contributions seem to rely on underlying assumptions borrowed from the more traditional “Newtonian” scientific traditions they frequently set out to reject. The approach often harkens back to Hayekian neo-classical economics, where the role of firms is to find the best way of allocating given and scarce resources.

In the same spirit, the traditional resource-based theory has been extended to include knowledge as a “resource” essential to achieving superior firm performance (e.g. Conner and Prahalad, 1996). Yet, in line with the assumption of *sustainable* competitive advantage (e.g. Porter, 1980; Barney, 1991), the underlying assumption remains that it is the role of management is to apply and co-ordinate knowledge as any other resource (Grant, 1996).

Such approaches seem inconsistent with recent developments in the field of economics. Brian Arthur’s description of the “knowledge economy” (Arthur, 1990), and Paul Romer’s “new growth theory” (Romer, 1986) refute neo-classical approaches by drawing knowledge and technology into the realm of endogenous variables having a direct impact on economic performance. Arthur’s work on increasing returns to scale is inspired by complex adaptive systems research, in its use of positive feedback and the existence of multiple equilibrium points, to build better theories of firms in the knowledge economy. In more recent work, Romer has even begun using “hill-climbing” analogies to describe organizational activities, stating that firms climb hills until they get diminishing returns, then they frequently take big leaps far away and land somewhere on a different mountain. Such a blend of knowledge and fitness landscapes concepts is also consistent with Kauffman’s application of fitness landscapes to technology development.<sup>5</sup>

In this article, we assert that rather than thinking of firms moving on fitness landscapes, we should think about individuals, workplace communities, and organizations (subsequently referred to by us as “actors”) moving on their own knowledge landscapes. But before elaborating on this conceptual leap, we believe it is essential to tackle a basic epistemological consideration.

In this article we do not consider knowledge to exist in a tangible or directly measurable form “out there”, but as something that can only be developed within an individual, then shared through interaction and interpretation in a social setting. Drawing on von Krogh et al (1994), and von Krogh and Roos (1995), we view knowledge development as an inherently private and unique process of converting raw data into knowledge. This epistemological point of view stands in contrast to so-called “cognitivist” or “connectivist” stances, which imply that “reality” resides outside the cognizing subject, and that we develop representations of this objective reality in our own minds. Unlike cognitivism and connectivism, the “autopoietic” epistemology<sup>6</sup> is not representationist. Autopoietic systems—individuals or organizations--(see Maturana and Varela, 1987) are self-referential, that is, they “know” through reference to past knowledge. “Reality” for the system is thus socially constructed when the system makes distinctions between other unities and its background.

Autopoietic systems engage their environment through a co-adaptive process of structural coupling, which leads to structural changes in both the system and its environment. This mutual co-adaptation occurs when a “perturbation”, or a difference between expectations and observed stimuli, occurs and creates “friction” in the observing system. The degree of change in the internal rules of the systems depends on the strength of the perturbation, and also on the extent to which the systems “slows down” to assimilate the effect of the perturbation.<sup>7</sup> It is from this epistemological point of view that we bring forth the concept of knowledge landscapes.<sup>8</sup>

From this perspective, individuals are open to data but closed to knowledge. All new signals from the environment into an individual or organization are thus only *potential* knowledge. Moreover, all new knowledge development developed by individuals depends on their previous knowledge (through self-reference). Thus, the *knowledge potential* of individuals, communities and organizations is virtually unlimited.

## THE KNOWLEDGE LANDSCAPE

From the rolling contours of a species' fitness landscape, using the notion of knowledge potential we can develop an analogy of an individual, community, or organization (actor) in its own "knowledge landscape". In its struggle for survival, an actor will attempt to move to higher and higher points on a *knowledge* landscape. Like the fitness landscape, the knowledge landscape contains peaks and valleys of varying heights, which will be of differing interest for an actor to climb. However, instead of "fitness", the peaks on an actor's landscape represent knowledge, or given our epistemological stance, *potential knowledge*. Examples of potential knowledge "peaks" could include signals from competitors, suppliers, customers, consultants, experts, academic institutions, research centers, government agencies, employees and journals. "Valleys" could include sources of obsolete data, such as knowledge of "telex" technology for telecommunications manufacturers. Thus, by definition, knowledge landscapes are unique and private to each actor.

### ***Balancing Climbing and Exploring***

Like species take "adaptive walks" on their fitness landscapes, actors embark on "knowledge development expeditions" on their knowledge landscapes, intentionally developing new knowledge to improve their chance of survival. As with fitness landscapes, actors on knowledge landscapes engage in two types of movement: taking incremental steps up peaks they have identified in their knowledge landscapes (climbing), or look for new peaks in their knowledge landscapes (exploring).<sup>9</sup> These activities occur simultaneously and across hierarchical levels, geographic locations, and over time. Some distinctions between climbing and exploring activities are illustrated in Figure 1.

--PLACE FIGURE 1 ABOUT HERE--

*Climbing Local Peaks.* Climbing is a "survival" activity, in which an actor moves up a potential knowledge peak that consists of data sources of which the individual or community is aware. The actor takes in and structurally couples with the data sources that make up the peak (for example, surfing the World Wide Web to learn more about the Internet). The "closed" part is where data is self-referenced and discussed to create knowledge, as well as where connections to previous knowledge occurs.

*Exploring the Landscape.* The actor can also engage in exploratory "advancement" activities to identify new knowledge peaks of which it is yet unaware. This process involves scanning broader regions of the landscape and evaluating the height and steepness of nearby peaks. Exploration activities can also lead to the appearance of entirely new peaks on the knowledge landscape, as the actor unintentionally deforms its landscape every time it climbs or explores. The actor can even intentionally deform the landscape to improve its position, and undertake

actions that will lead the local peak to rise, or others to decline. For example, a firm can “hop” or intentionally cause a chain reaction to deform its landscape and making its own peak rise, by publicly announcing new products, markets or changed strategic direction (see Bak and Chen’s (1991) notion of self-organized criticality). The resulting after-shocks of each step taken by an actor can be compared with the sensation of walking on a *rubber* surface.<sup>10</sup>

Analogous with fitness landscapes, the higher an individual or organization climbs on any particular peak on its own knowledge landscape, the more difficult it becomes to climb still higher. The reason is simply that more and more finer distinctions will need to be made, which requires more time and attention. The landscape also shifts dramatically as other landscape players change their climbing and exploration strategies and actions, thus making some potential knowledge peaks rise and others shrink in height. Actors try to avoid remaining on poor or shrinking local peaks on their own knowledge landscapes. Under time constraints, sustainability rests on their ability to achieve an effective balance between climbing and exploring activities.

### ***Identity Bounds Knowledge Potential***

Our identities limit knowledge potential by metaphorically limiting the area that can be climbed or explored, i.e. the area where new possibilities can be created. Kauffman refers to this as the “adjacent possible”. As epistasis defines the adjacent possible for fitness landscapes, identity defines knowledge potential for knowledge landscapes. Identity affects how we *see* peaks, and the *speed* with which we can move around on our knowledge landscapes. Despite some claims that there is no limit to the services that can be rendered by human resources (e.g. Tsoukas, 1996), from our perspective identities do, in fact, limit our ability to develop knowledge and therefore advance.

As all our knowledge depends on previous knowledge, our identities can also be seen to affect the *slope* of the peaks in our knowledge landscapes. In much the same way that epistasis is important for new genes to be evaluated on fitness landscapes, our identity is essential in developing new individual or organizational knowledge. Knowledge landscapes surrounding organizations with identities that are characterized by more connections will have more hills and valleys, containing many lower “compromise” peaks rather than one easily-apparent optimal peak.<sup>11</sup> As epistasis--the equivalent of “K” on fitness landscapes--increases, the knowledge landscape becomes more “rugged”. In such a case, you might see potential knowledge everywhere. The expected value of the knowledge peaks increases (Levinthal, 1997), resulting in a lower correlation among neighboring points.

The focus on epistatic interactions also finds support in Ashby’s well-known Law of Requisite Variety (Ashby, 1960). Actors in highly dynamic knowledge landscapes may require fewer connections, or a weaker identity to attain a balance in the level of variety inside and outside. Highly interconnected actors such as extremely bureaucratized firms will find it more difficult for data “signals” to lead to changes in the firm’s internal rules where the landscape is highly dynamic, so peaks appear steeper and the firm has difficulty surviving. The implication is that actors should have as much epistasis internally as that which exists in its environment.

The importance of understanding the effect of identity/epistasis on our perception of knowledge landscapes peaks and valleys is illustrated by Garud and Karnoe (1996), who studied the contrasting American and Danish attempts to enter the wind turbine market. They

noted that the Americans conducted costly and elaborate simulations on computers-- following what Garud and Karnoe call a “brilliance” approach. The Danes adopted a Levi-Strauss-inspired “bricolage” approach, conducting small-scale, endogenous tests.<sup>12</sup> Our observation is that the Americans perceived their wind turbine knowledge landscape to contain steep peaks, while the Danes saw shallow ones that were easier to climb.

### ***Co-Evolution Influences our Knowledge Potential***

Kauffman also draws the concept of co-evolution into a species’ climb up peaks on its fitness landscape. A co-evolutionary struggle can ensue between “predator” and “prey” species, in which the former develops a slightly better predation method that is subsequently countered by a new protection innovation by the latter, and so on. An example of a co-evolutionary struggle is the on-going battle between police and organized criminals to develop better new and innovative technologies to improve their ability to respectively prevent or commit crimes. As each group develops a new innovation, it *alters* the fitness landscape of the other--making a comfortable local peak appear to shrink. Door locks dating from the 1960s are swift work for thieves of today.

Like fitness landscapes, knowledge landscapes are far from static, with every step taken by an actor to attempt to develop new knowledge leading to reverberations deforming the entire knowledge landscape for all other actors operating in the same time-space continuum. Microsoft’s relatively late entry into the Internet browser industry shifted the landscape for competitors such as Netscape, who suddenly faced many steeper peaks. Actors, like species, *co-evolve* with their competitors in a seemingly endless “knowledge race” in an effort to create and leverage new knowledge faster than their competitors. As with fitness landscapes, error catastrophe has relevance in the organizational realm. Under frantic “Red Queen”<sup>13</sup> competitive conditions, the tops of the knowledge peaks would seem to moved away from the actor faster than it’s ability to climb.

Co-evolution would also seem to refute the somewhat similar metaphor of agents “surfing in a seascape” of unpredictable waves, crests and troughs, surrounding organizations (Szpiro, 1997).<sup>14</sup> The seascape analogy is appealing, however, unlike our thesis, it presumes a fundamentally different view of knowledge: what is a big wave for one person will be a big wave for another, the volume of water is the same for all surfers. A reinterpretation from our perspective would be that everyone experiences different-sized waves in the same body of water--a stretch for the metaphor. The analogy also neglects co-evolution, as while a surfer cannot affect the size of the waves, the actor on a knowledge landscape can create new “waves” that dwarf any existing waves, by making internal, autopoietic changes. Bill Gates’ computer science education certainly led to the creation of waves that swamped much of the computer software industry.

### ***Knowledge Landscapes within Knowledge Landscapes***

In addition to the above characteristics largely shared between fitness and knowledge landscapes, we suggest that knowledge landscapes include another important quality that has not yet been associated with fitness landscapes. Knowledge landscapes seem to be inherently *fractal*, with self-similar patterns observable on different levels of *scale*. From complex adaptive systems theory, we know that a *system* at one level of scale operates as an *agent* at a higher level of scale (much like the concept of “aggregation”, suggested by Holland, 1995). Similarly, each peak on a knowledge landscape represents an entire landscape on a lower level of scale--a knowledge landscape within a knowledge landscape--each peak of which in

turn contains a series of self-similar peaks on another knowledge landscape zoomed down another level.

In terms of dynamics, frequent changes at lower scale levels of knowledge landscapes leads to the emergence of new landscapes at higher levels. The rate of change at lower levels is always faster than the rate of change at higher levels. Merry (1996) suggests this relationship might follow a power law across scales. This would explain why, when viewed from the outside, entire organizations may appear stable when, in reality, change is occurring further down in subsystems such as departments, committees, and teams. Only rarely would the highly visible “large avalanche” occur at a high organizational level of scale. For example, while individuals within firms may make climbing and exploring decisions every few minutes (e.g. as the phone rings or they scan the newspaper), their division might make such decisions only every few days (e.g. to organize an internal training program), and the organization as a whole every few months (e.g. to establish an alliance with a new supplier).

## **IMPLICATIONS FOR ORGANIZATION SCIENCE RESEARCH**

By drawing an analogy to fitness landscapes, in this article we have introduced and discussed the concept of knowledge landscapes. Other scholars have preceded us in applying elements of these admittedly imperfect theories to the social and organizational sciences. Stacey (1992) states that long term planning is not useful as the long term future is unknowable, so companies and economies need to encourage self-organizing evolution. Levy (1994) similarly concludes that long term forecasting is almost impossible for chaotic systems, however, he accepts that short term forecasting can be made useful by focusing on pattern recognition. Jantsch (1980) advocates a co-evolutionary rather than rational approach to planning. According to Bettis and Prahalad (1995), organizations should always be prepared to “unlearn” their emergent “dominant logics”. Positive feedback has been carried into the realm of economics in work by Arthur (1990), who later (Arthur, 1996) asserts that in the knowledge economy, companies should focus on adapting, recognizing patterns, and building webs to amplify positive feedback rather than trying to achieve “optimal” performance.

In light of these earlier efforts, the concept of knowledge landscapes has some major implications for the core research issues of organization theory and organizational learning, as well as for research methodology.

### *1. Organization Theory*

We believe the concept of the knowledge landscape will serve as a useful perturbation, fuelling dialogue concerning the resource-based and knowledge-based views of the organization. In particular, it would appear to have major implications for boundary setting and spanning. What are the boundaries of the firm through the knowledge landscape perspective? Are Scott’s (1987) approaches to defining organizational boundaries by actors, social relations, or activities still appropriate? Scholars who are beginning to consider knowledge as the boundary of the firm (e.g. Kogut and Zander 1996; von Krogh et al, 1994) may find inspiration in the metaphor of an organization navigating in its (own) ever-changing fractal knowledge landscape.

The concept also contributes to the debate concerning the role of managers. The role of a species on its fitness landscape is not to reduce uncertainty, as it may have little control over

its environment. Species evolve through a process of selection and mutation. Likewise, the role of the manager is not to reduce environmental uncertainty (Thompson, 1967), or simply to wait for selection to take care of structural inertia (Hannan and Freeman, 1984), but to encourage *simultaneous* selection *and* adaptation—to balance climbing and exploring--on the knowledge landscapes of all organization members and communities.

In addition, scholars looking into how “tightly” or “loosely” coupled organizations should be (e.g. Burgelman, 1991), may find inspiration in notion that the level of organizational epistasis/identity should reflect the level of interconnectedness in its own environment. The co-operative strategy literature (e.g. Hamel, 1991 and the collection of papers in Beamish and Killing 1997) should benefit from the consideration of knowledge-based external alliances in terms of exploring distant peaks.

## 2. *Organizational Learning*

The knowledge landscape concept has the potential to enhance several of Huber’s (1991) organizational learning constructs and processes. For instance, “vicarious learning” could be seen as a process of “exploring” the landscape through contacts with data sources situated on other peaks. This would seem pertinent for empirical work such as Liebeskind’s et al (1996) study on the use of networks by biotechnology firms to source scientific knowledge. On the other hand, is it possible to “unlearn” something? Such a process of discarding obsolete information might be the equivalent of climbing *down* a small or shrinking local peak and forgetting that you had ever been there. Given that peaks in knowledge landscapes are potential knowledge, this meaning of “unlearning” does not make much sense.

The speed with which Huber’s “searching and noticing” organizational learning can occur appears to be constrained by the degree of epistasis within the organization. The balance between epistasis/identity within and without the autopoietic actor may also shed light on Senge’s (1990) work on use of dialogue as a means of stimulating teams to think together, Carley’s (1992) study on the linkage between personnel turnover and existence of hierarchical structures, and Kim’s (1993) work on “fragmented learning”. The self-reinforcing Red Queen effect in organization evolution/learning (Barnett & Hansen, 1996) could be described as co-evolutionary structural coupling between organizations and their environments.

Last but not least, search on knowledge landscapes would appear closely linked to existing literature on the role of exploration and exploitation in organizational learning (March, 1991). It may allow us to better understand March’s quandary of how scarce “resources” should be allocated between the two activities, by proposing that organizations seek a balance between internal and external coupling across all levels of scale.

## 3. *Methodology*

The knowledge landscape concept rests primarily on the theoretical grounds of complex adaptive systems and secondarily on theories of autopoiesis. The autopoietic perspective means that knowledge, or “knowing”, is an embodied process that cannot be studied directly. Methodologically, this points us in the direction of more inductive approaches such as long-term observation of interaction among organizational members, narratives, and stories.

The assumptions embedded in complex adaptive systems theory, however, are a much larger threat to traditional methodological research approaches in organization science, as already pointed out by McKelvey (1997). In order to describe and understand self-similar features in

time and space, we are beginning to replace Euclidean geometry with the fractal geometry developed by Benoit Mandelbrot. Similarly, contemporary organization science has to look beyond traditional logico-scientific based approaches to those that can better cope with *emergent* behavior. For instance, both deductive and inductive research methodologies rest on the 'countable additivity' assumption referred to by Kelly (1997), i.e. that parts adds up in either direction.<sup>15</sup> Such approaches ignore *emergence*, or the occurrence of unexpected behavior from unpredictable interaction among agents such as individuals, groups, organizations, or even concepts—a hallmark of any complex adaptive system. Organizational research conducted under the assumption of countable additivity will thus be hindered in much the same way that Euclidean geometry is largely unable to explain the space-time configuration of something as simple as a tree.

We understand the suspicion that in the absence of logico-scientific model of investigation, we face some kind of post-modern paradox, or “black hole of strategic analysis” (Spender and Grant, 1996). However, what now appears paradoxical may become clearer following a process of climbing and exploring new peaks in the multi-level knowledge landscapes of organization science scholars. We hope this article represents such a peak.

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## ENDNOTES

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<sup>1</sup> The “adjacent possible” (Kauffman, 1996) includes not only all organisms now on earth, but also those just one reaction step away from those that currently exist. The adjacent possible can be said to describe the fitness landscape that could exist in time  $t+1$ , which is the effective limit to adaptive walks for any given time  $t$ .

<sup>2</sup> Represented by “K” in the NK model.

<sup>3</sup> As species become more complicated, the network of existing genes with which a new gene must epistatically couple grows, increasing the probability of internal conflict within the species over the value of a particular step in its adaptive walk, and reducing the chance that an improvement will take place.

<sup>4</sup> “Error catastrophe” occurs when the rate of errors or miscopying of genetic code exceeds a critical “error threshold”, and information within a species is completely lost (Eigen and Oschatz, 1992).

<sup>5</sup> Technology is defined by the New Shorter Oxford English Dictionary as “the branch of knowledge that deals with the mechanical arts or applied sciences”, and can thus be considered knowledge-based.

<sup>6</sup> Like cells, which are open to energy but closed to information and control, autopoietic systems are *open* to receive signals from its “domain” (the realm or sphere within which it engages external systems), but *closed* to changes to internal rules or norms of operation. These rules change only when an external signal stimulates processes that already exist within the system. Embodied knowledge and internal rules the system follows to reproduce itself constitute the system’s “identity”--the basis from which autopoietic systems self-reference.

<sup>7</sup> Autopoiesis theory has been applied to social systems (e.g. Luhmann, 1986) and to legal systems (e.g. Teubner, 1989). There is also a growing application of the use of the autopoietic epistemology in the management literature, including work by Morgan (1986), von Krogh, Roos and Slocum (1994), Nonaka and Takeuchi (1995), and Sveiby (1996). Grant’s (1996b) assertion that only individuals can engage in knowledge creation would also seem to lend indirect support to the autopoietic epistemology.

<sup>8</sup> Our claim that the theory of autopoiesis can be used to better understand the complexity concept of fitness landscapes rests on several grounds. Each seem to share many anti-representationist assumptions (Varela, Thompson, and Rosch, 1991; von Krogh and Roos, 1995). Moreover, on a more fundamental level, a co-evolutionary world is brought forth through interaction: whether by structural coupling (autopoiesis) or non-linear interaction among adaptive agents (complex adaptive systems). The “autopoietic entity” can be compared to the adaptive agent in complex adaptive systems theory. Each theory has also been shown to be scalable--interaction on one scale leads to emergent behavior on a higher scale. Von Krogh and Roos (1995) postulate that autopoietic knowledge development might be fractal across different scales. If what is a system at one hierarchical level of scaling is an agent at the next level up, patterns that apply to one can be seen in the other in some form.

<sup>9</sup> The distinction also has a parallel in concepts such as “exploration/exploitation” (March, 1991), and “survival/advancement” (von Krogh, Roos and Slocum, 1994).

<sup>10</sup> A metaphor used by Waldrop (1992) to convey the dynamics of fitness landscapes.

<sup>11</sup> In highly interconnected organizations, an innovation which might benefit one part will almost always have a detrimental effect on another part. Such an organization is thus forced to make many internal compromises to develop new knowledge and adapt, and is prone to getting “stuck” on local peaks. At the other extreme, an extremely loosely-connected organization can explore a broader part of the landscape and take on new innovations/genes with relative ease. However, as each sub-unit attempts to selfishly climb peaks on its fitness landscape, positive innovations will not spread easily throughout the organization, possibly leading to a wildly-shifting fitness landscape.

<sup>12</sup> The Danes’ wind turbines were markedly superior to their American counterparts, as the Americans had overlooked the possibility that air flows and directions would vary drastically, once outside the confines of the laboratory.

<sup>13</sup> First used by Van Valen (1973), this metaphor is based on a passage from Lewis Carroll’s *Through the Looking Glass*.

<sup>14</sup> This metaphor is echoed in the common phrase “surfing the internet”.

<sup>15</sup> For example, we have traditionally believed that '2nd order concepts' developed from re-interpretation of ethnographic data should stem directly from the '1st order' concepts.

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**FIGURE**

Figure 1: Contrast Between Climbing and Exploring Activities

	<b>Climbing Local Peaks</b>	<b>Exploring Other Peaks</b>
Goal:	Optimization of Current Practices	Development of New Options for Potential Practice
Economic Law:	Diminishing Marginal Returns	Increasing Marginal Returns
Purpose of Alliances:	Internal Restructuring to Alter Epistatic Connections	External Alliances to Seek New Data
Working Mode:	Obeying Existing Rules	Challenging Existing Rules and Inventing New Rules
Way of Organizing:	Hierarchy	Network/Heterarchy