The interpretations and uses of fitness landscapes in the social sciences

Authors: Lasse-Martijn Gerrits and Peter Koenraad Marks

PLEASE READ THIS FIRST: This working paper precedes our full article entitled "The evolution of Wright's (1932) adaptive field to contemporary interpretations and uses of fitness landscapes in the social sciences" as published in the journal Biology & Philosophy (http://link.springer.com/article/10.1007/s10539-014-9450-2). The working paper features an extended literature overview of the ways in which fitness landscapes have been interpreted and used in the social sciences, for which there was not enough space in the full article. The article features an in-depth philosophical discussion about the added value of the various ways in which fitness landscapes are used in the social sciences. This discussion is absent in the current working paper.

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1.1 Introduction

Evolutionary biology tells us that for a species to survive it needs to adapt to its environment to obtain fitness. The mechanisms of adaptation and fitness have such an appeal that they have been used in other domains of science, including the social and behavioral sciences. One particular aspect of this theory transfer concerns the so-called *fitness landscape models*. At first sight, fitness landscapes provide a visual representation of how an agent, of any kind, relates to its environment, how its position is conditional because of the mutual interaction with other agents, and which possible routes towards improved fit there are. The allure of fitness landscapes is first and foremost that it represents a complex story about adaptation and fitness in one coherent image that helps summarizing the many aspects of those processes in an accessible way. Different accounts of fitness landscapes in different domains suggest that the properties and functions of fitness landscapes are attributed freely. These different approaches are testimony of the model's versatility. At the same time, one notices that the different approaches also hold the potential to create ambiguity about the meaning and role of fitness landscapes in the social and behavioral sciences. This contribution presents an extensive literature survey of the diverging interpretations and uses of fitness landscapes in the social sciences.

2.1 Method

The entry point of our inquiry constituted a broad scan of literature in different domains. For this we used the sEURch-engine, which combs through 167 academic electronic databases[i], and scholar.google.com to get a first overview. 'Sociological abstracts' is used for in-depth search. To make sure we did not miss possible relevant sources in other disciplines, we also checked PsyInfo, Philosopher's Index and Business Source Premier, and we used data from the citation database Web of Science for a general visualization of citation patterns. The search terms were "fitness", "landscape[s]", "fitness landscape[s]" "fitness field[s]", "performance landscape[s]",

and "landscape design". The sample covers peer-reviewed articles, working papers and conference papers. Additional sources were found through the references in the selected sources and by checking biographies of authors referred to quite often. References were cross-checked using the CiteSeerX search engine. Using this engine, we generated an overview of antecedent-consequent patterns in the literature. Some canonical books were added to the initial list of sources. The literature search was stopped using the criteria of saturation and diminishing diversity. A total of 230 have been categorized and 162 sources were selected for the overview. The full list of the used sources is included in the references to this article.
The sources were categorized in domains in order to structure the data processing. All sources were read and summarized in our own words. Subsequently, the texts were coded for the original sources on which the author(s) base the narrative, the various interpretations of the fitness landscapes, the methods used to research fitness landscapes, the particular (empirical) application, and the types of conclusions reached. Coding the data lead to the development of the syntheses per domain described below.

3.1 The principles of fitness landscape

Originally, fitness landscapes were developed as visual representations of the reproduction success of genotypes, i.e. the fitness or replication rate of particular genotypes. The distance between genotypes, i.e. whether they are more or less similar or very different, and the interactions between the genotypes define the fitness in the landscape. Fitness is represented by the height in the landscape. The first visual representation of an adaptive landscape was presented in Wright's work on biological evolution. Wright formulated a mathematical theory of evolution (1931), thereby showing how frequencies of alleles and genotypes could change in response to evolutionary pressures such as natural selection, mutation, and migration (Johnsen, 2008). Assigning values to each genotype enabled Wright (1932) to represent the distribution of adaptive values under a particular set of conditions over the space of genotypes in a two-dimensional field of gene combinations (Kauffman, 1993: 33).
Wright's adaptive field has been reintroduced and modified by Kauffman and Levin (1987). They took into consideration the criticisms on the adaptive hill climbing analogy[ii] to develop a general theory of adaptive 'walks' via fitter variants in combination processes (ibid: 11). In combining it with spin glass models[iii] and Evolutionary Stable Strategies[iv] they developed the rugged (fitness) landscape model (Weinberger, 1990). The fitness contribution of each N genes in a genotype depends on the interaction with K other genes and is visualized as a Boolean hypercube. This is the so-called NK-model. The fitness landscape is rugged when N and K are large, while it is smooth with only one peak when K is zero.
Kauffman and Levin demonstrated in an uncorrelated landscape the numbers of local optima, how long the adaptive walk is to attain a local optimum and the alternative optima accessible. They also showed that in many cases landscapes are correlated, i.e. that neighboring slightly different entities have similar fitness. In other words, fitness is not a property of a genotype alone, but depends upon its environmental context (Kauffman & Levin, 1987). Kauffman & Johnsen (1991) built on the uncorrelated fitness landscape model to show that the fitness of a genotype is affected by the genotypes of the species with which it is coupled, i.e. coevolution is introduced. Kauffman has written many articles alone and with others (e.g. Kauffman, 1989; Kauffman & Weinberger, 1989) about (un)correlated fitness landscapes in which the NK-model has been increasingly refined. This resulted in his seminal book 'The origins of order' (1993) in which he showed how self-organization and selection come together to bring forth biological order.

3.2 Adaptations of the basic model

In Kauffman's NK-model each gene has its own fitness component. In other words, "in his model control over each fitness component is, in fact, symmetric with respect to all the genes that affect it." (Altenberg, 1995: 26-27) Altenberg (1995; 1996) extended the NK model into a generalized version which can provide any number of elements and any number of functions. This generalized NK-model allows the number of fitness components to differ from the number of genes, and allows genes to be added to the genome while keeping the set of fitness components fixed. Gavrilets (1997; 2003; 2004; Gavrilets & Gravner, 1997) took the different ideas of speciation and the consequences this has for modeling it in NK-models even further, and developed many different interpretations and specifications of speciation and modeled this into different models, like the holey fitness landscape. All these adaptations in the mathematical and biological domains inspired some authors in their interpretations and use of fitness landscapes in the social and behavioral sciences.

4.1 Interpretation and use of fitness landscapes in social and behavioral sciences

The alluding nature of Kauffman's NK model is that it "allows for a very general description of *any* system consisting of N components with K interactions between the components and in which there can be any number of states for each N." (Weber, 1998: 135, italics original). Even Kauffman wrote an article about how the evolution of technology is not really different from genetic evolution (Kauffman, 1995a). He used the NK-model as a sensitizing concept to show that technologies evolve on fitness landscapes rugged by conflicting constraints, concluding that "at least an analogy between the unrolling panorama of interacting, coevolving species [...] and the way that technological evolution drives the emergence and extinction of technologies, goods, and services. This analogy can offer intriguing and fruitful insights into the ways that products, organizations, and economies develop." (Kauffman 1995a: 129) He even suspected that they are governed by the same or similar fundamental laws. As such, the NK-model can be seen as meta-theoretical. "First and foremost this refers to its graph-theoretical structure and bases in non-integral space, presupposing the connections between the elements in the system under scrutiny to have as much explanatory power in the analysis of its dynamics as the characteristics of those elements themselves." (Hovhannisian, 2004: 2) Kauffman's idea to apply NK-models to other domains has inspired many others.

"A useful starting point for an analysis of adaptation and selection processes is a specification of a mapping from a characterization of social organization's form to a statement of its relative fitness or likelihood of survival" (Levinthal, 1997: 935). Based on Kauffman (1993), Levinthal developed a simple analytical structure to model effects and explore the implications for processes of adaptation and selection. He operationalized the model for firms and organizations, where N constitutes the attributes that comprise an organization and K the interaction effect among the attributes. The fitness of a particular organization is the average for the N attributes that comprise it. Based on the NK-model, he ran simulations to understand persistence and diversity of organizations across time. Kauffmann's 1993 and Levinthal's 1997 interpretations have triggered many researchers to adapt, apply and/or extend the possibilities of the NK-model to the social and behavioral sciences. The full variety of such adaptations is detailed in the literature review below.

4.2 Economics

Interpretations of fitness landscapes in economics range from loosely interpreted metaphors (e.g. (Freeman, 2000; Schettkat, 2003; Tan, 2007), using fitness landscapes as sensitizing concepts (e.g. Clark & Urwin, 2010; Ellerman, 2004; Becker, Knudsen, & March, 2006; Chae, 2012), running simulations based on fitness landscapes (e.g. Marengo & Dosi, 2005; Situngkir, 2009), to operationalized NK-models that are applied to empirical material (e.g. Alkemade, et al., 2009; Geisendorf, 2010; Kitts, Edvinsson, & Beding, 2001; McCarthy & Tan, 2000). Within the field of economics the NK model is used for mainly two things, (1) the study of properties of different fitness landscapes themselves (e.g. decomposition, connectivity), (2) how search should be structured or how search algorithms perform given particular fitness landscapes (Geisendorf, 2010: 396).

The first group of authors that loosely interprets fitness landscapes, does not go into the mechanism of either the NK-model or the fitness landscape and as such hardly refer to any fitness landscape theory. The authors that use fitness landscapes as a sensitizing concept mostly refer to Kauffman 1993 without going into the specifics of his interpretation and consequences, e.g. only mentioning that through complexities of fitness landscapes history matters (Blyth, et al., 2011). Authors that run simulations almost always refer to Kauffman 1993 as the basic model that they work on. These authors run simulations based on a value-assigned NK-model and then draw implications on the results from the simulations, e.g. cost and distance of search on technological fitness landscapes (Kauffman, Lobo, & Macready, 2000), trade-offs between possible improvements processes in multiple markets (Knudsen & Stieglitz, 2008), strategies of innovative change by making search rules (Hovhannisian, 2004). The authors that operationalize the NK-model *all* refer to Kauffman (1993), but also to Levinthal (1997) or Auerswald, et al. (2000). Within the economics domain Auerswald et al. (2000) are one of the first to really operationalize and hence make a variant of the NK-model of Kauffman to analyze the dynamics of manufacturing costs. They run a computational model on existing data to generate and interpret production recipes. Kaufmann (1993), Levinthal (1997) and Auerswald et al. (2000) have had impact on others for operationalizing NK-models and applying them to empirical material, e.g. a created NK technology landscape to test performance of common managerial search rules (Strumbsky & Lobo, 2002), the internal and external fit and the consistency of choices in a fashion apparel company (Siggelkow, 2001: 415).

Many economists reinterpret the concept of fitness as performance because NK are linked to complete configurations of which the realization is in the marketplace, influencing the organizational performance (Rivkin, 2000). Hence, they build performance landscapes (e.g. Porter & Siggelkow, 2008; Siggelkow & Levinthal, 2003).

Another, recurring adaptation of the NK-model into the economical and organizational (see next section) domain is that of the technological landscape. Frenken (2006a; 2006b) for instance, uses the generalized fitness landscape approach, referring to Simon (1969) and Altenberg (1995, 1997) to model complex technological systems in which interdependence in the working of elements make up the system. His generalized model of complex technological systems is a model of technological design, through which he runs simulations to see how transaction costs, decomposability, modularity and vertical disintegration should be integrated in future modeling exercises.

A bit of an odd one out in the way it deals with fitness landscapes, but which is referred to quite often, is the thought-provoking seminal book by Beinhocker (2006), in which evolution and complexity (theory) is used as the new paradigm in economics. He builds his argument about a new way of looking at wealth by, amongst others, fitness landscapes as metaphor, sensitizing concept and how (social) technologies evolve.

4.3 Organization & Management Sciences

Fitness landscapes have also caught on in organization and management sciences. Wright (1932) is sometimes referred to but not used. The starting point in *most* publications is Kauffmann (1993). Levinthal (1997) is another key-publication. One article predates Levinthal's work, namely Westhoff, Yarbrough, & Yarbrough (1996) who assess how Kauffman (1993) informs the analysis and understanding of organizational structure and performance. Some authors argue that Kauffman's findings are not directly applicable to issues of organization and management and that concepts and implications should be 'translated' first before being used in this domain (Anderson, 1999; McKelvey, 1999). Some even demonstrate that the use of NK-models in this domain leads to results that contradict Kauffman's conclusions (Rivkin & Siggelkow, 2002; 2006).

Most authors understand this issue of theory transfer and modify the NK-model to suit their particular research aims (cf. Levinthal & Warglien, 1997), but the extent of modification differs from application to application. Some use the NK-model as a testing ground for different organizational models and their performance (Siggelkow & Levinthal, 2005), whereas others build on the implications of the model as suggested by Kauffman (Carlisle & McMillan, 2006) or even assign predictive qualities to the original model (Vidal, 2004), discuss the model briefly to show how diversity ‘survives’ in firms (Winter, 2005), or discuss fitness landscapes to demonstrate the powerful insights of Complex Adaptive Systems into the nature of strategic work (Pascale, 1999).

Fitness landscapes are sometimes used as sensitizing concepts (e.g. Olson & Eoyang, 2001); for instance as an illustration how managers can deal with conflicts between organization and environment (Samoilenko, 2008), to make sense of the operation of supply networks (Pathak, et al., 2007), or how firms search for strategies (Girard & Stark, 2003; Beinhocker, 1999; Merry 1999). A small number of authors theorize about fitness landscapes as an alternative approach or framework to particular problems, such as survival in competitive environments (Dervitsiotis, 2004; 2007), collaboration in manufacturing chains (Dekkers, 2008), the design of work within and between organizations (Sinha & Van de Ven, 2005), or how leadership and order for free in complex adaptive systems operate in turbulent environments (Osborne & Hunt, 2007). McCarthy (2004) goes one step further and shows in a theoretical paper what fitness is for manufacturing, and how the fitness landscape helps in visualizing this.

By far the most common application is the NK-model in combination with computational simulations, often agent-based. The construction of the model and the values of the variables are based on Kauffman's NK-model but are always tailor-made to suit a particular research question, e.g. search processes of organizations. Examples include the performance of different search strategies (Baumann & Siggelkow, 2012), the relationship between exploration and exploitation (Becker, Knudsen, & Stieglitz, 2006; Knudsen & Stieglitz, 2007; Lee & Van den Steen, 2010, Bocanet & Ponsiglione, 2012), detecting the organizations' best position in a dynamic world (Gavetti, Levinthal, & Rivkin, 2005; Moran, Simoni, & Vagnani, 2011), choosing between forward and backward mapping (Gavetti & Levinthal, 2000), evaluating different selection strategies in uncertain environments (Sommer & Loch, 2004) and evaluation of options (Knudsen & Levinthal, 2007). NK-models are also used in combination with simulations to understand the causes and effects of organizational structure, especially where it concerns the fit between the organization and the environment. The roots of this focus can be traced back to Simon (1962; 1972). For example, authors investigate the relationship between structure and environmental uncertainty (Barr & Hanaki, 2008), and modes of centralization and decentralization (Ethiraj & Levinthal, 2004; Lovejoy & Sinha, 2010) or whole-part coevolution (Baum, 1999). Some authors have focused on the mutual relationships between organizational search and organizational structure (Chang & Harrington, 2000; Garrido, 2004; Rivkin & Siggelkow, 2002; Siggelkow & Levinthal, 2005), local search rules for organizations are tested against their ability to climb fitness peaks on fitness landscapes (Haslett & Osborne, 1999; 2002; 2003; Haslett et al. 2000), local search rules in alternatively generated rugged landscapes (Winter et al., 2007), or how an efficient network positively affects information diffusion, which facilitates the spread of effective strategies, but negatively affects information diversity, which is also positively related to performance (Monge et al., 2011) .

Except for a few cases (Cartier, 2004), the simulations are usually neither based on real-world data, nor are the outcomes validated against real cases. A much smaller number of authors developed real-world case studies. For example, Siggelkow (2002) presents a case study of the Vanguard Group to understand the developmental processes that lead to organizational configurations and fit, and Camuffo, et al. (2008) studied how Geox could become a worldwide manufacturer of shoes in a relatively short period of time. They used the NK-model to find that Geox's competitive advantage is rooted in particular configurations of complementary activities that are difficult to copy by rivals, even though they may have been able to copy discrete activities. Ettlie & Kubarek (2008) present a web-based survey to show how design reuse in industries is a strategy of coping on rugged landscapes. Jermias & Gani (2004) also carried out a survey and interviewed managers to demonstrate that the degree of contingent fit relates positively with business effectiveness. Fitness landscapes serve to define this contingent fit.

4.4 Anthropology

Wright's work is most often referred to in anthropology, especially his shifting balance theory of evolution as developed in his 1931 article and visualized in his 1932 article. Only once in the data we found is referred to Kauffman (1993). The other sources mentioned are the references to rugged fitness landscapes by Palmer (1991) in Perelson & Kauffman (1991), a proceedings of the workshop on applied molecular evolution held in 1989 at the Santa Fe Institute.

Fitness or adaptive landscapes are used as sensitizing concepts to discuss the relevance and consequences of representations (Agar, 2004), but also its limitations (Weiss 2004). Also, fitness landscapes are loosely interpreted as being representations that help to understand the evolution of for instance the Middle Paleolithic populations in different possible landscapes (Kuhn & Stiner, 2006; Kuhn, 2006).

Lansing (2003) goes one step beyond sensitizing and explains adaptive landscapes, basing his story on Kauffman 1993, to give an overview of the possible applications of complexity into anthropology. He also goes into the warning / critique on application of simulation fitness landscape models that de facto always leave out possibly critical variables (Helmreich, 1999). Helmreich builds his critique largely on another article of Lansing together with Kremer (1993). They run a simulation (with implicit application of the NK model) which they map to the physical evolution of the irrigation network of Bali. Another form of application of the adaptive landscape is in the simulation combined with an experiment by Mesoudi & O'Brien (2008). They conduct an experiment to see how cultural transmission strategies would perform compared to other strategies. Participants could modify certain attributes (overall fitness was the sum of the attributes) shaping the adaptive landscape. The simulation placed them at the start at random peaks in the landscape.

Hart goes into great detail explaining Wrights shifting balance theory of evolution and his fitness landscape metaphor, and combines it with the theory of coevolution by Rindos to apply it to the 'evolution' of the Maize agricultural production (Hart, 1999) or to the rapid appearance of matrilocality in northern Iroquia (Hart, 2001). In both researches he follows the phases of the shifting balance theory and shows that the model suggests the need for the generation of new data and a reassessment of existing evidence in the hope to get a much better understanding of prehistoric agricultural evolution than is currently possible.

4.5 Sociology

Researchers in sociology mainly focus on the narratives of fitness landscape and relatively little modeling is presented. A common point of departure is to regard fitness landscapes as a subset of the complexity sciences. Most authors in this field refer to one of Kauffman's publications (1993; 1995b; 2003) and fitness landscapes are often taken as a given and understood as a representation of social order. In short, the extent of adaptation to particular empirical objects is relatively low. Also there is very little cross referencing within the domain of sociology. It is therefore harder to pinpoint who introduced it in this domain.

Elliott & Kiel (2004) aimed to write such an introduction. Here, computational complexity and fitness landscapes are made relevant to study terrorism. However, there are earlier texts available; In an edited volume by Eve, Horsfall and Lee (1997), Elliott and Kiel introduce fitness landscapes, in line with Kauffman (1993); and Carley presents a performance landscape to demonstrate the effect of size and span of control on organizational performance for (un)constrained organizations. These authors all rely on modeling to prove their points. More recent modeling approaches are presented by Fellman, et al. (2007) and Fellman (2011a; 2011b), who use fitness landscapes to demonstrate how optimal decision-making in terrorist networks can be countered by dividing the network in separate compartments. The model presented by Ghemawat & Levinthal (2000) is used, unaltered, as the source for this.

Byrne (1997; 1998) was also one of the first to introduce fitness landscapes in which he presents an approach where the narrative rather than the mechanics of fitness landscapes are presented and elaborated upon. This approach is used, for example, to understand why households find it difficult to move from one social-spatial area to the other (Byrne, 1997), as a metaphor to make sense of knowledge development in organizations (Roos & Oliver, 1998; with reference to McKelvey, 1997), that human interaction is the critical source of intangible value in intellectual capital (O'Donnel et al. 2003), or as a theoretical construct to make sense of performance in education (Byrne, 1998). Urry (2008) uses fitness landscapes to "think of the future in different ways" (2008: 262), i.e. fitness landscapes aid sense-making. Stark (2000) presents fitness landscapes to demonstrate distributed intelligence and distributed authority as a way of dealing with uncertainty. This is used in his argument that the work of Talcott Parsons didn't pay enough attention to the issue of 'value'. In such approaches, fitness landscapes are not used in an analytical way or as sensitizing concept but rather as a means to further an argument.

The contribution of O'Brien and Bentley (2011) is hard to fit, since it is published in the realm of archeology, and they focus on technology evolution in modern society based on an approach that can be classified as actor-network theory. The authors engage in a dialogue with Schiffers' thesis of technology diffusion. Fitness landscapes are used to demonstrate the role of cultural selection in the change of speed regarding innovations and technology diffusion.

4.6 Psychology and cognitive sciences

In the psychology domain the term adaptive is frequently used because it refers to the idea of psychological elements that are evolved / adapted in their surroundings. The researchers in this domain interpret and apply fitness or adaptive landscapes in a wide variety, ranging from a real metaphorical 'thing out there' to building algorithms that show adaptation in an adaptive landscape. In line with this diversity is the diversity in sources referred to; they range from no source to Kauffman (1989, 1993 & 1995b) as well as Kauffman & Levin (1987), Kauffman & Johnsen (1991) and Wright (1932).

Interpretations that do not refer to any source documents range from loosely referring to the notion of fitness or adaptive landscape (e.g. Reschke 2006) to summing up a list of (co-)evolutionary approaches (e.g. Tamariz, 2009).

Fitness or adaptive landscapes have an appealing sensitizing element in them for psychology researches as they use them to show that fitness landscapes shape or condition the way people think, act and learn (for a theoretical and empirical insight see Rendell et al, 2010), how students trying different strategies and conversation topics in an experimental interaction setting with varying degrees of success, exploring the fitness landscapes (Kindt et al. 1999), or how religious and cultural diversity can be seen in the world and throughout human history as individual minds mutually interact within converging fitness landscapes in an open-ended time horizon (Atran & Norenzayan, 2004).

Rellihan (2012) builds on the ideas of adaptive landscapes, uses them as sensitizing concept, but at the same time after properly explaining them, builds an 'easy' search algorithm to show that the premises of evolutionary psychology are possibly under debate. He shows that evolutionary psychology can explain certain behavior, but that the origin of the adaptive elements cannot be traced, i.e. it offers no logic of discovery.

The way humans learn (in interaction), or how culture evolves is central to several researches. For instance, Mesoudi (2007) first argues based on Wright (1932) that experiments hold potential value for explaining the relationship between cultural microevolution and cultural macroevolution. He then runs an experimental simulation where, in multimodal adaptive landscapes, information scroungers will emerge and reduce group fitness by reducing the number of participants learning individually, thus reducing the chances that one of the higher fitness peaks will be found (Mesoudi, 2008). Others that run experiments, and thus have to operationalize NK-models, define fitness through for instance other theory about learning (Curran et al., 2007) which then defines the variables of the fitness landscape by a genome that is encoded with the solution of the landscape, and encoding imitation probability. Another manner in which fitness is defined is by the payoffs related to 'correct solutions' in a landscape (Mason & Watts, 2011). The shown history of the searched locations and payoffs of all participants makes clear how they have learned.

An alternative interpretation and especially application is given by Dooley et al. (2003). They define fitness of text by the words present in a text, and the number of nodes in the text network represents the parameter N in Kauffman's landscape models. In the case of a text network, K can be made operational by examining the connections between centering tokens. They examine 50 texts drawn from a wide variety of sources to conclude that understanding discourse evolution, as a complex phenomenon, is key to understanding complex human systems

4.7 Public administration and political science

In this domain some authors refer to Kauffman (1993; 1995b) as their source but the majority in this sample refers to secondary sources (such as Beinhocker 2006, Siggelkow & Levinthal, 2003, Gavrilets, 2004). Three authors use fitness landscapes without references to any source.

A number of authors have written introductions to complexity theory; fitness landscapes are then often presented as an element of complexity theory. The depth of the argument varies. For example, Bovaird (2006) and Klijn (2008) are very brief in their explanation of fitness landscapes, whereas Schneider & Bauer (2007) and Mischen & Jackson (2008) explain them in more detail. The first understand them as illustrative metaphors that integrate ideas from evolutionary theory with public policy, whereas the latter use them to describe the dynamics of policy implementation. Room (2011) goes a step further. His book offers a thorough and faithful reproduction of Kauffman (1993) and then moves ahead by using it as a sensitizing concept to understand institutionalism and public decision-making.

Using fitness landscapes as a sensitizing method is the most common practice. This generally means that authors don't operationalize the fitness landscapes for specific research. Instead, they refer to the secondary sources mentioned above without much consideration about the adoption or adaptation of the concepts. Consequently, they often don’t define what fitness entails, although there are exceptions. Fitness landscapes are used to develop an alternative view of a particular phenomenon concerning public administration and policy, for example to understand why the introduction of ICT in education failed to bring about the expected changes (Toh & So, 2011), to understand the considerations and actions of public managers (Teisman & Klijn, 2008), to understand the expansion of anti-corruption programs (Micheal, 2004), to understand social entrepreneurship (Rhodes & Donnelly-Cox, 2008), or to suggest that ostensibly powerless actors may not be so powerless after all, e.g. through public protests (Sword, 2007). Other authors use fitness landscapes to further an argument, for example that public learning programs about technology taught at schools should focus on the coevolution between technology and creativity (Solomon, 1998) or that communicative planning theories are sometimes misguided (Neuman, 2000).

A small number of authors aim for theory development; they attempt to adapt Kauffman (1993; 1995b) to this domain and consider how fitness landscapes need to be operationalized. Whitt (2009), following the recent financial and economic crises, proposes a theoretical framework to research adaptive policy-making for dealing with volatile markets. Fitness landscapes are then used as conceptual tools to develop analogies between ecologies and market mechanisms, where fitness is provided by market selection. Gerrits (2012) developed an operationalized fitness landscape for public decision-making where both process and content of such decision-making are accounted for. Fitness is defined as (temporal) goal alignment, i.e. whether an actor achieves the solving of its policy issue by successfully aligning with other actors who also aim to get their issues solved. The workings of the model are illustrated with a case study of urban renewal in the Netherlands.

Modeling efforts come from Axelrod & Bennett (1993), Lazer & Friedman (2007) and Geyer & Pickering (2011). Axelrod & Bennett model (myopic) actors such as nations in order to understand alignment or the reverse them. Two examples are modeled and validated using secondary data: the alignment of seventeen European nations in the Second World War and membership in competing alliances of nine computer companies to set standards for Unix computer operating systems. Lazer & Friedman present a simulation based on operationalized NK model to conclude that an efficient network positively affects information diffusion but negatively affects information diversity, which is also positively related to performance. Geyer & Pickering argue that fitness landscapes have more explanatory power than existing tools in international relations in interpreting development and conflict. Two case studies are presented. In the first, fitness is defined as growth, where N are the countries and K is time. In the second, N is disorder vs. order, K is countries and Z is non-conflict.

Rhodes (2008) may be the only author in this domain who presents a full-fledged qualitative empirical analysis, including an operationalized performance landscape and empirical data from six cases of urban regeneration in Ireland. In her performance landscapes, agents pursue their agendas, interact and achieve different outcomes. The landscape was developed in consultation with the stakeholders and shows that the relationship between strategic choices and performance outcomes is not as tightly coupled as e.g. Siggelkow & Levinthal (2003) suggest. The coupling would vary over time because of efforts of certain actors.

4.8 Law

Few articles in this domain were found to discuss fitness landscapes. References point to Ruhl (1996a) as the introductory text in this domain. Ruhl aims to explain how law changes and how this process unfolds. Central to his argument is the gain and loss of fit between laws and society, i.e. laws tell people what to do, how to behave, but at the same time those laws emerge from socially accepted norms. The occurrence of shifts in society and laws can mean that fit is attained or lost. Fitness is measured by the extent to which laws achieve their goals, which is not a normative statement but something that can be measured. A connection between complexity theory and evolutionary theories is made. He argues that legal theory should take the next step, besides only Darwinism, to include insights from complexity theory to explain changes in laws. He regards complexity theory as a unified and general theory of system evolution that brings much more explanatory mechanisms to the table than just pointing at the indeterminacy of changes in laws, as advocated in Darwinist explanations of legal change. He develops an analogy between fitness landscapes and the record of legal change. Examples from environmental law are used. Fitness landscapes are used in many ways: as a way of explaining legal change but also in a somewhat normative way, to show that theorist arguing for stability in legal systems are arguing for something impossible. Similar arguments are found in Ruhl (1996b; 1997; 1999) and Ruhl & Ruhl (1997).

Babcock (1996) builds on Ruhl's argument (1996a) and proposes to use complexity theory to reconsider the behavior of political communities as presented by Sandel, in particular about how such communities may be reactivated leading to enhanced citizenship. His discussion of fitness landscapes is similar to Ruhl's (1996a), which means that they are considered as a subset of complexity theory. An analogy between fitness landscapes, as presented in Kauffman (1993) and retold by Ruhl (1996a), and political communities as dynamical systems, are drawn. This leads Babcock to conclude that communities as proposed by Ruhl will fail to adapt to changing circumstances because they lack the random elements that are part of the fitness landscape model; or that Sandel's political fitness landscape "contains too many moderate peaks, making it difficult to cross, presenting no obvious solution to the hard problem of governing." (Babcock, 1996: 2102) Fitness landscapes here serve as a pure analogy to political communities as systems.

Katz, Stafford & Provins (2008), like Hornstein (2005), also use Ruhl (1996a) as their point of departure. Again, the point is made that fitness landscapes, as a subset of complexity theory, offers interesting analogies to common law, legal change and judicial decision-making - where law is said to display the properties of complex systems. For example, the authors state that the adaptive behavior of agents in the landscape means that, likewise, the micro behavior of federal jurists and the interactions between jurist help generate systemic changes in the common law. As these publications show, the dominant approach to fitness landscapes in the study of law is to use them as pure analogies in understanding the operation of legal systems.

5.1 Conclusions

The diversity of interpretations and applications as discussed above demonstrates the concept's enormous versatility: fitness landscapes are used in many ways, ranging from computational models to argumentative vehicles; and applied to countless subjects, ranging from discussions of Parsons' work to the physical evolution of Bali's irrigation network. We finish our overview with some general conclusions and discussion points. For a much more in-depth discussion of the findings, please refer to Gerrits & Marks (2014).

Interestingly, Wright (1932) is often credited for being the first to coin the concept but although his chapter does present a graph-theoretical approach to evolution, fitness landscapes are actually never mentioned anywhere in the text. The antecedent-consequent patterns show that

Kauffman's work occupies a central position in the literature on fitness landscapes. Besides Kauffman and Wright, we noticed how referencing is strongly domain-specific. Consider for example the central positions of e.g. Auerswald (economics), Levinthal (organization and management sciences) or Ruhl (law) in their respective domains. Furthermore, there are different interpretations regarding the source domain of fitness landscapes. The works of Wright and Kauffman are positioned in the domain of (theoretical) biology, yet a considerable number of authors consider fitness landscapes to be a subset of the loose collection of theories and concepts grouped under the header of complexity theory. This association is possibly due to Kauffman, whose work at the Santa Fe Institute has become associated with the complexity sciences (e.g. Waldrop, 1992). The connection is often made through complex adaptive systems (CAS), where most often fitness landscapes are considered functional to CAS.

Regarding the many interpretations, we noticed how some authors remain relatively true to Kauffman's work, whereas others have adopted a much looser interpretation. The implications are that some accounts never transcend the level of metaphors, and that some accounts are so far removed from the original meaning that one has to question the added value of calling something a fitness landscape, e.g. the metaphorical use of the adaptive walk. In addition, we sometimes noticed how fitness landscapes are attributed new qualities. In particular: normative conclusions based on computational simulations, or drawn directly from Kauffman's work to a different domain, e.g. that innovation comes from decentralization. This may demonstrate the versatility of fitness landscapes but at the same time also shows the pitfall of theory transfer. Also, we noticed that many authors prefer to use a select number of concepts from Kauffman's extensive work. For example, coupled landscapes are rarely mentioned, and coevolution may be referred to without any further details.

Still, the literature discussed here is a testimony to the potential of the fitness landscape model. To some, if offers a way of making sense of empirical phenomena, to others it helps developing an explanation, and again to others it opens new avenues of thought. There is actually use in all versions (cf. Gerrits & Marks, 2014) and time will tell which versions will prevail in the social sciences.

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[i] The full list of databases is published here: http://nb5yg3wl6x.search.serialssolutions.com/

[ii] These criticisms are that adaptation is a response to past environments, rather than an anticipation of the future, and that 'fitness' is not a property of a genotype alone.

[iii] Spin glasses derive from condensed matter physics and are models of disordered magnetic materials (Kauffman & Levin, 1987). "A feature of spin-glasses called frustration helps account for the multi-peaked features of fitness landscapes." (Kauffman, 1993: 43) Also the tools of statistical physics bare on population biology (Kauffman, 1993).

[iv] An Evolutionary Stable Strategy (ESS) is a strategy such that, if all the members of a population adopt it, there is no mutant strategy that would give higher reproductive fitness (Maynard Smith & Price, 1973: 15, and Maynard Smith, 1982).