2 Evolutionary dynamics in revolutionary times

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1 Diachronic profile of biological evolution

In a highly influential text with the intriguing title "What is Life?" (1944), the physicist Erwin Schrödinger tried to provide the sketch of an answer to a question that had puzzled him for quite some time. After the breathtaking progress in theoretical physics in the first decades of the twentieth century, the notion of time was still entering theory only via the second law of thermodynamics, which described a continuous, though stochastic, global increase of entropy – while the evolution of all kinds of living systems is characterized by an decrease in entropy. The two countervailing forces – one towards disorder, the other embedded in it and moving towards the build-up of order – are clearly coupled in the notion of a *stochastic* relationship. Indeed, it was the genius of Ludwig Boltzmann, who several decades earlier had simultaneously developed (advanced) probability theory and a theory of physical processes (the connection between randomly moving microparticles and stochastic laws governing observed aggregates). Schrödinger's courageous turn was to look at what happens in the physical processes of living matter to decrypt the apparent theoretical contradiction. To do so, it was necessary to step down to the smallest scales at which observation was possible: Schrödinger's text was a catalyst for microbiology. There, at the level of atoms and the even smaller units and processes they consist of, a completely new world had appeared: the world of quantum electrodynamics. It had been difficult to reconcile the opposing concepts found there: continuity versus discreteness;[1] particle versus wave; determinate causality versus stochastic openness; etc. Schrödinger considered the build-up of structure in non-living crystals,[2] and concluded that an additional twist – some aperiodic element – had to be present to distinguish the too repetitive growth of crystalline structures from the growing life forms. Some kind of "quantum jump" of endogenously induced deep restructuring seems to be present in living systems, a first hint of the necessity to model alternating (*at least two*) different dynamics to grasp the evolution of living forms.

But the focus on extremely small scales in the spatial dimension to discover the primate of discreteness as well as the stochastic nature of all macro-level laws also implied that the capacity of life forms to use such laws to propagate their own structure was only possible for organisms consisting of an enormous number of atoms in the spatial dimension. The conservation of living structure generally proceeds with an increase in size in space and an increase in consciousness. *Time* is the central concept that encompasses the emergence of consciousness in living systems.[3] Again, consideration of the extreme long-run evolution of living systems can help in the discovery of an underlying diachronic profile. First, it is straightforward that the stochastically occurring episodes of decreasing entropy during the long-run increase in entropy of the universe – i.e. living entities – are characterized by birth and death. In the end, each physical carrier system has to surrender to the second law of thermodynamics, while the birth of consciousness, located at an extremely small new physical nucleus, refers to the mysterious quantum jump that enables life as a species. It is the division of the species into independent physical entities that allows it to live longer than any individual member. The role of the concept of species is therefore central to an understanding of the evolution of life, despite the confusion that currently still obscures the theoretical discourse on this notion. A species is the mediating element, which on one side is the enduring frame for the evolution of its members, while on the other it assumes the role of an individual unit that is in turn conditioned by the evolution of other species, as well as by the non-living environment. A grand theory of evolution,[4] therefore, would address the historic development of the sequence of species. Charles Darwin, in the title of his famous book, tried to highlight the blind spot in this story: the *origin* of species. Based on his own empirical research, Darwin considers the framing environmental conditions to be the cause for the properties of a species. From Darwin's perspective, during the lifetime of a species its set of properties is *regulated*, even determined, by its more or less constant environment.[5] While this was a radically progressive opinion in a time when Christian ideology dominated social life, it was necessarily rather vague with respect to the "quantum jumps" that must have led from one species to the next. This, of course, is another aspect of origin: a species does not only originate in the stabilizing feedbacks that the environment produces in a population (basically a stable growth process, which can be called a "fast process" for a given stabilizing "regime"). At the beginning of a regime, new species emerge as the result of a much shorter process; their origin (in this second meaning) is thus to be found in the "revolutionary dynamics" following the far-reaching extinction of other species or a natural catastrophe. An often-cited example is the Cambrian revolution, which has clearly led to an enormous variety of species, which was only reduced by Darwinian selection processes to fewer species in a later stabilizing phase. These survivors had origins in both their original emergence and their superior survival feedbacks.

The evolution of different species needs much more refinement, therefore, and not just a simple variation-test mechanism.[6] A historically observed sequence of species, each defined by the stabilizing mechanism of a sequence of environments, only shifts the question of origin to the question of the reasons for shifts in the environment. For non-living environments this boils down to the assumption of a sequence of natural catastrophes, which in modern mainstream economics are bluntly called exogenous shocks. Darwin actually wanted to reveal an even more important issue as well: that newer species can be described as derived from earlier species. And this is exactly where the second meaning of "origin" has its place: the border between two different species in a sequence of the same timeline – what makes them distinguishable – is not just an instantaneous mutation, a point where the old species vanishes and the new one starts. Rather, it is a short process, which transforms *essential* elements of the old species and changes the main direction of its overall dynamics (see Figure 2.1). The newly emerged species after this short period of revolutionary transformation still carries some marks of earlier species, but new combinations of such older elements also enable a large set of qualitatively new features.[7]

The new dimension along which the stabilized growth of the new species develops differs visibly from that of the older species, though some material indices, like the size of population of species members, might be common (measured on the vertical axis in Figure 2.1). The two dice indicating the black box of revolutionary dynamics seems to not yet to have received appropriate attention from biologists. The search for some common features among these black boxes encounters similar problems as the search for general rules in innovation economics. Since Darwin's time, the path-breaking successes of microbiology have reallocated the properties characterizing a species (based now on the concept of genomes) to extremely small entities. And there, at the level of atoms, natural science has discovered two exciting facts: (1) The fundamental role of randomness; and (2) the unavoidable interdependence between the object of investigation and the scientific observer.[8] So far, these discoveries have not resulted in a convincing theory about the revolutionary dynamics generating a new species. To assume randomness only is a confession of (preliminary)

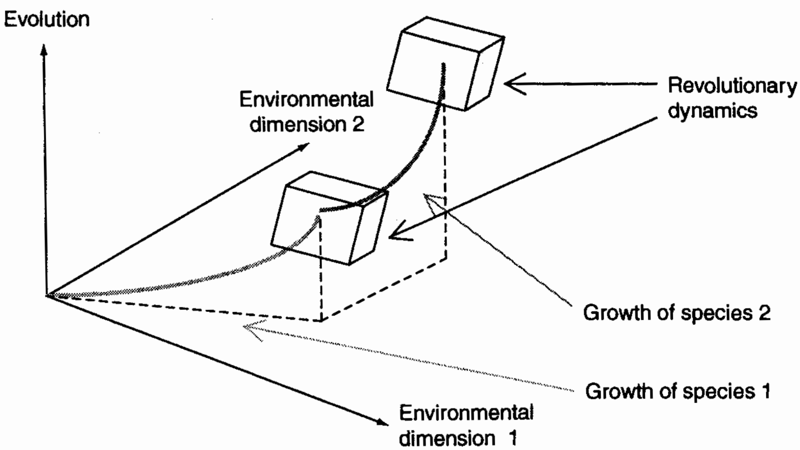

Figure 2.1 Evolution of species.

ignorance about the intermitting revolutionary dynamics, which is needed to understand the evolution of species.

How these revolutionary dynamics could be understood remained completely unexplained in Darwin's "survival of the fittest" argument. Indeed, Darwin had copied the latter expression from Malthus, an economist who was famous for the formulation of dynamic forces in capitalism that stabilize the real wage of workers at the lowest possible level. Darwin was not particularly explicit on the human species and political economy; he seems to have been rather intimidated by the conservative forces of his time. But he had started to describe a pattern for the evolution of life forms, which in the mid-nineteenth century had actually been in the air for some time already (see Figure 2.2). For each line of development in a sequence of species, the behaviour during that stage was connected to a set of exogenously fixed elements, which limited and were safeguarded by the fast adaption processes of the respective species. The border between species was drawn by sudden, mostly unexplained changes (revolutions) in the set of these limiting exogenous variables. In each new stage, (partially) different fast adaption processes were emerging. Looking at the sequence of changes in exogenously fixed variables, their movement can be described as a slow dynamics (shown by vertical arrows). Any evolutionary theory thus has to comprise at least two different speeds, to allow for the alternation between longer periods of relative stability and a perspective on long-run "tectonic" shifts in the overall system.

One of Darwin's contemporaries, Karl Marx, had presented an analogous scheme, for the evolution of the human species only.[9] According to Marx, the history of human societies can be understood as a sequence of modes of production. Each mode of production can be described as a relatively stable ensemble of production techniques and their encompassing cultural (sometimes called "institutional") and ideological frameworks. And Marx did lay emphasis on the revolutionary periods in the history of the species: he called them the "fast trains of history"! Moreover, Karl Marx had adopted and in a certain sense "inverted" the dialectical logic of his early teacher Hegel, which implied that he interpreted an observed historical sequence as a chain of sequentially solved (revolutionarily solved) contradictions. During each stage of relative stability a set of contradictions is slowly

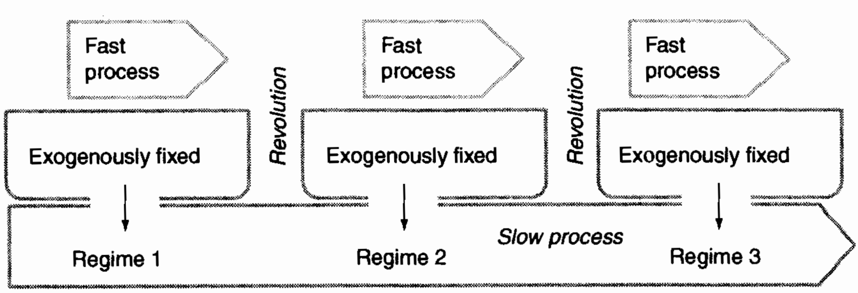

Figure 2.2 Typical profile of life dynamics.

building up. Some of the less severe contradictions can be solved without a change of regime, but a few get deeper and deeper until the final break in a short revolutionary process.[10]

The next revolutionary break, from capitalism to communism, was already approaching in Marx's view. In fact, some 30 years after his death it took the First World War finally to sweep away feudalism in the most advanced capitalist countries. The end of capitalism was postponed. A look back at the development of capitalism after the Second World War does suggest that capitalism should itself be divided into three distinct stages: merchant capitalism; industrial capitalism; and integrated capitalism (see Hanappi 1986, 1989, for a more detailed periodization of capitalism). In each of these stages some medium-sized contradictions build up, which then lead to a new type of capitalist sub-form that will integrate them. It is not surprising that Figure 2.2, in a Marxian interpretation, looks a bit more specific (see Figure 2.3).

The fast processes in this scheme are now the typical economic processes that a certain political regime needs and regulates to maintain its own stability. As a necessary ingredient of these economic processes a variety of contradictions occur, some of them typically named "externalities" in mainstream economics. The selection of contradictions, and the production of a variety of additional contradictions during a certain stage, is itself an evolutionary process: this results in an accumulating avalanche, which finally produces a revolutionary dynamics. To achieve this, it is necessary that processes be selected that can remain hidden from the ideologically biased eyes of the guardians of the prevailing regime. If they fail to detect the danger to their regime as a result of their own specific blindness – they are convinced of the ideology they spread – until the last moment, then the quick changes will take them by surprise. This description may serve as a starting point for a future discussion of short-run revolutionary dynamics; it will be continued in the next section of this chapter.

Another property that leads directly to questions of methodology is the finite fractal structure of evolutionary theory. As briefly mentioned above, commodity-producing societies consist of a sequence of modes of production; each mode of production is further structured into a sequence of stages (e.g. capitalism consists

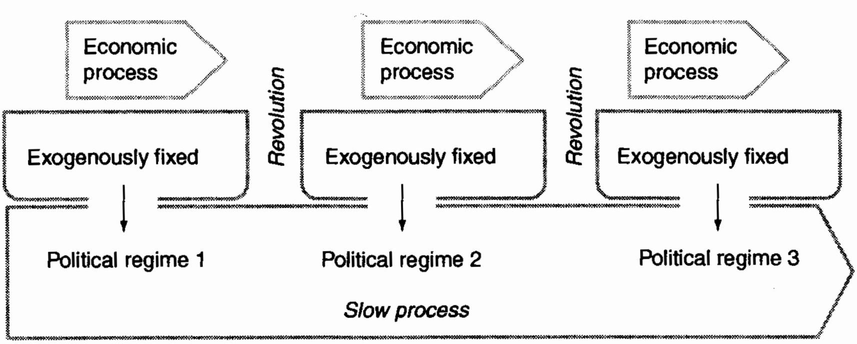

Figure 2.3 Profile of social dynamics of the human species.

of merchant capitalism, industrial capitalism and integrated capitalism), of which each one can be further taken apart. At each level of this structure, self-similarity with higher levels as well as with lower levels can be detected, e.g. the sequence of the build-up of contradictions that leads to revolutionary dynamics, or the self-stabilizing mechanisms (institutions) that guarantee an increase in times of a dominant species. The immediate theoretical consequences are the production of a taxonomy of species, a family tree and, for historians of the human society, the need to define progress against a background of endless, repeating, self-similar templates. This is reminscent of Schrödinger's problem of "aperiodic crystals": somehow, structure is preserved, but not in a too regular way. Hegel – influencing Marx – had a similar idea some hundred years earlier and expressed it using the double meaning of the German word "*aufheben*": it means saving something from the past but also erasing the past stage. The really difficult question, which cannot be solved by assigning names to it, is what actually happens in the short revolutionary periods when this "inversion" takes place. Historians so far seem only able to point at case studies, a necessary but insufficient starting point from which to open the black box.

A last lesson that can be learned from the history of the economic contemplation of human evolution over the last 300 years is the long-run swing in focus. It led from a dominance of national dynamics (already found in Quesnay's work) to a dominance of arguments concerning human individuality (the high times of the classical marginalist school, starting in 1874, and their rather anachronistic contemporary trailers in microeconomics), and more recently back to the possible hegemony of a macroeconomics that appears to be mirrored predominantly in most internally used models of microeconomic and mesoeconomic entities. Note that this long swing is *not* a swing in economic activity itself (e.g. a Kondratieff cycle); it is a swing in the history of economic thought. A possible explanation for the observed evolution is the following argument: first, during late feudalism, ordinary households and production units had so little to decide that the grand aggregates of a national economy, mainly based on agricultural dynamics, appeared as a natural macroprocess. During the first half of the nineteenth century, industrial capitalism made it increasingly difficult for social scientists to accept a naturalistic point of view. Class dynamics became all too visible: Malthus tried to find a taming "natural law" by formulating his "eternal law of wages"; Ricardo favoured the productivity-enhancing capitalist class over feudal landlords; Marx even saw a final victory for the working class. Instead of an amorphous grey mass lying below the ruling feudal nobility, the new generation of classical political scientists distinguished interdependent classes within a population. Moreover, this new setting induced scientists to declare their own positions; they more or less consciously became part of the dynamics they were describing. More generally, there emerged a confusing situation in which the observer of social dynamics could not escape from realizing that he was also one of the observed. When the surge of the French Enlightenment that resulted in the bourgeois revolution finally broke down in 1848, classical political economy followed its downturn with a lag of 26 years: in 1874 the theories of Léon Walras, William Stanley Jevons and Carl Menger seemingly freed economics from its recently acquired political component. Like mechanics, it was conceptualized as a politically neutral formal description of the interaction of the smallest "natural" elements: human individuals. As a matter of fact, such a perspective was well suited to the new coalition between a feudal and bourgeois class, the latter being allowed to run its capitalist business for the price of financing the former, which remained political ruler of last resort. This stabilized compromise prevailed until the First World War. The ideology it implied was a combination of the church's moderately decreasing influence, on the one hand, and on the other a politically tranquilizing introduction of metaphors taken from the natural sciences (mechanics of human individuals), in place of class analysis. An important lesson to be drawn from the period 1848 to 1918 is that ideology production can be efficient precisely because it provides *inadequate* mirror images of social dynamics, thereby helping to freeze the current status and thus helping the currently powerful classes. In the previous period, certain classes' social consciousness had been enhanced by *their* social theorists, who were catalysers of consciousness because they tried to provide an adequate picture of what was going on. Towards the end of the nineteenth century an inverted situation emerged: producing more inadequate models – preferably by using formal tools, making it more difficult to detect inadequacy – proved to be a more convenient way to absorb critical scholars and prevent them from stirring up class dynamics. This was the starting point for a new elite of social scientists who were safe in their ivory tower. They were safe in a double sense: they would do no harm to the prevailing power relations; and they themselves could feel safe because they were financed by the classes in power, substituting in that respect the fading role of the church.

With the First World War, the forces of the material world driven by capitalism outside the ivory tower ended the old constellation. But again it took some time, from 1918 to 1936, till John Maynard Keynes gave mainstream economics a new twist by pointing at an alternative framework that would save capitalism from being swept away by its own dynamics. The way Keynes chose to shift the focus of economic theory from microeconomics to macroeconomics is more interesting than most of the content of his texts. Keynes never did produce a mathematical model of his "general theory"; he preferred to use everyday language, brilliant in style but necessarily riddled with ambiguities.[11] In the face of unbelievably high disequilibrium in all markets and exploding unemployment during the Great Depression, the mathematical apparatus on which mainstream economics was based had lost its charm, still being based on the principle of considering only equilibrium positions. In other words, it ostensibly declared itself impotent concerning economic policy in times of crisis; it only covered economic policy issues when they were not needed (in general institution-free and frictionless equilibrium), and therefore concluded – what a surprise! – that public policy intervention is not appreciated. Keynes, the politician, saw that the hegemony of the capitalist class was in danger, and that using an abstract mathematical framework to study the interactions of individuals' optimal rational decision making was just cheap talk in this situation. Parallel to the fraction of mainstream economists in the microeconomic ivory tower, the ruling class needed a second fraction of economists, able to restore a sufficiently stable exploitation regime with the help of more or less crude state power: the macroeconomists. Macroeconomics had to provide a recipe to fight crisis without calling into question class relationships, and to start with it had to collect aggregated data in the newly installed state-owned statistical offices. In the sequel, the down-to-earth job of Keynes's generation of macroeconomists was to invent and to estimate the simplest possible systems, usually static linear systems, which were at least able to express the idea that the collection of relevant variables is interdependent and should be considered as a system. Keynes left this task to Hicks and Kalecki, and remained in the background with his vague qualitative statements. Keynes's return to a theory, which was to inform a new fraction of the elite of mainstream economists – a fraction that would be able handle class domination through direct intervention by the capitalist state institutions (and not just by disorienting critical minds) – this return to a pragmatic macroeconomic perspective triumphed when global capitalism had to reinvent itself at the end of the Second World War.[12]

During the following decades, the two fractions of mainstream economic theory – abstract microeconomics, which considered mathematical dream worlds,[13] and pragmatic macroeconomics, which consulted the piecemeal engineering of capitalist governments – marched in parallel. The repeated attempt of the former to build a mathematical bridge allowing macroeconomics to *derive* from axioms stated in microeconomics, the so-called microeconomic foundation of macroeconomics, gloriously failed.[14] The trajectories of the political economy of capitalist states evolved practically unaffected by either fraction of economic theory until 1971, when the system of fixed exchange rates, the Bretton Woods Agreement, was given up. During these years, from 1946 to 1971, only Keynes's rather unspecific advice, to enable a kind of integrated capitalism with the help of national credit systems aimed at ironing out business cycles, had some influence. With respect to the micro–macro relationship, the integrated capitalism of the first decades after the Second World War nevertheless had profound consequences. The possibility of stable reproduction, even at slowly rising living standards and profits, became deeply implanted in the internal models for households and small and medium-sized enterprises (SMEs). In many countries of the developed world, Keynes's vision of a "social market economy", of a capitalism with a flexible public credit system, invaded the minds and hearts of the population. And as long as the productivity gains, brought about by global trade integration and a pacified labour movement in the West, were able to provide a real economic basis for the self-fulfilling prophecies of monetary policy, as long as this tandem worked, the micro, meso and macro framework of internal models could remain largely consistent (as long as the cake to be distributed did grow sufficiently).

But when the sudden fall in the US dollar reduced the revenues of the world's large energy producers – in particular the cartel of the Seven Sisters, the main petroleum products producing multinationals – the first large oil crisis struck.[15] This crisis synchronized, and therefore amplified, the business cycles in all capitalist countries, leading to a crisis of the institutions of governments, of integrated capitalism. From 1980 onwards, the global rollback to conservative economic policy has been taking place, deconstructing the institutions of integrated capitalism. It has been accompanied, even enabled, by an offensive directed at the internal model-building process in the minds of individuals. Mass media and new ICT technologies have been increasingly successful in occupying a central place in the mental models people use to take decisions, whether in households, as employees or as firm owners. Centrally produced role models, stemming from a flourishing communications industry, have increasingly destroyed all other traditional patterns used for social identity formation.[16] Though again a new emphasis on the pragmatics of macroeconomic intervention was launched, this time it concentrated on turning public institutions, which in principle were co-determined by labour movement organizations to guarantee a smooth working of integrated capitalism, into private enterprises, which were usually at the disposal of members of the ruling class. Production, including the production of appropriate ideology, was streamlined to serve sustained accumulation and redirection of income flows towards the ruling class. An enormous new wave of enhanced exploitation in OECD countries started. Though it did not go unnoticed by large parts of the population, it was only with the beginning of the deep crisis in 2007 that the unavoidable divergence of economic forces in this type of capitalism brought the existence of theories of political economy back to the minds of ordinary people. What had happened to economics?

Taking 1982 as a somewhat arbitrary starting year for modern evolutionary economics,[17] the 30 years in which evolutionary economic theory developed can be interpreted as a struggle to overcome the interdependence between the micro-, meso- and macro-levels of the processes of political economy. In this sense, this discipline originated in an awareness of the inadequacy of many of the concepts of mainstream economic theory. If it had stayed at that level, and if that had been its only agenda, then the term "heterodox economic theory" would have sufficed, but evolutionary economic theory came to offer more. With respect to the above-mentioned issue of different levels of investigation it could draw on insights from general theories of evolution, particularly on biology's notion of self-similarity and fractal structure. Several other methodological instruments from neighbouring sciences were added to its toolbox and will be discussed in the next section.[18] Furthermore, due to its embedding in evolutionary theory, it tends to include both long-run consideration and its short-run complements. With the aspiration to acquire this capacity, evolutionary economic theory implicitly has to be able to describe the temporal aspect of short-run entities, i.e. the emergence of new essential elements as well as their eventual disappearance. It is not surprising that these high-flying goals of research have not yet been reached; they serve as a vision.

After the unfolding of the project involving the microfoundation of macroeconomics, the two fractions of mainstream economic theory fell apart even more drastically. The mathematically inclined microeconomic branch did find a hideaway from all empirically oriented disturbances using extreme assumptions about the knowledge and information-processing capacity of micro-units. In this quiet place of esoteric research, a lot of progress – i.e. additional insights into a tautological kind of truth – has been made. The pragmatic branch of mainstream theory focused on the immediate difficulties that occurred as discrepancies between the need to sustain profit rates and the possibilities of using credit frameworks became pressing again. This was usually expressed as the problems of reducing cost, stimulating demand and elaborating finance, and no common theoretic framework was envisaged any longer. Most of this branch degenerated and became managerial economics: accounting, marketing, finance and, in the end, marketing of finance. Mainstream economic theory had indeed collapsed many years before the Lehman Brothers disaster of 2007.

Evolutionary economic theory promises to fill the vacuum left by mainstream economists.

2 Synchronic profile of evolutionary methods

As the previous section has shown, evolutionary political economy, a specific method of a specific branch of evolutionary theory, has been emerging slowly during the last few hundred years, since the revolution of the natural sciences in the seventeenth century. The theory, by and large, has followed the ups and downs of general social evolution, eventually fighting on both sides of the ideological battlefield: on the progressive side (e.g. Hegel, Marx), as well as on the conservative side (e.g. Malthus, Schumpeter). Moreover, it is noteworthy that ideological attacks and counter-attacks have usually occurred only decades *after* a battle has been decided in material life. Hegel followed the French Revolution; the theory of the marginalist economists (Walras, Jevons and Menger) followed the events of 1848; Keynes's theories followed the disaster of the First World War; and so on. But let us now turn to the question of the *methods* used by evolutionary political economy.

A synchronic profile of these methods, that is, a structured collection of the currently available methods, evidently has to start with the traditional tools of the trade: *the writing of texts*, in a language close to everyday language, though with a touch of what in their time would have been called "philosophical aspiration". The writing of prose is the medium that has been used by almost every scholar up to the 1950s, including John Maynard Keynes. It is thus fully justifiable to consider a scholarly written text as the first example of formalization, and as a still valid contemporary tool. Nevertheless, not every prose text qualifies as scholarly work in evolutionary political economy. As the historical sketch provided in the previous section should have shown, economic history (including the history of economic thought) is only an indispensable instrument, indeed a method, if it is interpreted history. Only if the power of abstraction enables a scholar to provide a more systematic picture of historic events – e.g. by postulating a certain periodic reoccurrence or general features of different historic eras –

only then does a simple description of historic events become a theory of political economy.[19] While the reference to economic history is thus a necessary condition for evolutionary political economy, it is not a sufficient condition.

What is particularly interesting with respect to this first type of formalization is that it is usually a precursor to what is later developed in other types of formal languages. Since *evolutionary* political economy has identified evolution as a process of pulsation (see Figure 2.3), it is straightforward to identify its authors as those scholars who describe dynamics as a process involving countervailing forces. Only with forces pointing in opposite directions with different strength at different points in time can the workings of disequilibrium and emergence be encapsulated. When Richard Day produced his mathematical model of the ideas of Malthus, he explicitly cited the passage of Malthus's text referring to the "irregular movement" of social dynamics, presenting it as a chaotic dynamic system (Day 2000). Another, more recent example is Laszlo Barabási's book *Bursts* (Barabási 2011). In this text, a representative historical drama is interwoven with reports of cutting edge contemporary network research. The intention is to convey the sense that a sudden, unexpected burst of traditional behaviour occurs, and can have consequences in the sequel that go far beyond the original, singular manifestation. When and how such breaks happen, and the ways in which they depend on the network types within which a process in a singular node suddenly passes an invisible threshold: all these details are not readily available and cannot yet be neatly packed into a formalized framework. But the stories are seductive enough to release readers' creative potential. Instead of the hierarchy of languages, as introduced by the philosopher Hegel, which sees mathematics at the top and everyday language at the bottom, evolutionary theory rather considers a pulsation process (of language styles). While during a stable era a hegemony of more abstract styles prevails, towards the end of such an era the overshooting rigidity of abstract dogmas becomes inadequate and progress again depends on styles closer to empirically observed phenomena and everyday language. During a period of revolutionary dynamics, new combinations of daring abstractions are mingled with the needs stemming from the deep crisis of political economy. Language pulsation, which has emerged more recently, turns out to be just another tool of the human species.

The first type of mathematical abstraction extensively used by political economists in the post-war period is the *dynamic equation system*. The early ones were static and only allowed for a static comparison of different states of exogenous and endogenous variables. Endogenous variables were simply those variables in which the assumption of their actual value was substituted by an assumption about a static relationship between at least two variables. As soon as different points in time for the involved variables in such an equation were assumed, the system turned into a dynamic equation system, and the presentation of results became comparative dynamics, i.e. a comparison of the set of trajectories of variables for different start (or end) values of endogenous variables and different assumptions on the trajectories of exogenous variables. Introducing the element of time into the model immediately raised the question of whether it is to be considered a continuous or digital process. From a formal point of view that takes economic processes into account,[20] it is straightforward to allow for both possibilities, which means that difference-differential equation systems have to be considered. A further complication arises with respect to the type of functional relationships postulated: as long as the links introduced between variables are assumed to be linear, there exists a well-developed mathematical apparatus to study system behaviour. For non-linear links, such a treatment only exists for a few special cases. Yet linear relationships are extremely rare in the natural sciences; even Newton's gravitational forces decrease with the square of the distance of two masses, not to mention the forces present in the human species. The usual excuses for using linearity include treatability and the restriction to considering only very short time periods, which are assumed to be sufficiently approximated by linearity. The first of these excuses is countered by the argument that it is the insufficient formal apparatus that has to be changed: physical reality dictates its path of evolution, since it is itself part of that evolution. The second excuse for linearity is even more interesting, since it coincides with the economic approach of (neoclassical) marginalism: marginal changes (for economics, read: "of prices reflecting social value") adjust to marginal changes (for economics, read: "of each individual subjective utility") by law-like eternal rules (for economics, read: "of unconstrained market forces"). If the time scale is pushed to its limit – that is, processes are assumed to be either infinitely fast or infinitely slow – then very strange relationships between stock and flow variables emerge. The central issues of such theories usually discharge in a parallelism between a set of eternally valid laws and a protective belt of theory fragments, which explains why the paradigm represented by this set fails to explain what is observed empirically.[21] As a consequence of this dilemma, several textbooks in mainstream economics rather concentrate on explaining methods of calculus and algebra, with only an elusive link to problems of political economy.[22] Even if important lessons can be learned from this literature (see, particularly, Chiang 2005) with respect to the advantages of a rigid argument, it nevertheless remains rather unsatisfactory for the tenets of evolutionary modelling. This became visible when some dynamic equation systems with very specific parameter constellations were found to exhibit surprisingly unconventional behaviour: models of deterministic chaos did shake the self-confidence of the knights who were on a quest for the true economic dynamic equation system.

Chaotic systems differ from non-chaotic systems mainly by introducing randomness without the need to add (artificial and unexplained) stochastic terms to the equations. In other words, it is possible to produce a time series that is identical to white noise by setting up a rather simple specific deterministic equation system. Such a system is then called a chaotic system. This exciting finding would be of minor importance for economic theory if the specification of chaotic systems were to need strange and singular properties, but quite the opposite is the case: it has been proved that with increasing numbers of variables and equations the probability of chaotic behaviour increases. For systems mimicking the interactions in human societies, where each individual entity maintains an internal model (a projection of its environment, including communication), for these highly interconnected networks chaotic motions are almost inevitable. Turning the argument around, this implies that two candidates for evolutionary modelling emerge: on the one hand, straightforward complexity modelling (largely based on chaotic systems) might help;[23] while on the other hand, the question of how such chaotic motions can be coordinated at all has called into life diverse schools of "regulation theory" (Boyer and Saillard 2002). For the latter, the focus is on the understanding and design of (man-made) regulation systems: rule systems that allow for temporary coordination of social entities' actions. Such a focus brings politics (i.e. the discourse on power) and history back with force into the picture of economic theory.[24]

More recently, *complexity research* has joined forces with *network analyses* (see, e.g. Barabási *et al.* 2002b), *input-out analysis* (see, e.g. Newman 2010) and new approaches in *game theory* (see, e.g. Coolen 2005; Hanappi 2013b). The story behind this new mix is very plausible: social entities act as a tightly woven network in a way that makes it unreasonable to predetermine which direction of causality dominates a certain period, from the nodes to the overall network, or from overall network regulation to restrictions on the action of sets of single nodes.[25] As a consequence, the choice made by an entity sitting at a certain node is made with the help of an internal model, the goal variables of which are additionally influenced by choices made by other entities at other nodes. This is the typical starting point for game theoretic analysis, which is an extremely complex analysis since it has to be taken into account that entities are embedded in a communication system: they only perceive and interpret signals within a certain range of their communication network, and also only produce signals within a limited range. This is the essence of what Herbert Simon dubbed "bounded rationality" (Simon 1982); but now it is not just a theoretical attack on the assumption of hyper-rationality. It takes a positivist turn and tries to make explicit what has to be formalized instead of hyper-rationality. The sheer number of links to consider justifies calling such a system highly complicated; to characterize it as "complex" leads to an important discussion of the concept of complexity itself. This started in 1950s information science, when Andrei Kolmogorov and Gregory Chaitlin developed a very specific definition: a bit string was defined to be more complex than a second bit stream if it took a larger program to produce it. For the most complicated bit strings, the most complex ones, it turned out that no program at all could compute them: they are their own shortest description. And here is the surprising link to deterministic chaos (as described above): the stochastic-looking trajectories produced by a chaotic system can elegantly (though with demanding techniques) be reduced to their generating algorithm; they are much less complex than a look at the produced trajectories would suggest.[26] Generalizing this idea leads to the view that knowledge accumulation can be defined as the capacity to compress unintelligible-looking streams of signals to shorter generating programs, a task very similar to what in contemporary information science is called *pattern recognition*.[27] As a side issue of deep philosophical significance, Gregory Chaitlin emphasized the fact that most (infinitely many) bit strings (or numbers) cannot be compressed, which shows that there are sign structures outside our knowledge accumulation process that never will be understood.[28] Evolutionary economics therefore swims in a pool of limited time and space, trying to compress incoming data streams to sets of generating systems.[29] There is no hope for overarching "first principles". This is a disaster for all social theories aiming to model a convergence towards a final and global equilibrium state: the much appraised general equilibrium theory in mainstream economics or other more explicitly religious belief systems are excellent examples. For an evolutionary theory of the type sketched in the previous section – with pulsation and the need to include two well-specified but different time scales and models – Chaitlin's result is rather supportive. It restricts possible generality to a manageable size and at the same time stresses the need to get as close to the object of investigation as possible, even to accept the theorist as part of the object he or she studies. Self-reference is certainly not just a logical playground but rather a deeply rooted property of living systems. This leads directly to another fashionable technique to be included in the evolutionary toolbox: fractal analysis.

Fractal analysis formalizes the idea that structures are often characterized by the self-similarity of the parts from which they are constituted. In a self-similar entity of a given size, its components are smaller mirror images of itself, a kind of recursive cell of a program. Each program in such structure is smaller than the program within which it is embedded, and usually one big program contains several self-similar smaller ones. Self-references of the whole and its parts evidently work in both directions: from big to small and from small to big. To discover such a structure in nature typically implies a drastic reduction of complexity, since all self-similar features only have to be described once; the rest is done by a repeated reduce-and-copy command. Fractal analysis therefore provides an excellent tool for knowledge accumulation. Fractal objects can be ascribed a fractal dimension, a well-defined number that characterizes the process with which they are generated. In the simplest case,[30] this process is determined by the number of smaller mirror images, N, and the scaling factor used for reducing these images, call it S. The fractal dimension, D, then can be computed by inverting the formula

$$N = \frac{1}{S^D}.$$

The striking feature that objects can have a well-defined dimension in between the usual integers, due only to their internal self-similar structure, gives a new flavour to the evolutionary scheme displayed in Figure 2.2. Since there is no explicit absolute time scale needed (just two scales that are different relative to each other), this scheme lends itself to fractal replication! Fractal analysis can help to reduce complexity even in a quantitative way.[31] How this can be accomplished and how it links to the other elements of the evolutionary toolbox is currently being investigated intensively.[32] The focus of most of the research is on the question of how coordination and cooperation of the seemingly disparate copies of different sizes can come about at all. The emergence of novelty clearly has to be understood as a feature of the communication sphere, of non-knowledge mirrored as a process of emergence. Simulation techniques are not included in this brief list of tools in the evolutionary toolbox because simulation is omnipresent in all areas. To include them would be like adding knowledge of the alphabet to the skills necessary for writing impressive poetry.

The final question now is whether the use of these tools can influence the evolution of political economy. And, as the reader might easily guess, the answer given in the concluding section of this chapter is affirmative.

3 The feedback of methods on the evolution of political economy

In times of revolutionary dynamics – e.g. in current times – the global political economy is experienced as being in a state of widespread confusion. This concerns the dynamics of material flows as well as the organization of the world of ideas. For evolutionary theory, this signals that a time of rather fast creative rearrangement, of a push towards a new level of social form for the human species, has arrived. As in any transition phase of a living form (a species), the current potential jump to higher organization is at the same time threatened by an increased risk of extinction.[33] The dramatically increased global potential of destructive arms is an index showing how easy this possibility could be realized.

How can revolutionary dynamics be mastered, and even used to advance the species? For evolutionary theory – and evolutionary political economy is only one branch in this broader perspective – the answer is straightforward: still in accordance with the tenets of the French Enlightenment, what is needed are some action-guiding grand theories that will help to make progress and avoid setbacks on the global welfare-increasing track. Where do these grand theories come from? Evolutionary theory – referring to Schumpeter's ideas – would point to the surprisingly quick emergence of *new combinations* of existing (sometimes old or even almost forgotten) theory elements. Note that today theory production in the social sciences takes place by the extensive use of formal tools, of new languages that have been developed along the lines of a diversity of specialized research. The previous section of this chapter tried to collect some of these languages, while still keeping in mind that they cannot be arranged in a linear order. Rather, they proceed along a spiral, working up to higher grounds by a repeated return (in some dimensions) to earlier forms.[34] Building such new combinations is therefore the most urgent task for evolutionary theory, across all existing disciplines and eventually in the founding of new disciplines.

A big problem, then, is how to *implement* changes in global governance, which can enforce an improved organizational setting. As history shows, such political changes can only be brought about by the support of larger parts of the population. As a consequence any forceful new "ideology" needs a didactical component;[35] to refer to something as difficult to understand as "quantum electrodynamics" is not enough. The current theoretical goal is therefore not only to work on a synthesis (a new combination), but also to make it understandable to non-specialized people. Organizing the implementation is itself to be supported by evolutionary political theory, an extremely urgent task since time is rapidly running out.

Luckily there are not only obstacles but also some *advantages* to this newest transition phase. One concerns the electronic *availability of incredibly large amounts of data.* A scientist can do research in many directions without being restricted too much by restricted access to empirical observations; the problem rather consists in identifying redundant lines of scientific activity. A second advantage, mainly concerning the problem of implementation, is the quickly emerging general *ability of the population to use state-of-the-art computer technology*, not just in OECD countries but also in more and more parts of the developing world.[36] In that respect, the possibilities to distribute "enlightenment content" are increasing impressively.

Thus there is no reason for scientists working on evolutionary theory to despair, but every reason for them to engage fast and with additional energy in this theoretical research. As another example of self-reference, this chapter has been written as a modest attempt in this direction.

Notes

1 In a quickly written *tour de force* that tried to incorporate the new views into mathematics, John von Neumann wrote:

> what was fundamentally of greater significance, was that the general opinion in theoretical physics had accepted the idea that the principle of continuity ("natura non acit saltus"), prevailing in the perceived macroeconomic world, is merely simulated by an averaging processing a world which in truth is discontinuous by nature. This simulation is such that man generally perceives the sum of many billions of elementary processes simultaneously, so that the levelling law of large numbers completely obscures the real nature of the individual processes.
>
> (Neumann 1983 (1932): 4)

2 In my work of 20 years ago, I referred to evolutionary theories as follows: on the evolution of crystals, ET0 (evolutionary theory 0); for the evolutionary theory of plants and animals, ET1; and for evolutionary theories concerning the human species, ET2. See Hanappi 1992: 111.

3 In Schrödinger's answer to the question, "When is a piece of matter said to be alive?", time plays the same pivotal role. "He [Schrödinger] answered as simply as possible: 'When it goes on *doing something*, moving, exchanging material with its environment, and so forth, for a much longer period [!] than we would expect an inanimate piece of matter to *keep going* under similar circumstances" (Gleick 2011: 283).

4 Several scientists, mostly biologists, have set out to sketch such a grand theory. See, for example: Laszlo 1987; Davies 1988; Kauffman 1995; Bak 1996. Many of the ideas presented in this chapter have been inspired by these authors. A careful evaluation of their respective views would be very useful but is beyond the scope of this text.

5 The Galapagos Islands, which Darwin visited, were a wonderful substitute for such laboratory conditions.

6 The clearest and most concise definition of the evolutionary mechanism came from Herbert Simon:

> The simplest scheme of evolution is one that depends on two processes; a generator and a test. The task of the generator is to produce variety, new forms that have not existed previously, whereas the task of the test is to cull out the newly generated forms so that only those that are well fitted to the environment will survive. In modern biological Darwinism genetic mutation is the generator, natural selection is the test.
>
> (Simon 1985: 52)

7 Though Schumpeter refused to be called an evolutionary economist, his major theoretical innovations – e.g. the concept of "new combination" – point in the opposite direction. See Hanappi and Hanappi-Egger 2004.

8 A third observation at the micro-level concerned the difference between the growth of crystals, ET0, and life, ET1. Schrödinger had already articulated it in 1944:

> Solids in crystalline form; they can begin with a tiny germ and build up larger and larger structures; and quantum mechanics was beginning to give deep insight into the forces involved in their bonding. But Schrödinger felt something was missing. Crystals are *too* orderly – built up in "the comparatively dull way of repeating the same structure in three dimensions again and again." Elaborate though they seem, crystalline solids contain just a few types of atoms. Life must depend on a higher level of complexity, structure without predictable repetition, he argued. He invented the term: *aperiodic crystals*. This was his hypothesis: *We believe a gene – or perhaps the whole chromosome fiber – to be an aperiodic solid.*
>
> (Gleick 2011: 285)

9 There existed personal and intellectual links between Darwin and Marx. See Gould 1999.

10 It is tempting to rediscover in this process a "first law of thermodynamics" for the social sciences: the sum total of contradictions in a closed system is constant. If some smaller contradictions are locally solved, they reappear in disguised form as parts of larger ones; or, the system has to expand into new territories, has to become an open system.

11 This choice must have been made consciously since Keynes was always fond of mathematics, as his early written texts on probability theory proves (Keynes 1921).

12 Keynes had already proposed his new approach after the First World War, with his arguments to reconsider the impact of Germany's reparation payments on European macroeconomic stability, but at that time he failed to convince the relevant policy makers (see Keynes 1920).

13 Microeconomic theory rather resembles a religion, therefore, and as a consequence I have dubbed it micro-theology (Hanappi 1994: 9–11).

14 The best try remained Paul Samuelson's PhD thesis from 1947, which proclaimed a "neo-classical synthesis" (Samuelson 1947). It is the theoretical core of what has more recently been misnamed "neoliberalism". The latter term lumps together an unsound mixture of a critique of Samuelson's "neo-classical synthesis" and a diversity of conservative ad hoc policies devoid of any theoretical underpinning. It produces only confusion.

15 It is interesting to note that the trigger for the breakdown of Bretton Woods was that the US monetary authorities' slow build-up of doubts concerning the feasibility of the fixed exchange rate system had surpassed a certain threshold, and thus quickly led to a switch in policy. The repercussions of such a policy switch by a major player were not really anticipated at the time.

16 The surge of religious fundamentalism – e.g. in many US churches and the Arab world – just proves the strength and the broad range of applicability of the new techniques.

17 The famous book by Nelson and Winter (1982) can be used as first breakthrough.

18 Among the most exciting research fields to be integrated are network theory (see Barabási 2002a) and the Neumann-Morgenstern project of a new formal language for the social sciences, better known as "game theory" (cf. Hanappi 2013a).

19 One of the early debates in the discipline, the "Methodenstreit" between the German historic school (Gustav Schmoller) and the marginalist school (Walras, Menger), can be seen as the attempt to define what has to be added to simple storytelling to arrive at a respectable theory. From today's perspective, both sides were wrong and exaggerated their case tremendously to win the argument.

20 While decisions on government budgets, for example, are not taken continuously, some growth processes in agricultural economics might be formalized that way. Interestingly enough, theoretical physics – after an early emphasis on continuous time (Newton and Leibniz) – since Einstein has favoured a view that gives (digital) quantum considerations a certain primacy.

21 In the natural sciences this interplay is usually emphatically celebrated as the experimental method, which allows improving the set of "eternal laws". There is at least a certain in-built modesty, which admits that the current theory might be preliminary, only one special case of a more general theory. Neoclassical economists are often far less modest, since they assume that they can avoid laboratory experiments due to their object of investigation.

22 In the didactically very clear textbook by Giancarlo Gandolfo (Gandolfo 1998), many standard mainstream models are clearly discussed under the perspective of this mainstream formalism.

23 The scientific communities summarized under the label of "complex adaptive systems" (CAS) have recently attracted many young scholars worldwide.

24 The French school of regulation theory is just one early example of several scientific communities trying to accomplish such an approach. Though starting with fewer formal aspirations, these attempts have more recently reached out for methods explored by econophysics. An early inspiration has evidently been (chemistry) Nobel prizewinner Hermann Haken's theory about adiabatic approximation and the slavery principle. Compare Haken 1977, 2010; Zhang 1991: 193–212).

25 In mainstream economic jargon this would be expressed as discarding any primacy of microeconomics with respect to macroeconomics, or vice versa. In the same vein, the arguments of top-down versus bottom-up modelling lose their meaning.

26 Other interesting extensions of Chaitlin's approach were developed by Charles Bennett (1985, 2006).

27 See Hoyle 2006, for an interesting introduction to the field.

28 Chaitlin thus generalizes Kurt Gödel's famous proof on the limits of mathematics (Gödel 1931) by extending it to (general) algorithmic information science (Chaitlin 2001).

29 Work in microbiology is contributing important new concepts here, e.g. "network neutrality", which might also be fruitfully applied in the social sciences to model pulsation (see Schuster and Fontana 1999).

30 An interesting introduction to fractal analysis is the text by Brown and Liebovitch (2010). The stringent mathematical treatment of this area, of course, owes much to Benoit Mandelbrot (2012) for his memoir.

31 In Barábasi *et al.* (2002b), the link to the modelling of hierarchical structures in networks is made explicit.

32 For the link between input-output analysis and network modelling, the tool of adjacency matrices is the immediate bridge (see Newman 2010: 110–164).

33 In the larger perspective mentioned above, these quantum jumps are just possible – though transitory – escapes from the law of increasing entropy, the second law of thermodynamics.

34 This scheme, of course, is reminiscent of the methodological approach of dialectics that already intrigued researchers in Ancient Greece.

35 How opinions are formed within a population has not been a topic for most economic research. This is the reason why many scientists working on econophysics (e.g. Duncan Watts (2011)) turn rather to sociology as logical link to their methodological expertise. Compare, in particular, Schweitzer and Holyst (2000).

36 Today, the use of mobile phones and TV has to be included as a part of ICT.

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