ECONOMIC OPPORTUNITY AND EVOLUTION: BEYOND LANDSCAPES AND BOUNDED RATIONALITY*

TEPPO FELIN
University of Oxford
Said Business School
OX1 1HP, Oxford
United Kingdom
teppo.felin@gmail.edu

STUART KAUFFMAN
Complex Systems Center,
University of Vermont,
Burlington, Vermont, USA
stukauffman@gmail.com

ROGER KOPPL
Whitman School of Management
Syracuse University
Syracuse, NY, USA
rogerkoppl@gmail.com

GIUSEPPE LONGO
CNRS - Ecole Normale Superieure,
Paris, France
giuseeppe.longo@ens.fr
http://www.di.ens.fr/users/longo/

* In **Strat. Entrepreneurship Journal**, 8, issue 4: 269–282 (2014).

ECONOMIC OPPORTUNITY AND EVOLUTION: BEYOND LANDSCAPES AND BOUNDED RATIONALITY

ABSTRACT

The nature of economic opportunity has recently received significant attention in entrepreneurship and strategy. The notion of search on an (NK) opportunity landscape has been particularly relevant to these conversations and debates. We argue that existing notions of landscapes are overly focused on bounded rationality and search (often instantiated as the problem of NP-completeness), rather than focusing on how to account for the readily manifest, emergent novelty we see in the economic sphere (the "frame problem"). We discuss the entrepreneurial and economic implications of these arguments by building on unique insights from biology, the natural and computational sciences.

Key words: entrepreneurship, economic opportunity, novelty, strategy

1. Introduction

The origins of novelty and nature of economic opportunity have recently received significant attention in entrepreneurship, strategy and organization science. The notion of boundedly rational search (Simon, 1955, 1956)—on a strategy landscape or "phase space"—represents a particularly powerful and influential metaphor and tool for thinking about the nature of economic activity.[2] For example, NK modeling has been used to study how firms search locally or globally for peaks or opportunities within landscapes (Levinthal, 1997; Winter et al., 2007). Some have argued that behavior and "rationality" on this landscape is a process (Levinthal, 2011; also see March, 1994; Simon, 1978), thus emphasizing mechanisms such as experiential learning and environmental feedback—while yet others have recently focused on how novelty and opportunity might emerge via distant, cognitive leaps on a landscape (e.g., Gavetti, 2011; cf. Holyoak and Thagard, 1996). The discussion has centered on how economic actors navigate and map these opportunity landscapes, given uncertainty and such factors as the resources of the economic actors, the cognition or biases of the decision-makers, the dynamism of the environment, or competition and past experience. It is important to note—given the arguments in this paper—that the origins of the landscape metaphor, and associated tools such as NK modeling, can be traced back to computational and evolutionary biology (see Kauffman and Levin, 1987; Kauffman and Weinberger, 1989).[3] Furthermore, it is also quite significant that Herbert Simon's (1955, 1956) path-breaking arguments about bounded rationality were explicitly tied to biological intuition and mechanisms about organisms searching and optimizing behavior in environments.[4]

The metaphor and very nature of an opportunity landscape have recently been challenged and

[2] As we will later discuss, phase spaces and various combinatorial landscapes have been central in a number of disciplines, including physics, biology and chemistry (see Reidys and Stadler, 2002). To learn of the history and basic mathematics behind phase spaces, see Nolte, 2010.

[3] Links between biology and economics of course are deep, going back to Darwin and Malthus (Mayr, 1977). For a history of the extensive links between biology and economics, see Hodgson, 2005.

[4] Importantly, these arguments also provide the foundations for the field of artificial intelligence (Newell, Shaw and Simon, 1958; Newell and Simon, 1959; for an overview, see Russell and Norvig, 2009).

debated, particularly in the context of explaining novelty in economic settings. For example, Winter has raised questions about the notion of an opportunity landscape—specifically vis-à-vis Gavetti's (2011) arguments—and provocatively asks "why [we should even] theorize opportunity?" (2012: 291). Winter raises concerns about such issues as the stationary and objective nature of opportunity landscapes and extant mischaracterizations of rationality. We share some of these concerns. Scholars have also asked questions about how we specify the phase space of strategies and novel activities that are not actualized, but nonetheless possible (e.g., Bryce and Winter, 2009). Winter (2011) further argues that "serendipity" and "contextual factors" play an important role in the emergence of novelty and in the discovery of profitable opportunities (cf. Denrell et al., 2007; also see Winter, 2012). Importantly, scholars in entrepreneurship have also raised concerns that relate to the landscape metaphor, specifically in recent debates about the subjective versus objective nature of economic opportunities—whether opportunities are "created" and enacted versus "discovered" (e.g., Alvarez and Barney, 2007; Alvarez, Barney and Anderson, 2012; Eckhardt and Shane, 2012).

The above debates raise important questions about the origins of novelty and nature of economic opportunity. Given that scholars have extensively used phase spaces or landscapes both as a metaphor and tool (such as NK modeling), we explicitly revisit the underlying assumptions embedded in these approaches and more generally revisit the idea of bounded rationality and organism-environment relations, particularly as these apply to entrepreneurship and novel economic activity. We first discuss Herbert Simon's foundational notion of bounded rationality, which partly has led the field astray, and his ideas about search and computational complexity in uncertain environments. We focus on the rationality-related and biological and computational assumptions made by extant theories that focus on search, novelty and economic activity. In short, much of the strategy and organizational literature is built on computation and algorithm-oriented conceptions of activity and behavior, and we argue that these approaches suffer from some critical deficiencies. We address the weaknesses of these search and landscape-focused views, particularly vis-à-vis explaining novelty, by highlighting arguments from the disciplines from which these approaches stem: biology, physics, and computer science. While scholars have defined economic activity by computational limitation and complexity (for example, focusing on "NP-completeness"—e.g., Levinthal, 2011; Rivkin, 2000; cf. Weinberger, 1996), we argue that the real problem in explaining novelty instead is the "frame problem." Along with highlighting concerns about the extant use of the notion of search on a landscape or phase space, we also draw some links between the approach suggested herein and the aforementioned, ongoing debates about the origins and nature of economic opportunities (e.g., Alvarez, Barney, Anderson, 2011; Eckhardt and Shane, 2012; Gavetti, 2011; Gavetti et al., 2012; Levinthal, 2011; Winter, 2011).

To foreshadow our conclusion, our focus is on the unprestatable but nonetheless scientifically explicable nature of the phase or strategy space within which novel, economic activity takes place. We highlight parallels between evolution in the biological and economic spheres respectively (cf. Kauffman, 1993). We argue that economic actions—including behaviors, products and capabilities—yield constant flows of emergent possibilities that cannot be meaningfully listed, let alone "rationally" considered, searched and compared. Both in economics (particularly entrepreneurial settings) and in nature, there is no effective procedure or algorithm that can list the opportunities available for organisms, and this non-algorithmicity means that the emergent possibilities cannot be prestated. Thus the idea of search on a landscape or phase space, and the very notion of bounded rationality, is highly problematic for explaining novelty. However, this does not leave us outside the bounds of science. As we will discuss, explaining the origins of economic opportunities nonetheless is possible. We also seek to link these arguments with current debates about the nature of economic evolution and opportunity.

2. Economic Activity: Bounded Rationality and Computation in Uncertain Environments

The notion of "bounded rationality" has been central in advancing our understanding of economic activity. Herbert Simon's goal in introducing bounded rationality was "to replace the global rationality of economic man with a kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist" (1959: 99). Rather than assuming that organisms, such economic actors, are perfectly rational—that is, globally aware of all the possibilities and able to comparatively compute them and decide optimally—Simon emphasized the search for possibilities and the localness and limits of rationality. Bounded rationality of course has subsequently become a central assumption of many economic and organizational theories, including transaction cost economics (Williamson, 1991), the behavioral theory of the firm (March and Simon, 1952) and evolutionary economics (Nelson and Winter, 1982). The notion of bounded rationality indeed provides a much-needed contrast with and advance over models that assume perfect rationality and explicitly focus on the efficiency of markets (Arrow and Debreu, 1954). The assumption behind efficient markets, particularly in its extreme form, is that all possible goods and services—in effect, all possible futures—can be prestated and listed, and that all of this can be comparatively calculated and traded by economic actors.[5]

Simon's notion of bounded rationality is anchored on biological and computational language, mechanisms and metaphors. For example, Simon's original articles focus on "organisms including man, in the kinds of environments in which such organisms exist" (1955: 99). Thus the argument is meant to be general, to include man, and to highlight how organisms search and operate in environments. Not just the language is biological, but so are the examples. Simon's most extensive

[5] Here we are highlighting a very specific, extreme conception of markets. We certainly recognize that alternative conceptions exist, including the behavioral ones we discuss. For example, the non-equilibrium models of Hayek (1945) provide one example.

illustration of bounded rationality focuses on how an animal searches for randomly distributed food in an environment or "behavior space" (1956: 130-134). The basics of a behavioral model of boundedly rational search were thus developed early on. Note that this intuition is also quite closely linked with mathematical models of animal foraging and optimization in patchy environments (e.g., Pyke, Pulliam and Charnov, 1977).[6]

The advantage of Simon's approach, as a response to neoclassical, rational choice models, was that it could be mathematized and formalized in powerful ways. Organisms are seen as algorithmic (Turing machines) that process information via programs, within the bounds of their capability. Simon drew direct links between the way humans and computers solve problems, which is readily evident by the focus on concepts such as memory and storage capacity, programs, information processing, effectors, and receptors (see Newell, Shaw and Simon, 1958; cf. Simon, 1956, 1969). Simon provided a much-needed alternative to perfectly rational conceptions of agents. The overly-rational or even omniscient organism, or economic actor, was replaced by one who was boundedly rational: had computational limitations, needed to search for solutions, given limited access to information about alternatives. Note that these concepts—of search and problem-solving in environments, effectors and receptors, learning—also provide the very foundations of the field of artificial intelligence (see Russell and Norvig, 2009: chapter 2).

Our understanding of economic activity continues to be influenced by the notion of bounded rationality and by direct analogies and tools from the biological and computational sciences. As discussed at the outset, NK modeling was originally developed in evolutionary and computational biology (Kauffman and Levin, 1987; Kauffman and Weinberger, 1989), and this tool is now frequently used in strategy and organization science (e.g., Levinthal, 1997; also see Gavetti et al.,

[6] The organizational and economic sciences continue to make extensive use of biological tools, concepts and mechanisms. For example, beyond Simon's notion of bounded rationality, fields such as organizational ecology have borrowed and focused on concepts quite familiar to us from biology—such as population-level dynamics, resource partitioning, niches, carrying capacity, and fitness and selection (Carroll and Hannan, 2000; for an overview of these concepts, see Carroll, 1984; Singh and Lumsden, 1990).

2005; Levinthal and Warglien, 1999; Rivkin, 2000; Rivkin and Siggelkow, 2002; Siggelkow and Rivkin, 2005; Winter et al., 2007). This work has indeed generated many important insights about how firms and economic actors behave and search and find profitable opportunities in landscapes. The most basic mechanism for exploring the landscape has focused on experiential learning, where focal actors learn and adapt as they experience and sample the landscape itself and receive behavioral feedback from the environment (cf. Levinthal, 1997). This research has, for example, focused on the problem of getting stuck on sub-optimal, local peaks. The contrast between local exploitation versus more global exploration on landscapes has also been a central metaphor for understanding the tradeoffs that firms make (e.g., Levinthal and March, 1993; Rivkin and Siggelkow, 2007). These approaches can broadly be classified as part of evolutionary economics, as well as a more general behavioral program of research in organization science and strategic management (for an overview, see Gavetti et al., 2012).

There are however also some important tensions within this program of research, particularly vis-à-vis the respective emphasis that ought to be placed on the "rationality" of an organism itself versus the environment. Gavetti (2011) has recently argued that an emphasis should be placed on cognitive leaps that economic actors can make on landscapes (cf. Holyoak and Thagard, 1996). The focus is on finding ways to capture the crude but "forward-looking" representations that economic actors have about operating on uncertain opportunity landscapes (cf. Gavetti and Levinthal, 2001). This, more organism-centric approach strives to place some emphasis on agency and cognition—and more general search on a landscape—in response to the seemingly more deterministic approaches that characterize evolutionary economics. Winter (2011) responds to Gavetti's general emphasis on (more rational) cognitive search on landscapes and argues that serendipity and contextual factors play a central role. One of the central tensions in this discussion is how much rationality to afford organisms and economic actors—that is, the role of organisms or actors versus randomness, serendipity and luck.

It is worth making a specific note of the fact that much of the above discussion—and large swaths of evolutionary economics and organization science more generally—is based on a *one-to-one* importation of theories, mechanisms and tools from the biological and computational sciences. The links between economics and biology have indeed been quite tight, going back to Darwin and Malthus (see Mayr, 1977). Evolutionary economics has indeed been an effort to generalize the basic framework of Darwinism and the emphasis on environmental selection (for a recent overview, see Hodgson and Knudsen, 2011). Similarly, the mechanisms and tools in artificial intelligence and biology are also quite readily apparent in much organizational work, a focus on the computational and algorithmic aspects of behavior and decision-making. In all of the above, the notion of a phase space has been central: a representation of all possible actions for organisms, and their exploration of these landscapes through search and various cognitive mechanisms.

While the links between biology and economics have been fruitful, we argue that the phase space notion, and associated tools utilizing various forms of search, such as NK modeling, are problematic. We build on arguments from the biological, natural and computational sciences to make our point.

3.1. What is the Nature of the Problem? From NP to Frame

How, specifically, should the "problem" of explaining economic activity, opportunities and novelty (in particular) be conceptualized? We argue that the extant focus on computation and algorithmic search and behavior—embedded in arguments about bounded rationality—is problematic. While bounded rationality rightly amends models of global rationality by setting limits to both what can be considered and the abilities of actors to process all the relevant information, nonetheless, different foundations are needed. Specifically, we hope to amend the focus on bounded rationality and computational complexity to also consider the generative and productive aspects, beyond search and calculation, manifest in economic activity.

In existing work, economic actors and firms are treated as algorithmic information processors. Economic actors and firms are, in effect, seen as Turing machines. To illustrate, strategy scholars and organization scientists have specifically focused on bounded rationality in the form of the unfeasible computability of all choices and their interactions (e.g., Levinthal, 2012; Rivkin, 2000), known as the "NP" problem in computer science: problems that may be computable but only in too long (exponential) a time, due to complexities.[7] The setting of NK landscapes indeed is optimal for studying the NP-complete problem (cf. Weinberger, 1996). But the very premise of NP-completeness is problematic in the context of economic activity, just as it is in the context of biological activity. *That is, the NK approach presumes that solutions pre-exist—the landscape is given and needs to be searched (or calculated)—and that all options are somehow listable*. The economic problem is framed as one where all solutions are listable, searchable and comparable, though where the processing or comparison of all these solutions occurs in bounded fashion. This boundedness focuses on the limits of calculation and the impossibility of considering all possibilities, for example, as illustrated by the combinatorial interactions of various decision elements (proxied by K in NK work). NP-completeness, and the more general emphasis on search on a landscape, thus frames the central economic problem as one of information processing and cognitive limitation. The landscape itself is seen as given, and the economic problem is computational and algorithmic. A satisficing, and thus more limitedly, "rational" solution can be calculated (or learned over time) within the limitations of the computational power of the agent involved.

Note that the exercise of computing solutions has some striking similarities with neoclassical economics and rational choice approaches, namely, the emphasis on computation. While equilibrium-oriented models focus on the simultaneous and instantaneous nature of this economic calculation, evolutionary and computational approaches in turn focus on the temporal, cognitive and

[7] For an additional example of this type of complexity in economic settings, see Axtell, 2005.

search-related aspects of the climb to an optimum. We certainly find the latter conceptualization more convincing. But it also, particularly vis-à-vis explaining novelty in economic settings, deserves scrutiny.

The notion of NP-completeness mis-specifies what the economic problem entails. While complexity is involved in economic decision-making, the problem is *not* one where all (or even just some) solutions are listed, listable and comparable, *but rather one of how we can account for the emergence of these solutions in the first place*. The shift, then, if we seek to retain the landscape metaphor, is one of understanding how portions of the landscape—hidden to our view—emerge in the first place.

The central problem in question, then, is not NP-complete. Rather, we should instead focus on the "frame problem" (originally introduced by McCarthy and Hayes, 1969; for a broader sense of the frame problem, see Dennett, 1984).[8] Put simply, the frame problem focuses us on the problematic nature of explaining the full task set of activities and *possible* functionalities and uses for operating in the world (or some situation or environment, whether real or artificial). The problem is that there is no full account, or set of algorithms, that can be given about all possible actions, uses and functions. The shift here is also one of needing to move from an emphasis on the exogenous environment to endogenous nature (Felin, 2012).

We are not just talking about the narrow problem…

To illustrate the incapacity to solve the frame problem algorithmically, consider the familiar screwdriver (cf. Longo, Montevil and Kauffman, 2012). Suppose we try to list all its uses alone or with other objects or processes: screw in a screw, wedge open a door, open a can of paint, tie to a stick as a fish spear, rent to locals and take 5% of the catch, kill an assailant, and so forth. As we will

[8] For a broader conception of the frame problem, see Dreyfus, 2007. In short, Dreyfus highlights how the frame problem focuses on "which facts are relevant in a given situation" (something that computers cannot meaningfully bootstrap), the problem of the situation-specific nature of frames, and the problem of how to account for operating in a changing world. This, broader conception of the frame problem indeed is the one that we have in mind.

argue below with reference to biology (or to phenotypes, as forms and functions of the living), the number of uses of a screwdriver (as forms and functions of uses and activities) are both indefinite and unorderable. No effective procedure or algorithm can list all the uses of a screwdriver. This means, a fortiori, that the frame problem is not solvable algorithmically. However, as we discuss below, evolution in nature "solves" the frame problem non-algorithmically. But importantly, because we cannot list all the uses of evolving cellular or molecular screwdrivers we cannot prestate all the possibilities and thus do *not* (and can not) know the sample space of the process and therefore can make no probability statements in any known way. Not only do we not know what will happen, we typically do not know what *can* happen. Yet, we argue, it is from the unprestatable uses of screwdrivers in general that economic novelty emerges.

In the economy, the landscape metaphor and associated computational tools require every observable in a given environment (i.e. the possible "space" or landscape) to somehow be listed and classified, and assigned its proper uses and functionalities. To put this in more practical terms, every object "is-a," "has-a," "needs-a." But this list of possible "affordances" is not fully prestatable for operating in the world, other than for extremely limited circumstances. The problem is not only one of comparison amongst the best uses and functions of objects and spaces, but even the very generation of the full list is not algorithmically feasible. Or, to put this differently, as discussed by Gibson, "to perceive an affordance is not to classify an object" (1986: 134). Thus the problem is not one of informational complexity and computational limitation (NP-completeness)—though these of course also play a role in certain types of behavior. Rather, the problem is that the landscape itself is not listable or predefinable. The problem, then shifts to explaining the origins of uses and functions, particularly new ones. An artificial agent of course might be given tools to generate hypotheses about possible uses and functionalities, via mechanisms such as trial-and-error or association. But these are scarcely sufficient for explaining economic or entrepreneurial novelty (Felin and Zenger, 2009). Outcomes are only as good as the intelligence of the interpreter. This matters, since presently the mechanisms used in artificial intelligence are the same as those used in our study of human behavior (see Russell and Norvig, 2009).

Scholars have long been optimistic about the potential of artificial intelligence and computers to surpass the ability of humans. But, beyond the frame problem, it is hard to program and ascribe any meaningful form of creativity or novelty to artificial agents (Dreyfus, 1992). The future problems, related to the generation of novelty, were even anticipated by the very early pioneers of artificial intelligence, such as Ada Lovelace. She argues that "the Analytical Engine has no pretensions whatever to originate any thing. It can do whatever we know how to order it to perform. It can follow analysis, but it has no power of anticipating any analytical relations or truths. Its province is to assist us in making available what we are already acquainted with" (1848: 722).

The desire to capture biological and human activity, including entrepreneurial and economic such, in computational or mechanistic form of course is tempting and seemingly scientific, and represents a more general ethos of trying to unify the sciences through computational reduction. Works such as Jacques Loeb's (1912) *Mechanistic Conception of Life* capture this intuition: a heroic attempt to build a general theory focused on environmental inputs, stimulus-response relationships and selection. These mechanistic conceptions, and the focus on computational observables, also have links to prominent theories and approaches in psychology (Skinner, 1938) and physics (Mach, 1897). More broadly, the environment-oriented conceptions of evolutionary economics suffer from similar problems (Felin and Foss, 2012). While these approaches are influential, they are overly deterministic and unable to explain the emergence of variety.

3.2. The Origins of Variety and Novelty: Insights from Biology

Where, then, does variety and novelty—whether in the biological or economic sphere—originate from? Perhaps the best place to start is with reference to extant biological arguments that deal with similar questions about the origins of variety and novelty in nature. Evolutionary models that focus on selection require a counterpart to explain where the selection set comes from. In other words, both in biology and economics, we need to not just explain the survival of the fittest but also the "arrival" of the fittest (cf. Fontana and Buss, 1995). Radical and emergent heterogeneity in nature is not explainable by appealing to the mechanism of selection alone (cf. Kauffman, 1993).[9] As areas such as evolutionary economics are attempting to build on a general theory of evolution (Winter, 2011), it is important to highlight both sides of the argument: arrival or development and survival.[10]

Our argument, building on extant biology, is that there are selection-independent mechanisms that generate novelty in the biosphere. These arguments do not require a "mind," or intention or purposiveness. Rather, novelty is an emergent process observable in nature, and readily extendable into the domain of understanding entrepreneurial and economic activity.

Recall first that Darwin's "Origin of Species" is founded on two principles: descent with modification and selection. The first is as revolutionary as the second. It stresses the idea that

[9] Within the domain of biology and nature, the arrival of variety has focused on a host of factors. For example, scholars have highlighted such factors as niche construction (Odling-Smee et al., 2003), speciation and punctuated equilibria (Eldredge and Gould, 1977), exaptation (Gould and Vrba, 1982), epigenetics (Waddington, 1942), ontogeny (Gould, 1999), and morphogenesis or the growth of form (Thompson, 1917; Turing, 1952). In section 4. we revisit extant work in economics that touches on these issues. In all these approaches, the role of randomness is crucial in producing biological variability and diversity: it goes from Turing stochastic fluctuations in morphogenesis to Gould's broad notion of contingency.

[10] In terms of "general" Darwinism and the important of selection as a mechanism, Winter has argued that:

> natural selection and evolution should not be viewed as concepts developed for the specific purposes of biology and possibly appropriable for the specific purposes of economics, but rather as elements of the framework of a new conceptual structure that biology, economics and other social sciences can comfortably share (1987: 617).

We consider that Darwin's first principle, descent with modification, a key component of variability and diversity in evolution, should also be given a similar fundamental role.

organisms, beginning with unicellular ones, proliferate *with variation* under all circumstances. This radically changes the previous "evolutionist" perspective, by Buffon and Lamarck, as variation was supposed to be induced by the environment. Then, of course, Darwinian selection, *as the exclusion of the incompatible*, applies.

To illustrate, consider the emergence of the swim bladder (Kauffman, 2008; Longo, Montevil and Kauffman, 2012). Swim bladders help fish maintain neutral buoyancy via the ratio of water to air in the bladder (cf. Perry et al., 2001). This functionality, a Darwinian preadaptation, emerged from lungfish as some water seeped into lungs. Sacs in the lungs were partially filled with air and with water, poised to evolve into swim bladders. The possibility of developing this new and emergent functionality existed *a priori*, but was not a necessity: life could continue without it for that particular fish. But the novel functionality was an "adjacent possibility" once lungfish existed, but not before a mutation or other forms of inheritance made that possibility *actual* as well as *heritable.* In other words, the bladder represents a preadaptation that as an adjacent possible emerges without selection "acting" to achieve the possibility. It is a possibility enhanced by reproduction with heritable variation. So, both new functionalities and niches may emerge, possibly originating at molecular level (mutations). These new observable phenotypes are thus totally unpredictable: they may even depend on a quantum event in a germinal cell (Buiatti and Longo, 2013).[11]

Organisms in nature constantly develop surprising functional capabilities and uses that are not prestatable. The swim bladder, once it has evolved, may constitute an adjacent possible empty niche where, for example, bacterium may evolve to live. Once evolved, the swim bladder alters the adjacent possible evolution of the biosphere. But what is the role of natural selection here? Selection surely plays a role in the evolution of a population of lungfish to craft a working swim

[11] Another famous example by Gould, see (Gould and Vrba, 1982), is the formation of the vertebrate ears' bones. They derive, by "exaptation" (ex-post adaptation), from the double jaw of some vertebrate some 200 millions years ago. A typical case of Gould's contingency: there was no need, for animals, to have ears and the process required cascades of random mutations and many other explorations, possibly excluded by selection. The animals' interactions and thus the ecosystem changed by this new phenotype. Some, today, can sell Mozart's recorded piano concerts.

bladder by excluding incompatible ones. And once the swim bladder exists, it constitutes an adjacent possible empty niche, or “opportunity” altering the future possible evolution of the biosphere via the worm or bacterium that in turn might evolve to live in swim bladders. But critically, selection did not “act” to achieve the swim bladder as an adjacent possible empty niche or opportunity. This means something fundamental: without selection acting to do so, evolution is creating its own future possibilities and opportunities, by the first of Darwin's principles. Note that no fixed, known physical theory (or conceptualization of “phase space”) can list all biological possibilities. The forms of randomness proper to biological dynamics include both classical and quantum randomness (which happen not to be unified in one theory). They also include the unpredictable interactions between these two different forms of randomness as well as between different levels of organization—within a cell, a multicellular organisms, an ecosystem (see Buiatti and Longo, 2013).

The emergence of new, unprestatable functions and new, unprestatable opportunities is constant and continual. *Thus the phase space of the evolution* of organisms and phenotypes —if it even can be called a phase space or landscape—*is never fixed*, it is radically emergent. There are adjacent possibilities and niches for each trait, function or capability of an organism and new organisms maybe —in the terminology of Longo et al (2012)—“enabled.” It is not possible to map all of these possible adjacencies, just as all the uses of a screwdriver are not algorithmically listable, nor are all the opportunities that arise listable or prestatable. Moreover, all that must occur in evolution is that some molecular screwdriver in an evolving organism “finds a use” that enhances the fitness of the organism and that there be heritable variation for that use. Natural selection will then, often, positively select for this newly adapted use. This *is* the arrival of the fitter, missing in selection-oriented approaches. Moreover, the unprestatable new use alters the phase space of evolution in an unprestatable way, precluding writing laws of motion for that evolution.

One way to think about the emergence of novelty is that there is a constant “empty” set of possibilities that are adjacent to the existing phase space. The problem of specifying the phase space of possibilities is closely linked with our previous discussion of the algorithmic incapacity to list affordances and uses. Any product, skill or function represents a latent but unprestatable set of uses. The aforementioned screwdriver—a seemingly trivial object—illustrates the point. Since the number of uses of screwdrivers is indefinite and unorderable, it simply is not possible, *a priori*, to use any effective procedure to list all the possible uses of a screwdriver. The same goes for the possible functionality for any other product, function, capability or skill. As these examples illustrate, our goal is not to try to make predictions about why *a particular*—of many possible—novel use or functionality might emerge in the first place. Rather, our goal is to highlight the unprestatability of all the possibilities. Thus our approach is in fact complementary with existing evolutionary arguments, where the mechanisms for generating particular novelties might of course also emerge through random experimentation or trial and error. That said, randomness in evolution—whether economic or biological—is not randomness in the sense of "noise" or somehow measurable by probability theory, but rather it is at the origin of possible variability and diversity and thus contributes, in biology, to organisms, populations and ecosystem's structural stability (Longo et al., 2012; Buiatti and Longo, 2013).

It is also important to note that the evolving organism in its actual niche achieves "task closure" allowing it to reproduce, via causal pathways that pass through the environment. However, these pathways cannot be prestated non-circularly with respect to the evolving organism in its actual niche. In short, we cannot prestate the niche of an evolving organism; it is only revealed if the organism is successful, that is, by selection acting at the level of the *whole* organism.

This distinction touches on a key point about the need to distinguish *developmental* constraints from *selective* constraints (Maynard-Smith et al., 1985). Our emphasis is on the former. While variation and selection emphasize randomness, we emphasize the changing constraints that make further development possible. Constraints, such as the swim bladder, are "enabling." Development is not deterministic but allows for adjacencies to be explored, by variation at some other level (e.g., the changing bacterium). Enabling constraints suggest not just limitations but also evolutionary enablement toward possibilities and opportunities.

A further problem with focusing on selection alone—as a prestated, searchable landscape would suggest—is that particular traits or functions are rarely if ever selected for, rather, *whole* organisms are. Thus, not only is it hard to specify which functions or traits were selected for, but it is also hard to specify the latent set of possible future traits and functions, accompanying the "selected" one(s)—these simply are not listable. Whole organisms can be seen as complex bundles of parts, latent traits and possibilities, and thus even after selection "we cannot [pre-list] the newly relevant functional features of its parts revealed by selection" (Longo et al., 2012: 2). As we discuss next, there are indeed important links between organisms and environments and extant understandings of phase spaces and landscapes.

3.3. Revisiting the Phase Space and Landscape

Our arguments here have profound implications for the notion of "phase space"—a representation of the set of all possible actions, strategies or states—and associated modeling such as combinatorial landscapes (cf. Kauffman and Weinberger, 1989). These, after all, have been a central metaphor in the field of strategy, entrepreneurship and organization science (Levinthal, 1997). The notion of phase space originates from the physical sciences and the pioneering work of Ludwig Boltzmann, and the efforts in statistical mechanics (as well as thermodynamics, and later, quantum mechanics) to specify the full set of possible states that a particle or system can take. Boltzmann argued that even highly complex, non-reducible systems were "ergodic," that is, they randomly, but uniformly, explored all the possibilities in a given phase space. As a consequence, their *average* performance and behavior was predictable given sufficient historical information.

However, the problem in biological evolution, compared to thermodynamics, is that this phase space cannot be specified—even on average (Longo et al., 2012). While in Newtonian and Laplacian physics, which are given in a fixed phase space, we can determine and predict motion and direction, the biological sphere does not lend itself to such physical models given the aforementioned, latent functionalities of organisms. Specifically, there are several concerns with the notion of phase space. As discussed above, in the biological sphere organisms are selected as wholes. But organisms naturally embody myriad functionalities and uses that cannot be prestated or captured, which range from quantum to classical to "inter-level" interactions between the organism and ecosystem. Even retrospective imputation of a selected-for trait or phenotype can be difficult, if not impossible.

The argument that the phase space is not prestatable might be seen as an argument for unrestricted randomness or ergodicity as the exploration of all possibilities. However, the very notion of development, as the counterpart of selection, suggests that there are possible trajectories, or "evolvability" (cf. Wagner and Altenberg, 1996), within organisms. But evolution is not fully random in any extreme sense: its randomness is highly canalized. Biological entities can be said to be "poised" for a large set of possible adaptations (cf. Bailly and Longo, 2011; Mora and Bialek, 2011; also see Kauffman, 2012). The set of adjacent possible directions of course is extremely large, though not infinite—that is, within the limits, constraints and enablement of the nature of the organism in question. Scholars of course have tried to capture the developmental portions of the evolution of organisms mathematically, for example, in an effort to map the "topology of the possible" (Fontana and Schuster, 1998; Stadler et al., 2001). Certainly a new set of mathematical and empirical tools is needed to capture the richness of the emergent, unprestatable biological sphere and associated evolution, including economic evolution.

But, the bottom line is that extant notions of phase spaces and landscapes import certain assumptions from physics that are problematic in the context of biological evolution. Namely, phase spaces assume symmetries, invariance and that conservation laws are upheld (Kibble and Berkshire, 2004; cf. Sethna, 2006). These assumptions however do not hold in the case of biological evolution, let alone in economic or entrepreneurial settings. Biological evolution represents continual changes to symmetry as the trajectories of organisms evolve. In physics the observables yield the phase space and possible trajectories. That is, the mathematical construction of the phase space is based on invariants (e.g., momentum and energy conservation) and invariant-preserving transformations which allow us to analyze trajectories (momentum x position, or energy x time, in the two cases above). However, biological evolution cannot be captured by observables alone since the relevant observables (phenotypes and organisms) and pertinent variables shift constantly.

As we have already hinted, the problem of a prespecified phase space or landscape can also be looked at by highlighting quantum effects. Quantum physics highlights how it is highly problematic to identify the position of a particle or system—its state is indeterministic. Changes can be random, nonlocal and acausal. The whole notion of quantum effects raises hairy questions about the precise nature and state of things (particles versus waves), as well as measurement problems. The question is whether the outcome of any single quantum measurement can be calculated, for if not, that outcome is not entailed. The notion of observables and spatial location—at the very heart of a phase space or landscape—then is problematized given quantum non-locality. As closely analyzed by Buiatti and Longo (2013), these a-causal quantum events may have a major role in intracellular dynamics and thus affect biological evolution.

In all, the above arguments raise profound problems with the use of phase spaces and landscapes, whether as a metaphor or as a tool for understanding the evolution and development of organisms. That said, there are of course some, more narrow, settings where it indeed is possible to list all available options or to simulate the search for optimal outcomes. However, if we are seeking to explain the emergence of novelty and new-ness, whether in biological or economic settings, then focusing on phase spaces and landscapes will only lead us astray.

4. Future Questions and Conclusion

Our central argument is that notions of bounded rationality, calculation and search on phase spaces and landscapes are inappropriate for understanding the emergence of entrepreneurial and economic novelty. We have sought to make this point by highlighting how the specific theories, metaphors and methodologies, imported from the natural and biological sciences, are inappropriate for explaining novelty. E

volutionary arguments of economic activity need to move beyond landscape and phase space-type assumptions and search-laden, computational metaphors to explain emergent novelty. For example, rather than emphasizing NP-completeness, as extant work has, we think the frame problem offers a more realistic future focus for explaining the emergence of novelty in the economic sphere. After all, understanding the emergence of novel uses and functionalities is at the heart of economic and entrepreneurial activity. Some of these matters have of course been raised in the past. For example, Adner and Levinthal (2002) discuss punctuated equilibria in the context of the "speciation" of technologies, where surprising new uses and functionalities emerge for technologies intended for different purposes and contexts. And, Cattani (2005, 2006) offers an apt example of "preadaptation," where Corning's capabilities in glass manufacturing led to surprising new innovations in fiber optics technology. However, work in the domain of evolutionary economics, entrepreneurship and strategy continues to nonetheless be heavily focused on the environment, search and selection-type mechanisms (Felin, 2012). Evolutionary economics continues to be strongly linked with the selection logic. For example, in their recent review of evolutionary theories across the sciences (and calls for a generalized Darwinism), Hodgson and Knudsen only briefly reference "ontogeny" (2011: 55-56) and related concepts (e.g., "exaptation," 100-101), but no theory is explicitly developed as it relates to the emergence of novelty. Also, Giovanni Dosi briefly mentions (in a footnote: Cohen et al., 1996: 28) the need to develop "constructive" evolutionary models (cf. Fontana and Buss, 1995), though these issues have not been addressed in subsequent work. But, more is needed, since the landscape metaphors, and associated methodologies and tools, are irreparably constrained in terms of their ability to actually explain novel, entrepreneurial and economic activity, despite the continuing efforts to try to do so (e.g., Gavetti, 2012). Again, the development side of evolutionary arguments in entrepreneurship and the economic sciences, given the focus on search and environments (whether populations, selection or pre-specified phase spaces), has received little attention (cf. Felin, 2012). The effort in our paper has been to bring development and novelty center-stage, and to highlight how insights from biology might inform our understanding of the nature of entrepreneurship and novel economic opportunity.

Our argument features a critique of extant, behavioral conceptions of the mind that focus on bounded rationality and computation. Our concern simply is that the emphasis on boundedness and rationality suggests a highly computational and algorithmic conception of the mind—as illustrated by the emphasis on search and the NP problem—while we favor other, more generative alternatives. But in this paper we don't meaningfully provide an alternative theory of mind. Thus we might ask

: what role does the (entrepreneurial) mind play in all of this? Essentially, this is a question of the boundaries of the argument: do the processes that shape nature equally apply to human and economic contexts? Or are there differences? In our arguments we have purposefully said little about factors such as intentionality, and instead have focused on how emergent processes evident in nature have direct corollaries in entrepreneurial and economic settings. The extant literature has focused on selection, while we have focused on the need to understand origins and development. But, our discussion of bounded rationality, of course, inevitably implicates matters of mind. Our concern here is that the emphasis on boundedness and rationality suggests a highly computational and algorithmic conception of the mind—as illustrated by the emphasis on search and the NP problem—while we favor other, more generative alternatives. Humans, after all, constantly solve the frame problem, while computers don't. If the entrepreneur solves the frame problem, as we have argued humans do, then the mind is not algorithmic. No algorithm can pre-decide what to do in novel environments whose nature cannot be prestated (at the relevant level of specificity). But the mind is generative and perhaps somehow alert to new possibilities in the adjacent possible.[12]

In all,

the purpose of this paper has been to address recent theories and debates about the nature of economic opportunity and to highlight the crude beginnings of an alternative. We first discuss the current focus on computational and algorithmic approaches to economic activity, as manifest by the use of limited biological metaphors and tools associated with search on a landscape or phase space. We highlight how the notion of bounded rationality—central to key theories in entrepreneurship, strategy and organization science—is anchored on a computational view of search behavior, and thus not able to explain the emergence of novelty. Extant approaches pre-specify the phase space or economic landscape and then highlight the computational boundaries and limitations of actors. While this approach improves on efficient markets-type arguments that focus on the seeming omniscience of economic actors, nonetheless these approaches also feature some critical deficiencies, particularly in terms of explaining the emergence of novelty. For example, the current focus on NP-completeness mis-specifies the problem at hand. We argue that the frame problem more readily captures the central question for explaining the emergence of novelty, both in nature as well as in

[12] As a matter of fact, most physical dynamics are not programmable either, even not in an approximated way; mathematically, non-linear continuous dynamics (and the processes modeled by these dynamics as well) eventually diverge from any computable approximation, (Longo, 2009 and 2012).

entrepreneurial or economic settings. We provide examples from biology (lungfish), as well as common-day surroundings (screwdrivers), to highlight how novel uses and functionalities emerge constantly—ones that cannot be prestated or listed. In all, we argue that computational and algorithmic tools and metaphors, and, more generally, the use of mathematically pregiven phase spaces, mis-specify rather than clarify our understanding of novelty. In conclusion we provide some implications of our arguments, both by way of review and in an effort to speculate about directions for future research.

REFERENCES

Abell P, Felin T, Foss N. 2008. Building microfoundations for the routines, capabilities, and performance links. *Managerial and Decision Economics* 29: 489-502.

Adner R, Levinthal DA. 2002. The emergence of emerging technologies. *California Management Review* 45: 50-66.

Aldrich HE., Hodgson GM, Hull DL, Knudsen T, Mokyr J, Vanberg V. 2008. In defense of generalized Darwinism. *Journal of Evolutionary Economics* 18: 577-596.

Alvarez S, Barney J. 2007. Discovery and creation: Alternative theories of entrepreneurial action. *Strategic Entrepreneurship Journal* 1: 11-26.

Alvarez S, Barney J, Anderson P. 2012. Forming and exploiting opportunities: The implications of discovery and creation processes for entrepreneurial and organizational research. *Organization Science.*

Axtell R. 2005. The complexity of exchange. *Economic Journal* 115: 193-210.

Aldrich H.E. 1999. *Organizations evolving.* Sage Publications.

Arrow K, Debreu G. 1954. Existence of an equilibrium for a competitive economy. *Econometrica.*

Block N. 1981. Psychologism and behaviorism. *Philosophical Review* 90: 5–43

Block N. 1995. The mind as the software of the brain. In *An invitation to cognitive science,* D Osherson, L Gleitman, S Kosslyn, E Smith, S Sternberg (Eds.). MIT Press: Cambridge, MA

Bailly F, Longo G. 2011. *Mathematics And The Natural Sciences. The Physical Singularity of Life*. Imperial College Press, London.

Buiatti M, Longo G. 2013. Randomness and multi-level interactions in biology. *Theory of Biosciences.*, forthcoming.

Buchanan BG. 2001. Creativity at the metalevel – AAAI 2000 Presidential Address. *AI Magazine* **22**: 13-28

Carroll GR. 1984. Organizational ecology. *Annual Review of Sociology* 10: 71-93.

Cattani G. 2005. Pre-adaptation, firm heterogeneity, and technological performance: A study on the evolution of fiber optics, 1970–1995. *Organization Science* 16: 563–580.

Cattani G. 2006. Technological pre-adaptation, speciation, and emergence of new technologies: How Corning invented and developed fiber optics. *Industrial and Corporate Change* 15: 285–318.

Chomsky N. 1959. A Review of B.F. Skinner's Verbal Behavior. *Language* 35: 26-58.

Chomsky N. 2003. *Cartesian linguistics: A chapter in the history of rationalist thought*. Cybereditions Corporation.

Cyert RM, March JG. 1963. A Behavioral Theory of the Firm. Prentice-Hall, Englewood Cliffs, NJ.

Cohen MD, Burkhardt G, Dosi M, Edigi M, Marengo L, Warglien M, Winter S. 1996. Routines and other recurring action patterns of organizations. *Industrial and Corporate Change* 5: 653-698.

Dennett DC. 1984. Cognitive wheels: The frame problem of AI. In C Hookway, Ed., *Minds, Machines and Evolution.* Cambridge University Press, 129-150.

Dreyfus, H. 1992. *What computers still can't do.* MIT Press.

Dreyfus, H. 2007. Why heideggerian AI failed and how fixing it would require making it more heideggerian. *Philosophical Psychology* 20: 247-268.

Eckhardt J, Shane S. 2012. Response to the responses: The IO nexus integrates objective and subjective aspects of entrepreneurship. *Academy of Management Review*.

Felin T, 2012. Cosmologies of capability, markets and wisdom of crowds: Introduction and comparative agenda. *Managerial and Decision Economics* 33: 283-294.

Felin, T., Zenger, T. 2009. Entrepreneurs as theorists: On the origins of collective beliefs and novel strategies. *Strategic Entrepreneurship Journal* 3: 127-146.

Felin T, Foss, NJ. 2011. The endogenous origins of experience, routines and organizational capabilities: the poverty of stimulus. *Journal of Institutional Economics* 7: 231-256.

Fontana W, Buss LW. 1995. The arrival of the fittest: Toward a theory of biological organization. *Bulletin of Mathematical Biology* 56: 1-64.

Fontana W, Schuster P. 1998. Shaping space: The possible and the attainable in RNA genotype-phenotype mapping. *Journal of Theoretical Biology* 194: 491-515.

Foss N, Klein P, 2012. *Organizing entrepreneurial judgment: A new approach to the firm.* Cambridge University Press.

Gavetti G, Greve H, Levinthal D, Ocasio W. 2012. The behavioral theory of the firm: Assessment and prospects. *Academy of Management Annals*, forthcoming.

Gavetti G, Levinthal D. 2000. Looking forward and looking backward: Cognitive and experimental search. *Administrative Science Quarterly* **45**: 113-137.

Gavetti G, Levinthal D, Rivkin J. 2005. Strategy-making in novel and complex worlds: The power of analogy. *Strategic Management Journal*: Forthcoming.

Gibson JJ. The theory of affordances. In *Perceiving, Acting and Knowing*, Eds, Robert Shaw and John Bransford.

Gould S, Vrba ES. 1982. Exaptation-a missing term in the science of form. *Paleobiology* 8: 4-15.

Gould S, Eldgredge N. 1977. Puncuated equilibria: The tempo and mode of evolution reconsidered. *Paleobiology* 3: 115-151.

Hayek F. 1964. The theory of complex phenomena. *Studies in Philosophy, Politics and Economics*. London: Routledge and Kegan Paul.

Hannan MT, Freeman J. 1977. The population ecology of organizations. *American Journal of Sociology* 82: 929-964.

Hayek F. 1945. The Use of Knowledge in Society. *American Economic Review* 35: 519–30.

Hodgson G. 2005. Decomposition and growth: Biological metaphors in economics from the 1880s to the 1980s. In *The evolutionary foundations of economics*, Ed, Kurt Dopfer, Cambridge University Press, 105-150.

Hodgson G, Knudsen T. 2011. *Darwin's conjecture: the search for general principles of social and economic evolution.* University of Chicago Press.

Holyoak KJ, Thagard P. 1996. *Mental Leaps: Analogy in Creative Thought.* MIT Press.

Kauffman SA. 1986. Autocatalytic Sets of Proteins. *Journal of Theoretical Biology* 119: 1-24.

Kauffman SA, Levin S. 1987. Towards a general theory of adaptive walks on rugged landscapes, *Journal of Theoretical Biology* 128: 11–45.

Kauffman SA, Weinberger E. 1989. The N-k Model of the application to the maturation of the immune response. *Journal of Theoretical Biology* 141: 211-24.

Kauffman, SA. 1993. *The origins of order: self organization and selection in evolution*. Oxford University Press.

Kauffman, SA. 2012. Answering Descartes: Beyond Turing. In *Alan Turing Centennial Volume, The Once and Future Turing* Eds: S Barry Cooper and Andrew Hodges. Cambridge University Press.

Kirzner IM. 1973. *Competition and entrepreneurship.* University of Chicago Press.

Kirzner IM. 1982. Entrepreneurial discovery and the competitive market process: An Austrian approach. *Journal of Economic Literature* 35: 60-85.

Levinthal DA, March J. 1993. The myopia of learning. *Strategic Management Journal* 14: 95-112.

Levinthal DA. 1997. Adaptation in rugged landscapes. *Management Science* 43: 934-950.

Levinthal DA, Warglien N. 1999. Landscape design: Designing for location action in complex worlds. *Organization Science* 10: 342-357.

Levinthal DA. 2011. A behavioral approach to strategy – what's the alternative? *Strategic Management Journal* 32: 1517-1523.

Loeb J. 1912: *A mechanistic conception of life.* University of Chicago Press.

Longo G. 2009. Critique of Computational Reason in the Natural Sciences, In *Fundamental Concepts in Computer Science* (E. Gelenbe and J.-P. Kahane, eds.), Imperial College Press, pp. 43-70.

Longo G. 2012. Incomputability in physics and biology. *Mathematical Structures in Computer Science* 22: 880-900.

Longo G, Montevil M, Kauffman S. 2012. No entailing laws but enablement in the evolution of the biosphere. *arXiv preprint*.

Lovelace A. 1843. Scientific Memoirs. In *Selections from The Transactions of Foreign Academies and Learned Societies and from Foreign Journals,* T Richard (Ed.). F.S.A.;Vol III London: 1843, Article XXIX.

Lucas JR. 1961. Minds, machines and Godel. *Philosophy* 36: 112-127

Mach E. 1897. *The analysis of sensations.* Open Court Publishing.

Mayr E. 1977. Darwin and natural selection: how Darwin may have discovered his highly unconventional theory. *American Scientist* 65: 321-327.

Maynard-Smith J, J. Burian, R., Kauffman, S., Alberch, P., Campbell, J., Goodwin, B. Developmental constraints and evolution: A perspective from mountain lake conference on development and evolution. *Quarterly Journal of Biology* 60: 265-287.

McCarthy J, Hayes PJ. 1969. Some philosophical problems from the standpoint of artificial intelligence.

Mora T, Bialek W. 2011. Are biological systems poised at criticality? *Journal of Statistical Physics* 144: 268-302.

Mossio M, Longo G, Stewart J. 2009. A computable expression of closure to efficient causation. *Journal of Theoretical Biology* 257: 489-498.

Murmann JP, Aldrich H, Levinthal D, Winter SG. 2003. Evolutionary thought in management and organization theory at the beginning of the new millennium. *Journal of Management Inquiry* 12: 1-19.

Nelson R, Winter S. 1982. *Evolutionary theory of economic change.* Harvard University Press.

Newell A, Shaw JC, Simon HA. 1958. Elements of a theory of human problem solving. *Psychological Review.*

Newell A, Simon HA. 1959. The simulation of human thought. Santa Monica: Rand Corporation.

Nolte DD. 2010. The tangled tale of phase space. *Physics Today* (April): 33-38.

Odling-Smee FJ, Laland KN, Feldman MW. 2003. Niche construction: A neglected process in evolution. Princeton, NJ: Princeton University Press.

Perry SF, Wilson RJ, Straus C, Harris M, Remmers JE. 2001. Which came first, the lung or the breath. *Comparative Biochemistry and Physiology* 129: 37-47.

Pyke GH, Pulliam HR, Charnov EL. 1977. Optimal foraging: A selective review of theory and tests. *Quarterly Review of Biology* 52: 137-154.

Reidys CM, Stadler PF. 2002. Combinatorial landscapes. *SIAM Review* 44: 3-54.

Rivkin, JW. 2000. Imitation of complex strategies. *Management Science* 46: 824–844.

Rivkin, JW, Siggelkow N. 2007. Patterned interactions in complex systems: Implications for exploration. *Management Science* 53: 1068-1085.

Russell S, Norvig R. 2009. *Artificial intelligence: A modern approach*. Prentice Hall.

Sarasvathy SD. 2001. Causation and effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency. *Academy of Management Review* 26: 243–263.

Sethna JP. 2006. *Statistical mechanics: Entropy, order parameters, and complexity*. Oxford University Press.

Singh JV. Lumsden CJ. 1990. Theory and research in organizational ecology. *Annual Review of Sociology* 16: 161-195.

Simon HA. 1955. A behavioral model of rational choice. *Quarterly Journal of Economics* 69: 99-118

Simon HA. 1956. Rational choice and the structure of the environment. *Psychological Review*.

Simon HA. 1959. Theories of decision-making in economics and behavioral science. *American Economic Review.*

Simon HA, Newell A, Shaw JC. 1958. Elements of a theory of human problem solving. *Psychological Review* 65: 151-161.

Skinner BF. 1938. *The behavior of organisms: An experimental analysis*. Appleton Century: New York

Smith A. 1904. *A theory of moral sentiments*.

Spelke ES, Breinlinger K, Macomber J, Jacobson K. 1992. Origins of knowledge. *Psychological Review* 99: 605-632.

Stadler B, Stadler PF, Wagner G, Fontana W. 2001. The topology of the possible: Formal spaces underlying patterns of evolutionary change. *Journal of Theoretical Biology* 213: 241-274.

Thompson D. *On growth and form*. Cambridge University Press.

Turing A. 1952. The chemical basis of morphogenesis. *Philosophical Transactions of the Royal Society of London* 237: 37-72.

Venkataraman S, Sarasvathy S, Dew N, Forster WR. 2012. Reflections on the 2010 AMR Decade Award: Whither the promise? Moving forward with entrepreneurship as a science of the artificial. *Academy of Management Review* 37: 21-33.

Waddington CH. 1942. The epigenotype. *Endeavour* 1: 18-20.

Wagner GP, Altenberg L. 1996. Complex adaptations and the evolution of evolvability. *Evolution* 50: 967-976.

Weinberger E. 1996. NP-completeness of Kauffman's NK model, a Tuneably Rugged Fitness Landscape. *Santa Fe Institute Working Paper* 96-02-003.

Williamson O. 1991. Comparative economic organization: The analysis of discrete structural alternatives. *Administrative Science Quarterly* 36: 269-296.

Winter SG. 1987. Natural selection and evolution. In *The New Palgrave Dictionary of Economics*, Editors Eatwell H, Milgate M and Newman P. London: Macmillan.

Winter SG. 2011. Problems at the foundation? Comments on Felin and Foss. *Journal of Institutional Economics*.

Winter SG. 2011. Purpose and progress in the theory of strategy: Comments on Gavetti. *Organization Science.*

Winter SG. 2012. Capabilities: Their origin and ancestry. *Journal of Management Studies* 49: 1402-1406.

CUT SECTIONS

Longo et al. (2012) a general argument is given by showing the difference between these two sciences in the analysis of invariant properties: random events (including quantum effects at the molecular level, DNA and sets of proteins, see Buiatti and Longo, 2013) change the very biological observables (organisms and phenotypes) and not just the quantities of pre-given observables (e.g., energy, momentum, number of particles), as in physics.

A second implication of our arguments focuses on the recent debates about the precise "nature" of entrepreneurial opportunities. Entrepreneurship scholars have debated whether opportunities exist objectively—as the notion of a landscape might suggest—or whether they are subjectively created (e.g., Alvarez and Barney, 2007; Alvarez, Barney, and Anderson, 2011; Venkataraman et al., 2012). Given our focus on the unprestatable nature of the phase space, we of course do not think that opportunities are necessarily "objective," if that means "pre-existing." But our argument suggests that opportunities are objective in the sense that they are poised, latent and possible, though yet to be enabled by novel interactions in the economic and biological sphere. In other words, opportunities are in some sense *there*, simply not actualized. Opportunities are not created ex nihilo. Some kind of latent, initial conditions are needed. Thus, for the purposes of this paper, the discovery-creation dichotomy is not directly relevant, as our specific emphasis is more on the problem of search and the poised nature of biological and entrepreneurial possibilities. We thus emphasize the unprestatable but possible nature of opportunities.

Though we have, in part, sought to steer clear of these debates about the subjectivity or objectivity of opportunity, what our arguments suggest is that entrepreneurs (and humans more generally) indeed solve the aforementioned frame problem, by finding novel uses, functionalities and possibilities. It might be that entrepreneurial alertness (Kirzner, 1978; Kirzner, 1982), judgment (Foss and Klein, 2011), entrepreneurial theorizing (Felin and Zenger, 2009) or any number of other factors play a role. Again, in this paper we do not directly address this issue, though we certainly hope that future work does. Our specific emphasis is on the more general indeterminacy of economic evolution given the vast, unprestatable directions that evolution can take due to poised and latent functionalities that exist at the nexus of organisms, their traits (both part and whole) and their niches and environments. Thus we have sought to steer clear of factors such as enactment, entrepreneurial determination and will, effectuation, inter-subjectivity, various forms of social construction and so forth (e.g., Alvarez and Barney, 2007; Sarasvathy, 2001; Venkataraman, et al., 2012). Rather, we offer alternative mechanisms, extending insights from biology into the realm of understanding entrepreneurial and economic activity.

The third implication of our arguments suggests the possibility of a more nuanced discussion of how organisms and contexts co-evolve, rather than pitting one explanation against the other. Our focus admittedly has been on the side of organisms and their possible development, but there is much room for models that clearly specify the respective roles of *both* organism and context. For example, extant debates in the organization and economic sciences about micro- versus macrofoundations might indeed be seen as debates about whether the organism or its environment ought to be the center of focus when explaining heterogeneous outcomes. This debate has recently manifest itself in many ways, specifically in discussions about whether individuals should be emphasized over collective and historical factors (e.g., Abell et al., 2008; Felin and Foss, 2011; Winter, 2012) and in recent debates about the importance of cognition versus "contextual factors" in the emergence of economic novelty and innovation (Gavetti, 2011; Winter, 2011). Of course all of these factors, the micro and the macro, play a role. Organisms bring with them various poised possibilities for development, as illustrated by our lungfish example and our discussion of the possible uses for a screwdriver, and these notions are readily extendable into the entrepreneurial realm. But entrepreneurial possibilities, just like biological ones, also depend on the context. To use a trivial example (building on common notions such as complementarities), the remote control is possible because of the pre-existent TV, pre-existent content, and people sitting and watching TV. The opportunity represents a confluence of organism- and environment-related factors: a complex mix of technologies, people and surroundings coming together. Remote controls of course were not a possible, poised niche two million years ago. Thus the factors associated with novelty represent a mix of bottom-up and top-down mechanisms, implicating multiple levels of analysis and different interacting forms of randomness, perhaps including quantum randomness, as in biology (mutations and molecular dynamics with somantic consequences). Teasing out the respective *contribution* of various organism and context-related factors of course represents a tall task. We hope that our arguments have added some nuance to this discussion, though admittedly there are many additional details to be worked out.

Our general arguments about the problematic nature of phase spaces and the emergence of novelty in nature have a number of implications for economic settings. Again, these are quite important as biological intuition has long been tightly linked with economics (Mayr, 1977; for a history of the extensive links between biology and economics, see Hodgson, 2005), for example, through theories such as evolutionary economics (Nelson and Winter, 1982) as well as in the more general efforts to unify the sciences through "generalized" Darwinism (Aldrich et al., 2008; Hodgson and Knudsen, 2011). Furthermore, landscapes are one of the central tools and metaphors utilized by scholars advancing new theories in the field of entrepreneurship and strategy (e.g., Gavetti, 2012).

Simon's early projects of the possibilities of artificial intelligence capture

The very notion of the frame problem of course touches on fundamental debates about the ability of artificial intelligence to match or even exceed the capability of human actors. We have taken one side of the debate. While advances in AI are evident, the frame problem looms large and is related to the problem of whether computers can be programmed to generate novelty.

We certainly recognize that we are stating one side of the argument, while many are optimistic about a ‘strong form’ of artificial intelligence (e.g., Buchanan, 2001). But machine intelligence cannot solve the problem of introducing novelty outside a system. As put by Block, “the machine has the intelligence of a toaster. All the intelligence it exhibits is that of its programmers” (1981: 21). For artificial intelligence it simply is not possible to bootstrap anything outside itself. As further noted by Lucas: “However complicated a machine we construct, it will, if it is a machine, correspond to a formal system, which in turn will be liable to the Gödel procedure for finding a formula unprovable-in-that-system. This formula the machine will be unable to produce as true, although a mind can see that it is true. And so the machine will not be an adequate model of the mind” (1961: 116). As a matter of fact, many interesting problems, even in physics and biology, may now be analyzed in terms of “incomputability” of the intended natural process. In physics, the mathematics of continua, in given phase spaces, makes the process intelligible (it displays its causal structure), but proves also its incomputability (see Longo, 2009; 2012).

The human mind itself of course might be thought of as a poised realm, scarcely deterministic (Kauffman, 2012). This admittedly is speculative, though the notion that the mind is generative has much support in fields such as psychology, linguistics, and philosophy (e.g., Block, 1980; Chomsky, 2003; Spelke et al., 1992). For example, we know that Skinnerian, behaviorist input-output models of learning, or the notion of the mind as a Turing machine, are grossly mis-specified. Rather, the human mind has remarkable generative capacities, as for example manifest in the use of language (Chomsky, 1959). Language indeed represents an analogue to the adjacent possible, that is, while the number of our alphabetic letters is delimited, the possible constructions of sense are infinite. As put by Humboldt, the mind makes “infinite use of finite means.” This indeed captures the very nature of much entrepreneurial activity and the generation of novelty. But the links between the mind and the emergence of novelty in economic settings certainly deserve additional attention.