The Evolution of Knowledge and Knowledge of Evolution

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Summary

Human knowledge is a human creation: we seek to make sense by creating patterns, which are tested in various ways and with differing degrees and kinds of rigour. For each individual cognition is a scarce resource, but different people can apply it in diverse ways and to diverse subjects: each application has its own range of convenience and its own dangers. Thus the growth of knowledge is an evolutionary process of trial and error, the rate and content of which depends on its organization, both conscious and unconscious. In seeking to develop knowledge methodological choices are unavoidable, but often unconscious. As Simon pointed out, all evolution, of life, economic and social systems, and ideas, depends on quasi-decomposability, the limits of which can never be fully anticipated. Thus uncertainty is inescapable – but it is a condition of innovation.

Introduction

I begin with some questions. How can each of us make sense of our situation? In particular, why do some things change while others do not, and why do they sometimes switch between these categories? How do changes come about? How can a single person comprehend systems which are necessarily far more complex than any single brain, and especially in human societies, such as economic systems, which function through the interaction of many brains? Indeed, is 'comprehend' an appropriate term? How can we understand, and do the ways in which we understand themselves change? How can we draw on ways of understanding which have been developed by other people? Since 'making sense' is an active process of imposing understanding, how do the ways in which we try to understand affect the content and quality of our understanding? Methodology is not an optional extra.

The twin foundational premises of this paper are, first, that our environment (and indeed the universe) exhibits multiple combinations of relative stability and change and, second, that there can be no procedure by which we can establish an understanding which can be proven to be permanently correct; the best we can hope for is an understanding based on conjectures which have been thoroughly tested, as Karl Popper argued. This seems to be generally agreed among scientists (see Ziman 1978, 2000b). We are therefore considering an overall process which is composed of many localized processes, and in which at any time there will be stable understandings, each of which we may choose to call an equilibrium – which must be a partial equilibrium. An obvious label for both overall and localized processes is evolution, broadly defined as the emergence of novelty, much of which quickly disappears, but some of which survives for varying lengths of time.

We shall take a closer look at this definition later. We may first observe that there are two immediately obvious applications of some notions of evolution to economics. One is what is now almost officially labelled evolutionary economics, and includes the study of change in both the content of goods and services and production processes and also in organizational forms and the processes of decision making, including concepts of business strategy. The other is the history of the subject itself, which also exhibits changes in subject-matter, technology and the modes of decision-making within the discipline. Understanding this history as an evolutionary process may be of value to contemporary evolutionary economists in two ways: it may be helpful to compare analytical techniques, and they may also gain some insight into the management of relationships with economists who do not think of themselves as evolutionary economists.

Unlike most modern politicians (and many economists) Winston Churchill believed in the value of a historical perspective; he claimed that 'the further back you look, the further ahead you can see'. In considering the prospects for evolutionary economics it should not seem perverse to look back at some features of the history of economics to observe what has helped and what has hindered the development of what can now be identified (if not precisely defined) as a significant field of both theoretical and empirical research. This will lead us to look further back to early attempts to make sense of the human environment, and eventually to the most distant past to see how a process which permitted the continuous emergence and selective consolidation of novelty, together with selective elimination of established phenomena and knowledge, could be possible.

1 The concept of knowledge

My point of entry is the observation that evolutionary economists are increasingly emphasizing the significance of the growth of human knowledge in the development of economic systems. This prompted the idea that improvements – or, more cautiously, changes – in our understanding of economic development may themselves serve as evidence about ways in which knowledge grows. I begin by noting that knowledge is a tricky concept for anyone seeking to produce a formal analysis. In his contribution to a volume which I recommend to evolutionary economists (Ziman 2000a), which was inspired by the simple analogy between technological innovation, with its 'many starters and very few finishers', and the ruthless selection between genetic mutations which is exhibited in biological evolution, James Fleck (2000: 248) seeks to explore 'the co-evolution of artefacts, knowledge and organization in technological innovation', but soon decides that a 'focus on knowledge makes the evolutionary problem very tough. It is very difficult to put boundaries around an idea' (Fleck 2000: 255); he therefore confines his analysis to the relationship between artefacts and activities. The obvious parallel in standard economics is the general exclusion of the concept of knowledge in favour of information, the significance of which is never in doubt (as in information theory) because it is defined against a closed set of possibilities. This exclusion of anything currently unthought of is essential to the strict notion of rational choice and the standard concept of efficiency, both of which demand logical deduction from precisely defined premises. However, as many scientists have observed, the creation of conceptions hitherto unthought of is crucial to the evolution of knowledge. Here is a nice example of the influence of method on concepts, which indicates why methodology may be of practical importance.

The inherent ambiguity of ideas certainly creates problems, which Fleck manages to avoid while still producing some useful knowledge, but it is crucial both to the growth of knowledge, within each individual and within groups, and to its application in economic systems, precisely because it provides the potential for novel connections. Indeed novel applications of knowledge are themselves major contributors to the growth of knowledge, and these are possible only because the boundaries of knowledge are not well defined. This continuous sequence of extending boundaries by making novel connections is the core of Penrose's (1959) account of how firms grow by finding new applications for their newly-developed capabilities and new opportunities for these new applications: exploiting these opportunities then creates new capabilities with their own ill-defined boundaries, thus facilitating the perception of new productive services which may generate ideas for new profit opportunities.

In order to develop this account Penrose took care (following Schumpeter's example) to locate it in a theoretical space that she clearly distinguished from the theory of the firm in microeconomics, in which all production possibilities and market opportunities are public knowledge. (It is not only in economics that the imposition of a strict boundary is a condition of successful theoretical innovation.) Microeconomic theory, as Coase (1972) pointed out, does not recognize firms as organizations – precisely because, as Coase (1937) argued, firms emerge as pools of resources with a potential range of applications in circumstances which cannot yet be specified, and are therefore unfit for price theory. They have accordingly been selected out, in a classic evolutionary process. Changing theoretical locations is a rather common phenomenon in the growth of both academic and business knowledge; and large-scale relocations are sometimes labelled paradigm shifts. Such relocations may cause trouble not only for theorists but also for many practitioners; and firms may have great – and sometimes fatal – difficulties when faced with structural changes of relevant knowledge in technology or markets. This has become a focus of empirical research in evolutionary economics – an open frontier.

Before we proceed any further, it is important to make clear that I am not suggesting that economics is a peculiar subject, or that economists are peculiar people. The point is that human knowledge is necessarily a human product and is therefore shaped by human characteristics. Let me cite a Nobel Prize Winner in the queen of the sciences, Werner Heisenberg.

> From the very start we are involved in the argument between nature and man in which science plays only a part, so that the common division of the world into subject and object, inner world and outer world, body and soul, is no longer adequate and leads us into difficulties. Thus even in science, *the object of research is no longer nature itself, but man's investigation of nature*.
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> (Heisenberg 1958: 58)

Even in physics, our knowledge is conditioned by the ways in which we attempt to develop it; and this is not simply a matter of the techniques that we use (though these are important) but of the fundamental, but not always explicit, assumptions that we make about the characteristics of the subject-matter, the questions to be posed and the kinds of answers that are considered to be acceptable. Contemporary physics would have been impossible without radical changes in these assumptions, and some further changes may be in prospect to help resolve current problems.

There are three fundamental obstacles to establishing an unquestionable basis for human knowledge. Two are strictly logical; but we may begin with a practical consideration which has clear logical implications. The human brain, for all its remarkable capabilities, is very small in relation to the contents of the universe – and even to the sum of the contents of all human brains; therefore it cannot simply absorb correct information, but must select, simplify and compress in order to construct knowledge. The substantial energy consumption of the brain presents a classic economic problem for any omnipotent designer of humans, a problem which is ignored in models of rational choice; Simon's insistence on the crucial theoretical importance of this ultimate scarce resource seems to be commonly rejected (if it is not ignored) as an advocacy of unrigorous theory. Scientists and philosophers of science, however, take Simon's view. In his Presidential address to the Royal Society of Edinburgh, Sir Michael Atiyah (2008) pointed out that even sight, which has conspicuous priority over our other senses, does not record or reproduce what is within the field of vision, but selects and excludes, thereby creating patterns; and some of these patterns are false. (For example, our very useful ability to judge distance by the apparent size of objects leaves us susceptible to illusions; but the exploitation of this susceptibility by painters using perspective has given us great art.) Atiyah emphasises that although some patterns – notably in mathematics – may have logical form they are created not by logic but by imagination; and he identifies the creation of new patterns which provide fresh insight – not by deduction but by imagination – as the mathematician's greatest delight. It has very recently been suggested that the even greater priority given to sight in Neanderthal brains fatally impeded the capacity for pattern-making which creates intelligence – which if true is a notable example of opportunity costs.

Even at the sensory level, our knowledge consists of created patterns; and though we have some ability to modify our mental operations we cannot simply override or replace them. As soon as one becomes sensitized to references to patterns one finds frequent citations of pattern-creation in descriptions of how we (or our brains) function in scientific enquiry, business and everyday life; and in all these spheres we then exploit the uncertain boundaries of application for these patterns which Fleck found so inconvenient. Moreover rules for the proper use of this ability to create patterns cannot be derived from unchallengeable first principles, although a search for foundations may be, and often has been, useful in providing guidance.

It is time to look back. The two logical difficulties in creating new knowledge were both identified by David Hume. First, although logic is invaluable in allowing us to derive conclusions from premises – some of them far from obvious without such systematic enquiry – we cannot deduce a novel theory from evidence because reason can never produce a new idea (Hume 1878: 164). (Atiyah is familiar with Hume's argument.) We may note that rational choice, as defined in economics, is a purely logical operation; indeed economists regularly deduce the actions of their theoretical subjects from the specification of their situation, although they believe that their own behaviour is not so strictly determined. (The psychologist George Kelly (1963) noted a similar contrast between psychologists' explanations of their own behaviour and their explanations of the behaviour of their human subjects.) Logic cannot produce innovation; patent law is quite clear about this. It follows, as Popper and Ziman have insisted, that the content of any particular innovation, in theory or technology, cannot be predicted, although we may have plausible, though fallible, reasons for expecting innovations of a particular kind within a particular field and at a particular time, unlike the context-independent mutations of genetics. Schumpeter and Penrose follow Smith in recognising the importance of context in the generation as well as the selection of innovations. When a new theory has been created, we encounter Hume's second difficulty. No evidence, however abundant and consistent, can establish the truth of any general proposition beyond doubt, simply because we can never prove that there are no undiscovered counterinstances (Hume 1875: 33).

Adam Smith, who we should remember had a close intellectual relationship with Hume, respected both propositions. In his 'History of Astronomy', which is essentially a history of the powerful motives and processes of pattern-creation and acceptance (and takes us much further back in human history), he observed that the evidence in favour of Newton's theory was so persuasive that he had himself been 'insensibly drawn in' to present its principles 'as if they were the real chains which Nature makes use of to bind together her several operations' (Smith [1795] 1980: 105). Nevertheless, he clearly states that, like all preceding theories, these principles were in fact the product of human imagination, and accepted so readily because of their appeal to the imagination of others. As he explicitly observes, they did not appeal to the imagination of those who objected that the postulated gravitational effects relied on action at a distance, for which Newton declined to offer any explanation, and which was disturbingly reminiscent of astrological influences. Smith therefore avoided Kant's great problem, which was simply this: how can we reconcile Hume's obviously correct proposition that the truth of Newton's theory cannot be proved with the inescapable conviction that the theory is true and irrefutable (Popper 1963: 190-191)? That Kant's attempt to resolve this problem resulted in a major contribution to philosophy is a reminder that false problems can stimulate the growth of knowledge.

2 Frameworks for knowledge

Human knowledge is a human creation, and is necessarily provisional. How it is created, the effects of the means of creation on its content, and the ways in which it is confirmed, modified or rejected are therefore worth attention, especially for those who are explicitly in the business of knowledge creation, testing and transmission, and even more especially for those who take the development and application of knowledge as a subject of study. We cannot avoid making methodological choices; and these choices have consequences.

To indicate both the generality of this problem and its potential importance I shall consider a spectacular example from another subject. Psychologists have often been worried about their scientific status; and between the wars they sought to emulate natural scientists by relying strictly on observation and experimentation. Psychology was to be the study of observable behaviour; and since mental processes were not observable they were to be excluded. What was left was the discovery of correlations between a class of actions and a class of preceding circumstances, without any investigation of the mechanisms by which these circumstances produced these actions – at a time when the search for the mechanisms which produced natural phenomena was the central preoccupation in theoretical physics. Psychologists nevertheless found it difficult to exclude causal language, notably in using such terms as stimulus and response which clearly imply causality.

An indication of the opportunity costs for psychology of this aberration can be found in the introduction by Heinrich Klüver, an eminent psychologist, to Friedrich Hayek's theory of the mind which, although published as *The Sensory Order* in 1952, was based on ideas formulated thirty years earlier. Hayek's first basic idea, in Klüver's words, is that 'sensory perception must be regarded as an act of classification. What we perceive are never unique properties of individual objects, but always only properties which the objects have in common with other objects. Perception is thus always an interpretation, the placing of something into one or several classes of objects' (Klüver, Introduction, in Hayek 1952: xviii). (This is a crucial principle for evolutionary economists.) How it is done is the second basic idea. 'The transmission of impulses from neuron to neuron within the nervous system ... is ... conceived as constituting the apparatus of classification' (Hayek 1952: 52); consequently '[t]he qualities which we attribute to the experienced objects are strictly speaking not properties of that object at all, but a set of relations by which our nervous system classifies them' (Hayek 1952: 143). Knowledge is constituted by selective connections. Thus even as psychologists were resolutely ignoring any explanation of the mental processes which connected the actions of their experimental subjects to some feature of their circumstances they were also failing to recognise that their own observations were powerfully influenced by their classification systems. Meanwhile Hayek was laying a foundation for neuroscience.

Why Hayek's theory matters for our study of the evolution of knowledge, and in particular of the significance of organization in both its development and its application, is the possibility of developing multiple classification systems in many fields, including academic communities and formal and informal organizations such as firms, as well as within individual brains. This perspective provides a basis for exploring both the sources of the ambiguities of which Fleck complained and also the potential which they offer for the growth of knowledge by the modification or replacement of familiar patterns – a domain-specific tendency to variation which produces evolution. Indeed Hayek's enquiry, which arose from his early studies in psychology, including the dissection of brains, was motivated precisely by his realisation that scientific progress had not deepened our knowledge of the sensory order but had created new forms of order by rearranging its elements on different principles. This extraordinary demonstration of the unintended consequences of intelligent enquiry may have had a more powerful influence on Hayek's views on the organization of human society than is commonly recognized.

As has been pointed out by others, the injunction to 'observe' is almost meaningless; the scientific tradition of requiring doctoral students to work with their professor is intended to habituate them to particular modes of observation that rely on particular classification systems which are believed to be appropriate to current problems in that particular field. This necessarily implies that many things will not be noticed; and the possibility that a few of them might be potentially significant creates occasional opportunities for those who have escaped or rejected the standard conditioning. Scientists create patterns which they find useful for their purposes – which are typically not the purposes which are reflected in the sensory patterns formed by the evolving brain. Explaining this disjunction was Hayek's motivation. The subject-matter of science is indeed man's investigation of nature, as Heisenberg wrote. This investigation is presumably enabled by the outcome of human evolution, but since it requires the creation of novel ideas it cannot be genetically determined, any more than the innovations of Penrosian firms.

The fundamental significance of multiple classification systems for human knowledge and for human action has been recognised by others. Two examples seem to be worth attention in the context of this paper. Perhaps the most striking, because it was developed at very nearly the same time as Hayek's psychological studies, is Frank Knight's (1921) analysis. Knight contrasted the simplicity of decision-making in a world of certainty, or even in a world of well-defined probability distributions, where no more was required than logical deduction from a closed data set, with the problem of making sense of a world which cannot be adequately represented in this way. He points out that only in an environment of uncertainty is there any role for profit, the firm, or entrepreneurship. We may observe that all three concepts are absent from general equilibrium systems – and necessarily so if these are to be internally consistent. Knight comments that if nothing more than deduction is required then automata will suffice; indeed anything more is a waste of scarce resources. His assessment may be directly applied to the subsequently-completed Walrasian model of an economy which is precisely governed by a complete array of contingent contracts, which (as Frank Hahn pointed out) must be in place before the economy opens.

Uncertainty – the impossibility of closing the system – is a precondition for the emergence of intelligence, which Knight implicitly regards as superior to rationality because it provides the context for it. To act intelligently we sort phenomena into categories according to some criterion of similarity which seems appropriate for our particular purpose. As Knight points out, there may be many different criteria which are appropriate for different purposes, and each should not be employed beyond its scope – the limits of which may not be obvious. This combination of multiple intersecting classification systems, each with an uncertain range of applications, explains the difficulty of putting boundaries round an idea which caused Fleck to make such a drastic revision to his own initial classification system. It also explains the potential for entrepreneurship, which transcends existing boundaries in order to create new combinations – a possibility which is excluded by a comprehensive and correct specification of everything.

Knight's principle of intelligent behaviour justifies the use of mutually incompatible frameworks for different problems, even within one field, and for ways of organizing both economic systems and fields of study (including the sciences) in ways that permit this – though it does not justify insouciance about such incompatibilities. Indeed it warns us that we may be led astray by using an inappropriate classification system, especially if it seems to have worked well hitherto: this has happened to many business enterprises, and also to many researchers in all fields of study. This is a major and, in my view, a necessary characteristic of evolutionary processes; I therefore believe that the analysis of such failures deserves more attention by evolutionary economists.

It is easy to see that this conception of classification systems, in which perceptions are linked to actions within particular domains, fits naturally into an analysis which is framed in terms of partial equilibria. It also supports a theory of development which rests on specialisation between domains and variation within each. Such was Alfred Marshall's theoretical system, and though the specific evidence of a conscious connection is quite modest it is easy to see – once Raffaelli (2003) had pointed it out – a correspondence between this theory and his early and elaborate formulation of a model in which 'machines' developed effective routines by forming domain-specific linkages between 'ideas of impressions' and 'ideas of action' by trial and error. In view of Marshall's attraction to Darwin's idea of evolution we may find especial interest in his conclusion that machines of identical design, placed in different environments, would develop different patterns of behaviour (Marshall 1994) – an idea to which we shall return. Marshall's model, which is remarkably elaborate, should not be conflated with Hayek's; but (in Knight's terminology) they are similar in certain respects which are relevant in the present context. What does deserve attention is that it produces an outcome which is crucial to Adam Smith's theory of development ([1776] 1976: 29): differences in human abilities are often the consequence rather than the cause of the division of labour. For Smith and Marshall, increasing return is not a property of a production function but a process which modifies production functions. The classic exposition is by Allyn Young (1928).

The second advocate of multiple frameworks I have chosen is the American psychologist George Kelly, who called this 'constructive alternativism'(Kelly 1963: 8). He was at least in part reacting against the conceptual basis and inadequate results of the behavioural psychology which we noted earlier. He observed that this implicitly treated psychologists and their experimental subjects as different species: the scientist, who possessed the skills and knowledge necessary to predict and control a class of phenomena, and other human organisms whose behaviour was governed by various impulses. Why not, he asked, give them equal status as people who are seeking to make sense by applying interpretative frameworks to their situations as they perceived them? (Kelly 1963: 5). He even suggested that experimental psychologists were implicitly challenging their subjects to discover the interpretative framework that was being used by the experimenter (Kelly 1963: 77). Rational choice theorists make a similar implicit claim to superiority over economic agents in their own ability to go beyond rationality and predictability by creating new models, which agents cannot be allowed to do if their behaviour is to be predictable.

Kelly (1963: 6-7) assumes that the universe exists by happening: what we have to study are processes by which we attempt to develop and apply our understanding of the particular small part of the universe in which each of us is located. These activities drive the evolution of knowledge, technology and organizational structures, all of which are constituted by classification systems with uncertain boundaries. For this to be possible, an essential condition is that, although the universe is a single system, so that every element is ultimately linked to every other element, these connections differ enormously in their strength and the time for the connections to take effect. For clinical psychologists, this created the possibility of changing the patients' behaviour in relation to many – though not all – features of their environment.

Kelly's conception has obvious similarities to Simon's ([1962] 1969) architecture of complexity (to which we shall return in the next-but-one section), not least in its implications for substantial but fallible intelligence. Both give extensive scope for the isolation of subsystems, with a warning that the serviceable patterns that we learn within a particular subsystem are always liable to be overridden because the isolation on which they depend may erode over time or be disrupted without warning. A direct implication for economists is that their analysable subsystems cannot be proper subsets of a general equilibrium system; our brains are incapable of formulating the correct full specification of such a system, and any specification that we impose may lead us astray. Partial, not general equilibrium, is the better basis for explaining how a complex system can work, and how it can break down (Raffaelli 2003).

Kelly's (1963: 9-11) fundamental proposition is that people (including scientists) invent patterns which they use to 'construe the replication of events'; they may differ in their criteria for a successful construction, and in their ability first to achieve and then to maintain it. Each theory has a limited range of convenience (including, as he is careful to point out, the theory which he is proposing), although these limits cannot be known; moreover it may be particularly effective in certain parts of this range. He argues that there are always, in principle, alternative construction systems which are conceivable – if not yet conceived; so if one pattern is no longer satisfactory, we can look for another. The gradual supersession of the sensory order by the physical order, for scientific purposes but not for most ordinary living, is perhaps the most pervasive illustration of this process.

Evolutionary economists may be particularly interested both in the process by which a new emphasis by well-established companies on innovation led some of them to make radical changes to their styles of management, and in the interpretation of their behaviour based on a conceptual distinction between 'mechanistic' and 'organic' systems which was developed by a sociologist in order to analyse their experiences (Burns/Stalker 1961).

The concept of 'constructive alternativism' was particularly relevant to Kelly's work as a clinical psychologist: the most effective form of treatment for patients might be to help them to look at things in a different way. This may also be the most effective way for a scientist or entrepreneur to resolve an intractable problem, as Smith demonstrated in his 'History of Astronomy'. As Kelly noted, however, patients may find it very difficult to amend a crucial part of a construction system if this is closely linked to another part which seems indispensable. This is not just a problem for patients. Smith noted it as a general human phenomenon, and it may be observed in major changes in scientific fields.

Organizations which rely on a closely-connected network of construction systems may likewise find it very hard to convert to another network even when it is obvious that the established pattern is no longer working. The conversion of Du Pont from a functional to a product-based structure was actually impeded by the directors' faith in contemporary organization theory. We should not be surprised that most organizations eventually disappear, or that reform of the financial system is so problematic. We might consider whether the dissolution of organizations should be made easier, as Drucker (1969: 293) seems to imply. It certainly seems worth considering whether any scheme for closer integration between complex systems to overcome frictions or failures risks generating problems far worse that those it is intended to resolve. These issues deserve more attention in industrial economics; evolutionary economists may provide it.

3 Construction systems in economics

Economists have often tried to emulate what they think are the principles and methods of science. In the 1930s and 1940s one of the manifestations of this desire was the attempt to maintain a clear distinction between positive and normative reasoning, and in particular to produce policy advice which avoided any value judgements. Greater attention to logic would have been helpful here. What were proclaimed at the time as major products of this endeavour were the twin foundational propositions of welfare economics: every perfectly competitive equilibrium is a Pareto optimum, and every Pareto optimum can be realised by a perfectly competitive equilibrium. Of course, these propositions relate simply to allocative efficiency, and explicitly exclude any consideration of wealth or income distribution, which requires value judgements. They also exclude any consideration of the effects of different forms of economic organization on the prospects of enlarging the possibility set – and necessarily so, for the process of innovation is incompatible with perfect competition.

The unfortunate consequences of closed-system reasoning may be clearly displayed in an observation by Paul Samuelson, perhaps the cleverest economist of the twentieth century, and who was certainly capable of good sense on some occasions. 'Increasing returns is the enemy of perfect competition. And therefore it is the enemy of the optimality conditions that perfect competition can ensure' (Samuelson 1967: 39). Samuelson's logic is correct: but the perception of increasing returns as a threat to an obviously desirable state of affairs is simply a consequence of the desire of economists, like psychologists in the interwar years, to attain a supposedly scientific precision – in contrast to the often-lamented imprecision of Alfred Marshall. (It is an ironic comment on the notion of scientific precision that the liberation of economics from psychology by developing a pure logic of choice coincided quite closely with the psychologists' search for scientific precision by excluding the concept of choice from their theories of behaviour.) The powerful effects of highly focussed ways of developing a theoretical system which is often presented as a realisation of the insights of Adam Smith included the total disregard of Smith's exposition of the welfare gains that could be delivered by organizational arrangements which promoted the growth of knowledge. As George Richardson (1975: 353) observed, this exaltation of perfect competition 'might reasonably be regarded as a denial of Smith's central principle erected into a system of political economy'.

How did this happen? Whereas most economists and most psychologists through much of the last century sought to avoid the contamination of their systems by mental and emotional processes (with Schumpeter's theory of economic development as a notable exception), Smith had incorporated these processes both into his theory of the growth of knowledge (Smith [1795] 1980), which has obvious resemblances to both Knight's and Kelly's ideas about the construction of domain-appropriate systems, and also into his theory of human interaction. The latter included the readiness to adopt apparently successful practices without understanding why they were successful (Smith [1759] 1976a); this powerful cognitive economy permitted far more rapid diffusion than is possible by the inheritance of superior genetic material.

Smith's ([1776] 1976b) theoretical system explained how the division of labour fostered the development of new knowledge, which promoted economic growth and the development of new markets; these then created opportunities for further division of labour. This is economic dynamics, as subsequently developed by Penrose, and Smith gave considerable thought to its organization and stability. Marshall adopted Smith's conception, and supplied a definition of 'increasing returns' which explicitly included changes in organization (Marshall 1920: 318). Allyn Young (1928) subsequently provided the classic exposition of increasing returns, in Marshall's sense, as the key to economic progress. Different ways of organizing activities change the boundaries of existing ideas and so may generate different ideas, some of which can be realized only by further organizational change, which may produce additional ideas – as in Penrose's sequence. This combination has an obvious counterpart in evolutionary biology, but differs in combining chance discoveries with conscious thought and direction.

An essential feature of this theoretical system is that the activities of economic agents change the data of the economy, often in ways which cannot in principle be predicted because they rely on novel classifications and novel connections between them. That scientific discovery is likewise unpredictable, for the same reason, has been argued by Popper, by John Ziman (1978, 2000b) and with abundant illustrations in a lecture by Sir John Meurig Thomas (2007). This process is indeed, as Samuelson declared, the enemy of both perfect competition and the supposedly scientific welfare ideal; but it has a natural home in an economics whose 'central idea ...even when its Foundations alone are under discussion, must be that of 'living force and movement' (Marshall 1920: xv) – which is Smith's perspective. To preserve the particular concept of equilibrium which had been developed in the process of providing a theoretical solution to the intellectual problem of co-ordination in a fully-specified economy, increasing returns can be no more than a property of an unchanging production function.

Whereas Smith and Marshall wished to encompass co-ordination and development within a single theoretical system, subsequent economists practised a division of labour between the two, concentrating first on the relatively straightforward co-ordination problem but without realising how difficult their method of dealing with that problem would make it to incorporate economic development within their theoretical structure. The problem is illustrated by what is probably the greatest intellectual achievement of this research programme, the completion of the Walrasian model by defining goods not only by their intrinsic properties but also by their location, date, and the state of the world at that date, in order to allow every agent to optimise with respect to all possible futures. The equilibrium of such a system already incorporates not only everything that might happen but also whenever and wherever it might happen. This is essential to the internal consistency of the model; if all agents are to make rational choices there can be no ambiguity and no surprises. Agents are equipped with well-specified preference functions and probability distributions over all contingencies for every date; but they cannot modify the range and certainly must never conceive a new idea. (As is rarely made explicit, the model must also incorporate all agents who will be active at all future dates.) Within this theoretical system what Schumpeter called development from within the economic system is therefore strictly unthinkable.

Schumpeter's own response to the inherent limitations of this intellectual programme (which he admired as an intellectual achievement) was to perceive them as a productive opportunity for himself. By ignoring the orthodox concern with efficiency and optimality which he (like Smith and Marshall) thought were ultimately of less importance than growth through innovation, and the methods of marginal analysis which seemed appropriate for that concern, he was free to explore the importance of system disruption, which was inherently unpredictable by economic agents or economic analysts because it resulted from novel conceptions. Almost as a side-issue, he commented that although rational choice was always a fiction it was a good predictor precisely when people were not consciously choosing at all, but following routines which had proved suitable for familiar contingencies (Schumpeter 1934: 80). What is interesting from our present perspective is that this interpretation of orderly behaviour is a close match to the psychologists' orthodoxy that we noted earlier. Rational choice as defined in orthodox economics is a purely logical operation, and therefore, in Niels Bohr's judgement, excludes thinking (Frisch 1979: 95), as did the psychologists' model. But as Schumpeter realised, the predominance of routine behaviour within an economic system was necessary to provide the reliable data for entrepreneurial planning. That for each individual, the predominance of established connections within the brain was necessary to release cognitive capacity for search was a crucial feature of Marshall's (1994) early model of the brain. What if Schumpeter had known of this model?

4 The precondition of evolution

The central paradox in the development of human knowledge was stated by Hayek (1952: 185): 'any apparatus of classification must possess a structure of a higher degree of complexity than is possessed by the objects which it classifies'. We have noted earlier that the human brain cannot match the complexity of its visual environment despite the high priority which this receives, but has to impose its own fallible order within boundaries which are inherently unknowable. We then observed that human knowledge has grown by the imposition of a great variety of created patterns on many phenomena – some of which may even be constituted as phenomena by the patterns that we impose. We should not be surprised that this highly disaggregated structure of knowledge sometimes fails us; the problem is why it should ever succeed? Indeed in respect of economic systems the authorised wisdom is that only a single comprehensive model can be relied on. Unfortunately for this view, no single comprehensive model can be contained within a human brain.

The answer to this puzzle was provided by Herbert Simon ([1962] 1969): what we can hope to understand, at least to a useful degree, are quasi-decomposable systems. In coping with a multi-level system we can, most of the time, make progress by focussing on the interactions at one level, provided that this level interacts with the level above predominantly as a unit and not through its component elements, and that each of these component elements also functions within this system predominantly as a unity, even though this unity is the product of interactions between its own constituent elements. Simon not only argued that the assumption of quasi-decomposability was a precondition of human knowledge, but that the very existence of a complex universe was overwhelming evidence for its quasi-decomposability – simply because if every element were directly connected to every other, then failure anywhere within the system could precipitate collapse. He illustrated his argument with the fable of two watchmakers, whose work was frequently interrupted: the one with the modular design prospered while the one with an intricate network of connections did not.

Simon's argument is neatly counterpointed by that of the highly-distinguished French zoologist and palaeontologist Georges Cuvier (1769–1832), a pioneer in the study of fossils. He argued that since every species was a fully-integrated system, there was no possibility of any modification; therefore any shock which disrupted its relationship with its environment led to extinction, as was evidenced by the extensive fossil record of failed species. The evolution of species was simply impossible. In seeking to develop a coherent model of general equilibrium economists have replicated Cuvier's argument, which inevitably leads to the same conclusion: because all future possibilities must be incorporated in a single general equilibrium, no future adjustment can be permitted. I believe that we should assert clearly that the first principle of any evolutionary theory is that evolution requires decomposability.

That this is true both for the organization of scientific enquiry and for the possibility of developing viable theories about scientific phenomena is emphasised by Ziman (2000b: 326): 'The assembly of primary entities into more or less distinct compound entities that can interact as wholes ... makes scientific research possible'. It also makes new knowledge unpredictable.

I next wish to emphasise that, by Simon's argument, the evolutionary process which we attempt to study started with the origins of the universe. Fortunately his argument also assures us that we do not need to be professional physicists, chemists and biologists before we are fit to study evolutionary economics. Biological evolution is a relatively late example, and it requires not only substantial – though not total – independence of the particular activities of biological organisms from the details of their chemical structure, but also substantial independence of chemical compounds from the atomic structure of their elements.

It is quasi-decomposability which makes pattern recognition and pattern creation possible, and these are deeply embedded in scientific practice (Ziman 2000b: 120). Within economic systems the principle of quasi-decomposability allows the development of locallyappropriate construction systems at three levels: within individual brains, among people engaged in similar activities as members of different organizations (exemplified in Marshall's comments on the value of industrial districts in securing and diffusing the benefits of the tendency to variation among firms in the same trade), and between different trades, including the different occupations to be found in any large organization. The particular arrangements which may be necessary to cope with the limits to decomposability imposed by the need to co-ordinate activities which, though dissimilar, are nevertheless closely complementary, have been examined by Richardson (1972). The development of knowledge within Penrosian firms is both driven by and drives the schemes of decomposition and the (usually sparse) connections between them.

Though that principle entails a rejection of general equilibrium thinking, it does not require the rejection of equilibrium in its literal sense of balance: this may be observed in any pattern and procedure which is in regular use. However, what distinguishes this class of equilibria from the conventional concept of a relationship between agents from which none of them has an incentive to depart, is that each equilibrium is maintained by a continuing process. As Kelly argued, the world exists by happening, and so does each of the classification systems that Hayek, Knight and Kelly have written about. When a previously satisfactory process is perceived to have become less successful there is a natural stimulus for insiders or outsiders to imagine ways to modify or replace it. However, because cognition is such a scarce resource, as Hayek and Simon have highlighted in very different (but perhaps complementary) ways, modification or replacement, even within a substantially decomposed system, can receive adequate attention only if most systems are working effectively. Increasing claims on cognitive resources and reduced decomposability can interact with disastrous effect.

Because of the factors which permit the development of knowledge, and of economic systems which both produce and use knowledge, systemic breakdown is always a possibility, for individuals and for groups. The evidence is in history and in the present. General equilibrium theorists are right to claim that without such an equilibrium we cannot guarantee that there will be no disorder. Evolutionary economists should not disagree. However they can claim that within such an equilibrium there can be no evolution. What they should perhaps add is that the potential for large-scale breakdowns can probably be reduced by preserving both decomposability and variety within the components of the economic system and the systems of knowledge.

5 Frontiers

I do not think it would be helpful to propose a comprehensive programme for evolutionary economics in the next twenty or thirty years, for reasons which may be deduced from this paper; but I can suggest some topics and ways of thinking which I believe deserve some emphasis.

One topic which I believe has now been sufficiently discussed is 'Universal Darwinism'. However there has been a fairly recent development in understanding the role of genes which is worth some attention: an evidence-based critique of genetic determinism which proposed 'one-to-one relationships between specific genes (or specific sets of genes) and complex higher level behaviours like altruism, aggression, intelligence, spatial cognition, or language' (Karmiloff-Smith 2000: 526). This principle, which had been repeatedly endorsed by Steven Pinker, was judged sufficiently misleading to become the theme of the Special Lecture to mark the centenary of the British Psychological Society, delivered by Annette Karmiloff-Smith, who drew on her own and others' clinical experience.

A key exhibit in this critique was the Williams syndrome, a genetic disorder which involves the deletion of 17 genes and is strongly associated with a particular set of effects. However, among these effects are 'atypical interactions between brain regions. The WS brain is not a normal brain with parts intact and parts impaired' (Karmiloff-Smith 2002: 528). Karmiloff-Smith focuses on the contrast between the severe impairment of spatial skills and the apparently preserved skills in facial recognition, from which Pinker deduced that the Williams syndrome has no effect on facial recognition. However, detailed study of patients clearly demonstrated that their facial recognition was based not on the normal method of recognising configurations but on scanning individual features, a process which has been definitively associated with other elements of the brain. We may pause to note, first that configuration (pattern-recognition) is a lower-cost method, but with two opportunity costs: substantial difficulties in providing a detailed description even of a familiar face (we know it when we see it), and in recognising inverted faces, for which identification by feature is the standard procedure.

Karmiloff-Smith's general argument, developed in this lecture with a range of evidence, is that at least a significant proportion of the genes which guide the development of the human brain are carriers of what students of Penrose would call capabilities, the particular application of which is influenced by the environment. Therefore we need to study 'how genes are expressed *through development*' (Karmiloff-Smith (2001: 540) – like capabilities.

Of particular significance for our purpose is her contrast between the initial alternative possibilities in an infant brain and the often-formidable difficulties of reconfiguring a well-established cognitive procedure. We may note a similar contrast in leaf-cutter ants, in which there are sharp distinctions in both size and behaviour between soldiers, large workers who are foragers, and small workers who feed the infants. Since these are all sisters, the differences cannot be innate; they are produced by differences in the length of the feeding period. Here too the genetic material provides a range of possibilities, but the outcomes of development are not reversible. This principle of specialised applications of genetic potential seems to explain Adam Smith's observation that 'the very different genius which appears to distinguish men of different professions, when grown up to maturity, is not upon many occasions so much the cause, as the effect of the division of labour' (Smith ([1776] 1976: 28). It is crucially important for both economic and scientific development that these differences between people, unlike the differences produced by the differentiated rearing of leafcutter ants, are not embodied in narrowly-defined routines; nevertheless (as Smith recognised) it is typically much more difficult, even for economists, to make a substantial change to skill sets, or ways of thinking, than to acquire the first skill.

This view of the role of genes reinforces the argument that the familiar Darwinian principle which denies any influence of the selection environment on the characteristics of genetic mutation, in contrast to its influence on the survival of mutations, is not especially relevant to evolutionary economics. Of much greater importance is a cluster of propositions about environmental influences. First, the perception of problems or opportunities motivates search; second, this perception deserves an explanation in each specific case; third, search will be undertaken only if someone can both conceive and implement a research strategy; and finally, the outcome of this search is necessarily unpredictable. Almost all ideas fail to work; outright failure is common (especially at the individual level), and quite often a new discovery is irrelevant to the search objective. The prime result of a research programme precisely targeted on the discovery of pesticides which were both highly specific and persistent was the discovery of one which is universal but inactivated by contact with the soil. This changed the role of research targets within the company.

Since the overwhelming impression of our universe is diversity, I believe we should not seek to be very prescriptive about the future of evolutionary economics. However I suggest that the concept of organization should be central, because not only is knowledge itself an organizational phenomenon, its development is substantially influenced by its organizational setting – in both the internal structure and external relationships of firms and research institutes, and by institutions both in the sense of formal entities and as sets of standard practices, all of which economise human cognition and influence its application. This proposition is summarised in what may be thought the most important pair of sentences in Marshall's *Principles*, on the crucial roles of knowledge and the multiple forms of organization which shape its development (Marshall 1920: 138). Organization is ubiquitous (Loasby 2007).

My final proposition is that evolutionary economists should recognise the fundamental twin contributions to thinking about their subject which have been provided by Herbert Simon. Cognition must be recognised as the most crucial of all scarce resources, both for the allocation of their own capabilities and as a research topic; and the exploitation of quasi-decomposability, both in their field of enquiry and in their discipline, is the key both to the organisation of their studies and to the understanding of their subject. These are the keys to man's investigation of nature, and to the investigation of economic systems.

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