Philosophy of science: short description of approaches, models & theories

A basic function of philosophy is to analyze and criticize the implicit assumptions building the way of our thinking in science, culture or common sense. As such, philosophy on the one hand can help to clarify the principles of thought that characterize complexity science. In this way, the varied sciences of complex systems are inspired by philosophy (Goldstein 1994). The philosophy of science is not a simple separate theory, but rather a meta-science that spans several views and proposals for analysing and assessing scientific methods, theories and fields often in a historical perspective. Thus philosophy of science constitutes a kind of meta-science, which is analyzing and criticizing the implicit assumptions behind our thinking based in science, culture or common sense.

Descartes' reductionism

One of the best known principles which was formulated by the philosopher-scientist Descartes (1596-1650), is that of analysis or reductionism: To understand any complex phenomenon, you have to take it apart and reduce it to its individual components. If these are still complex, you need to take your analysis one step further, and look at their components. If you continue this subdivision long enough, you will end up with the smallest possible parts, the atoms or elementary particles. Particles can be seen as separate pieces of the same hard, permanent substance that is called matter. This (later also Newtonian) ontology is therefore materialistic. It assumes that all phenomena, whether physical, biological, mental or social, are ultimately constituted of matter.

The only property that fundamentally distinguishes particles is their position in space (which may include dimensions other than the conventional three). Apparently different substances, systems or phenomena are merely different arrangements in space of fundamentally equivalent pieces of matter. Any change, development or evolution is therefore merely a geometrical rearrangement caused by the movement of the components. This movement is governed by deterministic laws of cause and effect. If you know the initial positions and velocities of the particles constituting a system together with the forces acting on those particles (which are themselves determined by the positions of these and other particles), then you can in principle predict the further evolution of the system with complete certainty and accuracy. The trajectory of the system is not only determined towards the future, but towards the past. Given its present state, you can in principle reverse the evolution to reconstruct any earlier state it has gone through.

Another approach to copy with complexity was proposed by Simon (1916-2001). In his pioneer work "The Sciences of the Artificial" he tries to describe complex systems or complex objects (for example an organization of a human face) by the method of an analytical decomposability. Simon stated that many complex systems have a nearly decomposable, hierarchic structure which could facilitate the description and understanding of such systems and their parts. Since this approach does not work for complex *non*-hierarchical systems, the analysis of such systems should focuses on their behaviour involving the comprehensive study of the interactions of their elementary parts (Simon 1998). In this context Hayek's propose of patterns recognition and prediction, that is exhibited below should be mentioned.

Newtonian mechanistic paradigm

Until the early 20th century, classical mechanics, as first formulated by Newton (1643-1727) and further developed by Laplace (1749-1827) and other philosophers, was seen as the foundation for science as a whole. Newtonian mechanics tried to reduce complex motion (particularly the complex motion of the planets) to simple and predictable regularities. The influence was so huge, that most people implicitly equated “scientific thinking” with “Newtonian thinking”. The reason for this influence is that the mechanistic paradigm is compelling by its simplicity, coherence and apparent completeness. Moreover, it was not only very successful in its scientific applications, but largely in agreement with intuition and common-sense (Heylighen et al. 2006). Later theories of mechanics, such as relativity theory and quantum mechanics, while at least as successful in the realm of applications, lacked this simplicity and intuitive appeal, and are still plagued by paradoxes, confusions and multiple interpretations (Heylighen et al. 2006). In general physics and particularly mechanics has succeeded because it deals (in our sense) with relatively simple phenomena (Hayek 1972). But a simple theory of phenomena which are inherently complex will be probably merely of necessity false. However the addition of specified ceteris paribus assumptions could help, but after the full statement the theory would no longer be simple (Hayek 1972). Hayek proposes another way to deal with naturally complex phenomena that is exhibited in the following.

Newtonian epistemology is based on the reflection-correspondence view of knowledge (Turchin 1990): Our knowledge is merely an often imperfect reflection of the particular arrangements of matter outside us. The task of science is to make the mapping or correspondence between the external, material objects and the internal, cognitive elements (concepts or symbols) that represent them as accurate as possible. That can be achieved by simple observation, where information about external phenomena is collected and registered, thus further completing the internal picture that is taking shape. At the limit, this should lead to a perfect, objective representation of the world outside us, which would allow us to accurately predict all phenomena.

All these different assumptions can be summarized by the principle of distinction conservation (Heylighen 1990). Classical science begins by making as precise as possible distinctions between the different components, properties and states of the system under

observation. These distinctions are assumed to be absolute and objective, i.e. the same for all observers. The evolution of the system conserves all these distinctions, as distinct initial states are necessarily mapped onto distinct subsequent states, and vice versa.
In particular, distinct entities (particles) remain distinct. Thus there is no way for particles to merge, divide, appear or disappear. In other words, in the Newtonian world view there is no place for novelty or creation (Prigogine & Stengers, 1984) but everything that exists now has existed from the beginning of time and will continue to exist. Knowledge is nothing more than another such distinction-conserving mapping from the object to subject. Scientific discovery is not a creative process, but it is merely an “uncovering” of distinctions that were waiting to be observed.

Up to this point, Newtonian logic is perfectly consistent. But if we moreover want to include human agency, we come to a basic contradiction between our intuitive notion of free will and the principle of determinism. The only way Newtonian reasoning can be extended to encompass the idea that people can act purposefully is by postulating the independent category of mind. This reasoning led Descartes to propose the *philosophy of dualism*, which assumes that while material objects obey mechanical laws, the mind does not. However, while we can easily conceive the mind as a passive receptacle registering observations in order to develop ever more complete knowledge, we cannot explain how the mind can freely act upon those systems without contradicting the determinism of natural law. This explains why classical science ignores all issues of ethics or values. There simply is no place for purposeful action in the Newtonian world view.

At best, economic science has managed to avoid the problem by postulating the principle of rational choice, which assumes that an agent will always choose the option that maximises its utility. Utility is supposed to be an objective measure of the degree of value, "happiness" or "goodness" produced by a state of affairs. Assuming perfect information about the utility of the possible options, the actions of mind then become as determined or predictable as the movements of matter. This allowed social scientists to describe human agency with most of the Newtonian principles intact. Moreover, it led them to a notion of linear progress, so that the continuous increase in global utility (seen mostly as quantifiable, material welfare) made possible by increases in scientific knowledge. Although such directed change towards the greater good contradicts the Newtonian assumption of reversibility, it maintains the basic assumptions of determinism, materialism and objective knowledge, thus defining what is often called the project of modernity.

The assumptions of determinism and of objective, observer-independent knowledge have been challenged soon after classic mechanics reached its apex, by its successor theories within physics: quantum mechanics, relativity theory, and non-linear dynamics (chaos theory). This has produced more than half a century of philosophical debate, resulting in the conclusion that our scientific knowledge of the world is fundamentally uncertain (Prigogine & Stengers 1997). While the notion of uncertainty or indeterminacy is an essential aspect of the newly emerging world view on complexity (Gershenson & Heylighen 2005; Cilliers 1998), it is in itself not complex, and the physical theories that introduced it are still in essence reductionist. Thus there is an obvious need for new theoretical methods and approaches which shall help to analyse and explore complex phenomena. One of the pioneers in the field of philosophy of science who not merely clarified the distinction between simple and complex phenomena but moreover outlined general difficulties and principles for handling complex phenomena was the Austrian economist and philosopher Friedrich August von Hayek (1899-1992).

Hayek's theory of complex phenomena

In the common case, the formation of theories always draws from existing paradigms. These paradigms determine patterns of thought, which allow to identify and to understand observed phenomena that scientists take interest in. While this approach found a wide implementation for recognition, analysis and explanation of rather simple phenomena, there are some difficulties with analysis of complex phenomena.

Inherently the distinction between simplicity and complexity raises considerable philosophical difficulties when applied to statements and furthermore to phenomena (Hayek 1972). Nevertheless due to Hayek the natural sciences deal with relatively simple phenomena while the phenomena of life, mind and society are more complex (Hayek 1972). Also Scriven states, that "the difference between the scientific study of behaviour and that of physical phenomena is thus partly due to the relatively greater complexity of the simplest phenomena we are concerned to account for in a behavioural theory" (Scriven 1956).

Hayek's proposal to deal with complex phenomena is the approach of pattern recognition and pattern prediction. The theory provides the description and knowledge of the pattern. Particularly in natural sciences i.e. physics, the theory as the knowledge of specific periodical patterns is commonly regarded as a tool used for prediction of the particular manifestations of these patterns that will appear in specific circumstances (Hayek 1972). In general natural and particularly physical sciences tend to assume that it will (in principle) always be possible to specify prediction of the appearance of a pattern to any degree desired (Hayek 1972). As the phenomena these sciences deal with are relatively simple, they can indeed settle this claim. However a theory will always describe only a kind or a class of patterns. As mentioned above, the particular manifestation of the pattern will depend on the specific circumstances[1] - such specific initial conditions also can be referred as data (Hayek 1972). In such a way every algebraic equation defines a class, a kind or a tendency of patterns. The individual or particular manifestation of these patterns can be specified by substitution of variables by definite values or data. The predictability of particular manifestations (or our ability to predict these manifestations using our knowledge about patterns, thus using a theory) will depend

[1] Thus, if we can define a general description of an abstract pattern, we also can describe each particular case or manifestation that this pattern must include.

on how many of those data we can ascertain. In the case of complex phenomena, these data, which specify the particular pattern manifestation in the given circumstances described by a theory, will be more numerous and much more difficult to ascertain and control than in the case of simple phenomena (Hayek 1972). In turn, a simple theory of natural complex phenomena will be probably merely of necessity false. However, the addition of specified ceteris paribus assumptions could help to reduce the falsifiability of this theory, but after the complete modelling of all (or near complete) ceteris paribus assumptions, the theory would no longer be simple (Hayek 1972). Thus there is a gap or trade off between the initial incomplete data for theory formulation concerning complex phenomena and more unlikely falsifiable statement this theory leads to. According to Popper such a theory will be of small empirical content because it enables us to explain only certain general features of a situation which may be compatible with a large number of specific manifestations (Popper 1959). Popper distinguished between falsifiable and non-falsifiable theories as a kind of ranking or criterion for the scientific character or status of a theory. The first he regarded as scientific, and the last as non-scientific. However, concerning complexity and particularly complex systems, this criterion seems to be quite naïve and unsophisticated: While in some circumstances it may be falsified, in others not. Since it is so complex you may never expose the falsifiable dimensions. Although the usefulness of such a theory is restricted by the formulation of so called "hypothetical predictions" - predictions depend on yet unknown future events (Scriven 1959, Popper 1963) - the range of phenomena compatible with these predictions will be rather wide and thus the theory likely falsifying - somehow less scientific in Popper's terms - it will nevertheless extend the range of the possible advance of scientific knowledge.

Furthermore complex phenomena have attributes which can not be derived from the specifications of theirs elements. Therefore another difficulty exploring complex phenomena arises due to their measurement. Hayek proposes as a measure for complexity the *degree of complexity* of different kinds of abstract patterns. According to Hayek "there seems to exist a fairly easy and adequate way to measure the degree of complexity of different kinds of abstract patterns" (Hayek 1972). An "unambiguous criterion" for the measurement of complexity degree is the minimum number of elements of which a manifestation of the pattern must consist in order to represent all the characteristic attributes of the class of patterns.[2] Thereby Hayek means the degree of complexity characteristic of a kind or class of phenomenon. It is beyond dispute, that physical phenomena may achieve any degree of complexity. But if we consider the minimum of distinct variables to describe a formula or a model needed, the drastically increasing complexity as we go forward from the inanimate to the animate ("more highly organized") and social (the most complex) phenomena becomes obvious. However, Hayek does not give us any further advises, how we can measure the degree of complexity in practical manner. In fact we "only" can say, if a particular phenomenon is simple, complex, or more complex.

[2] Kolmogorov defines complexity in an analogous way by the minimum possible length of a description in some language.

According to Hayek we must get rid of the naïve idea that the world is so organized that it is possible by direct observation to discover simple structures and regularities between all phenomena and that is a necessary presupposition for the application of the scientific method (Hayek 1972). He emphasises that what we have by now discovered about the structure of many complex phenomena should be a sufficient advise for handling of complex phenomena: "If we want to get ahead in these fields our aims will have to be somewhat different from what they are in the fields of simple phenomena" (Hayek 1972).

Conclusion

It is obvious that there is traditionally a dichotomy between the natural sciences - based on measurements and analytics - and life and social sciences. Scientists look into complex systems across a variety of disciplines and problem areas trying to understand and elucidate general characteristics and concepts common to such systems. One looks into complexity as an emerging phenomenon to be understood, while the other looks into complexity as an engineering problem to be tackled.

Complexity research mainly happens at the borders between various disciplines and thrives on interactions between engineering and the sciences creating thus unique but still fragile bridges. Indeed, the most common trigger of complexity is the encounter of natural/living systems with artificial, man-made systems. Our guess here is that ideas born out of complexity research will culminate in hundreds of practical applications articulating slowly some major technologies on which mature businesses will thrive beyond the next decade or so.

The traditional scientific method, which is based on analysis, isolation, and the gathering of complete information about a phenomenon, is incapable to deal with such complex interdependencies. In the 1980's a new scientific stream emerged which is generally called complexity science (Waldrop 1992) with its core concept of complex adaptive systems (Holland 1996). The emerging science of complexity (Waldrop 1992; Cilliers 1998; Heylighen 1997) offers the promise of an alternative methodology to the Newtonian paradigm that would be able to deal with these challenges. However, such an approach needs a clear understanding and definition of the underlying concepts and principles.

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