Tracing Back the Roots of the Concept of Teleology*

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Abstract
Artificial Intelligence (AI) is one of the newest disciplines in human history, having its emergence after Second World War [1]. The term "Artificial Intelligence" has been coined in 1956 [1] to denote the intelligence displayed by artificial machines in opposition to natural intelligence demonstrated by biological systems (e.g. human and animals). Since in many AI fields the concept of intelligence is deeply connected with human intelligence and goals [2, 1], this paper traces back the early roots of the concept of *teleology* in Science and Philosophy. Teleology comes from the Greek word τέλος (télos) that means ends, goals or purposes [3] and carry this idea that things happen to fulfill a goal. In performing this effort, the paper provides an integrated overview of the concept, clarifying the different shades of teleology presented in literature, representing a preliminary step towards defining an ontology for complex systems.

Keywords
Teleleogy, Complex Systems, Ontology, Epistemology, Artificial Intelligence

1. Introduction

Artificial Intelligence (AI) is one of the newest disciplines in human history, having its emergence after Second World War [1]. The term "Artificial Intelligence" has been coined in 1956 [1] to denote the intelligence displayed by artificial machines in opposition to natural intelligence demonstrated by biological systems (e.g. human and animals). Although the field has made astonishing advances in terms of technological development within the last 70 years, no universal consensus about the definition of "natural intelligence" exist so far [2]. Such lack of consensus together with misconceptions about intelligence hindres the progress of the field of Artificial Intelligence [2].

In many AI fields, the concept of intelligence is deeply connected with human intelligence and cognition [2, 1]. The core abstraction used in the field is the "rational agent" [1] that is an agent endowed with human mental abilities, like perceiving the environment, elaborating on goals, operating autonomously to achieve such goals and adapting to environment changes. Such agent may interact with other agents to collectively perform problem-solving tasks to solve a particular problem [4]. Either individually or collectivelly, intelligence (or rationality) means to be able to find strategies to achieve either personal or collective goals.

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Since many AI fields rely on the definition of "intelligence" attached to the pursuit of goals, this paper traces back the early roots of the concept of *teleology*. Teleology comes from the Greek word τέλος (télos) that means ends, goals or purposes [3] and carry this idea that things happen to fulfill a goal. To conduct this effort, two searching strategies have been employed. The first strategy started in a classical AI textbook [1] with the idea that Aristotle was one of the first that attempted to codify the “right reasoning process” (rationality or intelligence), being this reasoning process related with the definition of goals (telos). From this Aristotelian idea, a historical forward search has been conducted by checking the references, which allowed the tracing of an ascending historical sequence of authors. This search ended by reaching the disciplines of General Systems Theory (GST) and cybernetics that were fields concerned with the definition of a "universal science" (regardless whether phenomena belongs to natural, biological or social spheres) and were the precursors of the modern discipline of AI. The second strategy then started in the fields of GST and cybernetics and performed a historical backward search to find more authors (also checking the references). In this search, there were many overlaps among authors and ideas of the first strategy, but it also allowed a richer historical sequence and characterization of ideas. This search approach is called integrative review approach [5] and aim at synthesizing the state of knowledge, combining perspectives to create new theoretical frameworks. As the integrative approach focuses on ideas, some authors have been excluded because they share very similar ideas which are already discussed here by other authors (e.g., Leibniz [6] share very similar ideas with Aristotle).

In this effort of tracing back its early roots, it was discovered that teleology is a concept in vogue since the most remote times, developing an *explanatory role* for all sorts of phenomena in many branches of Philosophy and Science. For this reason, this paper reviews the concept of teleology within the three fields of Science and Philosophy (natural, biological and human fields), together with the field of Artificial Intelligence. In each field, the paper describes how the concept of teleology develops an explanatory role, providing justification (explanations) for all sorts of phenomena and the human knowledge about such phenomena. In addition to that, it is also explained in which sense being goal-oriented amounts to display intelligence.

The contributions of this paper are twofold: (i) By tracing back the roots of the term, this paper works towards defining a taxonomy (ontology or conceptualization) of intelligence, more specifically, the dimension of intelligence connected to goal-orientation. Understanding the meaning of a certain concept is the first step towards establishing a common vocabulary for a certain discipline, thus achieving semantic interoperability among AI researchers. As we will see, the paper presents quite interdisciplinary research, and this in principle may look distracting, but the influence of many distinct fields is instrumental to build conceptualizations that accounts for the building blocks from reality [7], which is the ultimate goal of building ontologies; (ii) by compiling an integrated overview of the main ideas connected to the concept of teleology, this paper represents a preliminary effort towards defining an ontology for complex systems.

This paper is further structured as follows: Section 2 provides a brief overview of Philosophy of Science, describing the different mentalities and assumptions that shaped the search for knowledge along human history. This overview is useful for understanding how the concept of teleology has been used by the contemporary mentality to provide justification for all sorts of phenomena in different areas of human knowledge. Section 3 presents how the concept of teleology is actually used in many fields of knowledge to provide explanations, in particular, Section 3.1, 3.2, 3.3 and 3.4 respectively discusses teleology within natural, biological, human sciences and AI. Section 4 discusses the findings of tracing back the concept by presenting a summary of the main ideas and integrative analysis and finally, Section 5 concludes the paper with some remarks about the findings and outlines some future work.

2. Baseline

Since immemorial times, humanity strived to acquire knowledge about the world we live in, to construct theories in an attempt to make sense of reality. In this context, Epistemology raises as a branch of Philosophy that studies human knowledge, its nature and extent [8]. More especifically, Philosophy of Science is the branch of Epistemology that studies the nature of scientific knowledge and its acquisition process [9]. Since the process of knowledge acquisition is conditioned by concomitant time-dependent beliefs and knowledge, this section gives a brief overview of the most relevant periods in Philosophy of Science.

While the modern conception of Philosophy of Science has only been established in the 20th century with the foundation of the *Vienna Circle* and its logical empiricism movement [9], epistemology dates back the classical antiquity [10]. In ancient Greece, the realization that rational thinking could be used as an instrument of inquiry of the world drove the development of *Philosophy*. Both Plato and Aristotle (and others) emphasized the importance of installing the "true knowledge" (epistēmē), in opposition to the myth (*mythos*) and personal opinion (*doxa*). In Philosophy, the discourse must be rational, discursive and argumentative, although ancient greeks were not concerned about validating such knowledge with the realization of experiments, only relying on logic and common sense [11].

During the Middle Ages, the search for knowledge took place within the boundaries of Theology, that is, scientific knowledge was acknowledged only when it conciliated with religion and the limits between philosophy and theology were uncertain [12, 13].

In Modern Era (16th - 18th centuries), we start to see the beginning of the rupture between Science and Philosophy. The realization that our senses can mislead the perception and understanding of the world (the method from Philosophy) leads to the installation of scientific models based on empirical investigation and mathematics (the scientific method) [13, p. 59]. This empirical agenda had the goal of ensuring objective justification of scientific knowledge. Newtonian mechanics (classical mechanics) formulated on the basis of mathematics and experimentation became the paradigm of science as a whole [13, p. 63] [14]. The chief goal of Science then became to reduce the explanation of all sorts of phenomena to classical physics [11]. In this mechanicist paradigm, knowledge is acquired through *analysis* or *reduction* that reduces nature to its most elementary units to find the laws that govern such units [14] [13, p. 59][11].

In 20th century, some discoveries led to the questioning of the method and assumptions of the standard scientific paradigm. With the discovery of quantum physics and relativity, the first questioning addressed the empirical, observer-independent assumptions, due to the influence the observer plays in the systems they interact during experiments [11, 12]. Second, although fundamental physics and reductionism have been instrumental in explaining the very large (relativity) and very small (quantum physics) physics, they have been practically mute in dealing with complex systems close to human scale. Complex systems (e.g. ant collonies, immune systems, brain and consciousness, etc.) are systems in which a large number of components, with no central control and simple rules of interaction at microscopic level give rise to complex, collective and emergent behaviour at a macroscopic level [11]. Since the properties from the macroscopic behaviour (sophisticated information processing, adaptation by learning or evolution, emergent properties, goal-orientation) cannot be reduced to the parts of the system due to their non-linear interactions, the study of those systems was also decisive in the questioning the reductionist method for generating exact mathematical models that describe the functioning of systems along time. Third, the availability of computational tools during the second half of the 20th century also made possible the study of the behaviour of complex systems and chaos theory, which also challenged the reductionist agenda. In 20th century, there is no epistemological consensus on how to face complexity and subjective concerns [15, 13]. Some authors assert that scientific knowledge is subjective (depending on the observer) [14, 13] and uncertain due the emergence of collective properties that arise from the interactions of the simple parts from complex systems [14].

This brief overview of Philosophy of Science explained the mentality that shaped the scientific inquiry and the search for knowledge through each periof of human history. The understanding of each mentality is essential for grasping how teleology has been used as an explanatory concept during each historical period in the different disciplines.

3. The Concept of Teleology

3.1. Natural Philosophy and Science

The modern word *teleology* is derived from the Greek word τέλος (télos) whose meaning is end, purpose or goal [3]. The concept of teleology has its early roots in the works of Plato and Aristotle in natural philosophy and cosmology [16]. Both philosophers strived to establish an account for the explanation of cosmos and universe on a rational basis, including principles for change and motion of bodies.

In his work *Timaeus*, Plato discusses the necessary and sufficient conditions as an account for the universe. While the type of matter that compose physical bodies are the necessary conditions for explaining the material properties of a body (why it moves or behaves in given way), they are indeed not the trully causes. Instead, the true cause is the is the good (*aitia*) [16]. The universe is then the result of handiwork of a rational, purposive and anthropomorphic agent, the divine Craftsman (*Demiurge*), who arranges the cosmos and its parts with the *purpose* of producing a vast array of good effects. In order to produce the material world, this divine Craftsman imitates an eternal and immaterial model (called *Forms*), thus imposing mathematical order on a preexistent chaos to generate the ordered universe (*kosmos*) [17].

In *Physics*, Aristotle's natural philosophy establishes the general (philosophical) principles about things that are subject to change and motion [18]. These changes may be motion (change in place), quantitative change (change in terms of numbers or dimensions), qualitative change (colour), and substantial change coming into existence/generation or corruption/decay. Aristotle argues that generated things (e.g. artifacts and products of change) have a generative source, while natural change is governed by the inner "nature" (principle and cause) of things. If one understands this inner nature of a thing, then it is possible to grasp not only the reason why this thing has been generated, but also to determine the characteristics of change. In Physics, Aristotle argues that four causes can explain the process of change and movement [3]. The *material cause* (of change) provides an explanation of the material that compose something (the changing or moving thing), e.g., the marble is the material cause of a statue. The *formal cause* regards the essential forms or shapes of things, explaining a change or movement in the thing caused by the necessity to conform to a form or shape, for example, the plans of an sculptor to build a statue. The *efficient cause* consists of the entity that provokes the change or movement, i.e., the primary originator of the change and its cessation, for example, the efficient cause of a child is a parent. Finally, the *final cause* (teleology) is given when one specifies the intended purpose of change, for example, the telos of the seed is to become an adult plant. Also related to final causes and changes, Aristotle discusses the concepts of *potentiality* and *actuality* [18]. He argues that changes that occur in time arise from a potential, which is actualized when the change is completed. The "actual" is logically prior to the "potential", since the potential aims at reaching the actual and therefore, it must be defined in terms of this actual. The introduction of the notions of potentiality and actuality allows Aristotle to characterize nature with a immanent teleology that is not the result of the actions of an anthropomorfic creator [3, 19].

In scholastic times, the theologian Saint Thomas Aquinas' thinking follows the Aristotelian explanations of four causes [20]. In terms of final causes, Aquinas sticks to Aristotelian idea that teleolgy is the ultimate end for everything, that is, the universe has an intelligible order that directs all kinds of things, both living (plants and trees seek to grow towards sunlight) and innanimate things (stones tend to fall towards the earth center). This order must ultimately come from an intelligent source (God) who is the ultimate end of all things.

In early modern times, with the instalation of the modern scientific method, Science strives to find the efficient causes (in the Aristotelian sense) for natural phenomena [13] and the mechanisms that govern the causal structure of the world (mechanicist explanations) [21]. The final causes (teleology) are rejected as explanations [22, 19] as it requires the existence of a vital force (God) that cannot be scientifically proved [23].

With the 20th century discoveries of quantum physics, relativity, non-equilibrium thermodynamics, chaos and complex systems have shocken the search for deterministic and mechanicist explanations in Science [12, 13], and we see a revival in the tendency to use teleological explanations in natural sciences. For example, in modern physics (relativity and quantum theory), the motion of systems are described by a set of differential equations that depends on the events occurring in the immediate temporal and spatial neighborhood of the system. This set of differential equations is entirely governed by the principle of least action that states that natural phenomena have the tendency to optimise some variable (e.g. minimize action) [6], or in other words, to purse an optimization goal. Although the fundamental meaning and the reason why nature applies the principle of least action is unknown [24], the principle has a great importance for many physicists (Einstein, Max Planck, Helmholtz [24]) due to its apparent ability in explaning the real world. By incorporating the principle of least action in their theories, scientists acknowledge that physical systems are governed by final causes, what has a deep philosophical significance. Similarly, in classical thermodynamics (close to equilibrium) and in thermodynamics far from equilibrium (dissipative structures that tend to reach order through fluctuations), scientists also identified the tendendy for the system to reach a final equilibrium state (teleology) [13]. In face of the controversies whether thermodynamics can be explained in teleological terms or not, in [19], authors propose that the concept of teleology can be rephrased in mechanistic terms.

3.2. Philosophy of Biology and Biology

The discussion of teleology in the natural world can be extended by including teleological considerations in living beings.

Plato's explanation for alive beings follows an anthropocentric and creationist account [25]. Like in natural sciences, the Demiurge is the source of all universe and motion. Living beings are artifacts modeled on the *Forms*, whose goal is the production of the eternal good of Forms. In contrast, Aristotelian's explanations are naturalistic and functional [25]. His four causes are also used as explanation for the phenomenon of life [18] and biological explanations provide the four causes of an organism and species (the material that composes it, the processes that makes it to function, the form and its purpose). Furthermore, biological explanations rely on two levels. One level provides causal knowledge for parts of organisms of individual kinds. For example, eyes have similar function of seeing in both men and horse, and causal explanations have to be provided for each kind separetely (i.e., one explanation for men and other for horses). This teleological or goal-directed orientation of Aristotle's biology allows him to explain the various *functions* of living creatures like nutrition and reproduction in terms of growth and preservation of form. At the second level, explanations provide the causes for the persistence of the *organisms* of each specie. In general, he considers that final cause for the persistence of each specie is self-preservation. This drive towards self-preservation and the impetus for organismal development are goal-directed processes and this telos is an immanet property of both [25].

This creationist idea that alive beings have been created by a deity and their forms have predominantly remained the same since their creation [11] had prevailed during Middle Age. With the arrival of modern times, a number of philosophers sought to provide mechanicists, functional explanations for life-related phenomena. René Descartes strived to explain the heart movement in terms of "matter in motion" that compose the circulating blood. He also attempted to explain embriology in the same terms, that is, tissue and organ origination is accounted for matter aggregation in different regions of the embryo [26]. Immanuel Kant articulated a mixture between teleological and mechanistic explanations for the functioning of organisms in which the mechanistic outlook was modeled on Newtonian mechanics in his *Critique of Judgment* [26, 6]. He argued that other functions like growth and reproduction could not be explained in mechanical terms and therefore, they received teleological explanations [25]. His work was influential in the understanding of biological phenomena as it helped to frame the question of teleology vs. mechanicism in the early 19th century, encouraging the search for new forces that would explain biological phenomena in mechanistic terms.

In the late 19th and early 20th century the debate between teleological versus mechanicist explanations re-appeared in the controversy of vitalism [26]. Vitalism is the view that biological systems are governed by forces beyond physico-chemical properties, due to the goal-directed organization of living things. These "vital forces" were also required to explain the differences between physical and living systems [25]. Vitalism originated in the work of Hans Driesch that studied sea urchin embryos. He discovered that when he separated a cell of the sea urchin embryo after the first cell division, each cell turned into a complete animal, contrasting with his expectation that each cell would develop into the corresponding half of the animal [26].

The deathblow in the concept of teleology in Biology has given been in the 18th century by Darwin in his book *On the Origin of Species* [23, 27]. By following the empirical method in evolutionary biology [28], Darwin elaborated the theory of natural selection that states that all species of living organisms arise from a common ancestor and transform gradually through the natural selection of small, inherited variations. Such variations increase the individual's ability to compete, survive, and reproduce in an environment of limited food resources. Darwin called this process of evolution of species "natural selection" [11]. Although the result of evolution by natural selection appears to be driven by special forces (some sort of designer or Creator) towards more adapted species, variations are purely random. In this way, the theory of evolution is a series of pure causal transformations that working together produce "evolved species" [11], not being directed by a telos or goal. In addition to natural selection, Darwin believed that inheritance of acquired characteristics was also one of the mechanisms of evolution, although he did not know how this could take place [11, p. 91]. In subsequent years, genes have been discovered by Mendel and the unification of the theory of evolution with genes and inheritance gave rise to the field of "Modern Synthesis" [11]. Nowadays, Modern Synthesis still acknowledges the inexistence of any "intelligent" force directing the evolution or design of organisms [11]. To prevent a confusion with Aristotelian teleology, the term *teleonomy* was introduced to denote the evolutionary interpretation that uses teleological language for explanation [29, 25].

In modern Biology, approaches strive to explain goal-oriented characteristics in nature in different ways. One approach is to naturalize teleology, devoiding it from theological explanations, although biologists and philosophers have continued to question the legitimacy of such teleological notions [25]. For example, the existence of parts of organisms (functional traits) may follow a deductive pattern of explanation [25], in which the presence of a trait in an organism is explained by being sufficient or necessary condition for producing its function. A second way of naturalizing teleology is using a natural selection account [25]. In this case, a trait's functions causally explain the existence of that trait in a given population by means of the mechanisms of natural selection.

Another way to explain the apparent purposiveness of biological organisms uses feedback mechanisms and self-organizing characteristics of living systems from the *theory of autopoiesis*. The theory of autopoiesis from the biologists Humberto Maturana and Francisco Varela [30] states that living systems are defined as self-organized, autopoietic systems (capable of autonomous production of themselves). As autopoiesis and adaptations to environment are the requirements for life, living beings are in constant self-production, including structure and self-regulation with the environment. Therefore, although organization appears to be goal-oriented, changes occurred in the context of self-organization are subordinated to the maintainance of the system. The theory of autopoiesis is applicable not only for the goal-oriented explanations of organisms, but also for societies of living beings, like ant or bees collonies [11].

3.3. Human Sciences and Philosophy

In Human Sciences and Philosophy, the object of the study is the human beings and their societies. In this context, teleology is also used in a number of fields.

Aristotle's natural framework of four causes is extended to ethics and politics [3]. In ethical theory, Aristotle argues that all human actions are goal-oriented (teleological), as humans reason about the means to achieve certain ends (consequences). For him, the choice of actions to bring about the consequences must be guided by the exercise of reason, conducted in accordance with moral virtues and excellence. In other words, happiness involves excellence and virtues in executing a rational activity to bring about desired consequences. The discussion of human happiness is concluded in his *Nicomachean Ethics* by introducing political theory as an extension of ethical theory. Whereas ethical theory characterizes the best form of human life, political theory characterizes the best social organization to realize the best forms of human life.

Following the same tendencies of Physics and Biology, in modern times, Human Sciences witness the rupture between Metaphysics (branch of Philosophy that investigates reality that transcends the material experience) and Science. It is strived to elaborate a scientific human nature theory grounded on mathematical-mechanical essences, eliminating concepts like soul, emotions and divine providence [10]. Like in natural sciences, human nature is analyzed from the empirical and experimental point of view (*positivism*), and human history is reduced to a set of observable and objective facts [10]. With time, this approach revealed itself limited in the further development of Human Sciences, as it became devoided of motives (telos), values and meaning that explain subjective human and social phenomena. To restore its status, the philosopher Wilheim Dilthey argues that although the standard scientific paradigm comes from natural sciences (driven by mechanicist, causal explanations (Sec. 2)), Human Sciences has its own standards, driven by hermeneutics (embeeded with interpretation) and teleology, goals and value schemas need to be considered in order to make human and historical data intelligible [10].

A second attempt to restore goals and meaning intrinsic to the human phenonema comes from Philosophy of Mind. In the mechanicist era, natural sciences, empirical knowledge and causal order were considered to be the standard scientific model. Some philosophers argued that, if there exist a science of the mind, it must be consistent with this standard model in one of two ways [31]. It would be either reducible to natural sciences by relating mental objects with objects and events that arise within this causal, physical order, or at least, it would acquire its empirical methodological aspects, even if it does not ultimately reduce to physics. Friedrich Hegel questioned such assumption of the priority of the causal order of the universe. For him, truly understanding something was not a matter of locating it within the causal order of the universe, but rather, Hegel's metaphysics holds the idea that the ultimate reality of the universe is driven by God's mind and its Absolute order. Therefore, to understand something consists of locating it within the self-realization of the Absolute, a teleological structure that transcends the physical order of efficient causes. This understanding led him to state that human historical development follows this teleological order of universe, allowing one to assign meaning to the entire course of historical events of the world [32]. This teleological account of history has been turned into a materialist theory by Karl Marx that argued that human historical development would culminate in a stateless, communist society [32].

Nowadays, purposiveness and cognition of human mind are also explained by the theory of autopoiesis [30]. Humans as biological, autopoietic systems are realized through their structural organization and self-adaptation to environment. Cognition is related to our ability to get to know the world, and thus, the way how we handle the universe and knowledge is private and cannot be transferred. Therefore, purposes and cognition are associated with our biological integrity towards maintenance of life.

3.4. Artificial Intelligence

Artificial Intelligence has its raise in the 60s, with the promise to build intelligent, artificial machines that takes inspiration from natural intelligence [1]. Several AI fields imitate natural intelligence in different ways. In this section, I include the AI ideas that somehow use goal-orientation to embeed intelligence in the system.

Cybernetics, created in 1948 by Norbert Wiener in his book *Cybernetics or Control and Communication in the Animal and the Machine*, is a field that studies living systems through analogy with physical systems (machines) [12]. In cybernetics, biological systems like the brain have been studied to conclude that purposive behavior consists of a regulatory, feedback mechanism that strives to minimize the "error" (difference between current state and goal state). In *"Behaviour, purpose and teleology*, Wiener, Rosenblueth and Bigelow establish the early cybernetics ideas. Cybernetics has inspired the modern field of Machine Learning in AI [1, p. 757].

In the 18th and 19th centuries, the controversy between mechanists and vitalists (see Sec. 3.2) in the study of cell functioning end up with the vitalistics positions falling into disuse. As many biologists were still concerned to account for differences between living cells and ordinary matter, another prominent position called *holism* (or organicism) has arisen. Holism stated that living systems were still built of material parts, but the properties and functioning of the whole organism should be accounted not only by these material parts, but also by the properties resulting from their interaction (their organization). In this context, Ludwig von Bertallanfy was a biologist that acknowledged the holistic position within Biology. With time, by noticing holistic tendencies in many other areas of Science (e.g., classical newtonian physics), he started postulating the *General Systems Theory (GST)*, an interdisciplinary field that contains principles and laws that are valid for "systems" in general, regardless if these systems belong to physical, biological or sociological realms [33, p. 66]. Teleology is one of the properties of systems. In his book, Bertallanfy enumerates different types of teleology [33, p. 128]: (i) static teleology (e.g., feathers exist to conserve warmth in mammal's organism, spine protects plants from animals), (ii) dynamic teleology (direction towards a final state, i.e. causal connection from a future state to a present state), (iii) dynamic teleology based on structure (direction based on structure. The structure directs the process to move towards organistic regulation to keep homeostasis (e.g. body's temperature, heart as a pump to keep blood's pH)) and finally, (iv) teleology in the Aristotelian sense (also called as conformity in finality), an anthropomorphic psychic capacity of having a goal and behavior to achieve this goal that directs present actions (human behavior).

In AI, goal-based agents are a central tenet in many fields, from Aristotle's ethics to McCarthy's work on logical AI [1]. In robotics, the first robot (Shakey from Stanford Research Institute) was an embodiment of a logical, goal-based agent. Goal-based agents also have a connection with the logical (symbolic) community, by being specified in logics. A goal-based, agent-oriented methodology has been also developed by Shoham for the specification of agent-oriented software (in the area of multi-agent systems). (Distributed) problem solving is another area where goal-orientation dominates, having its beginning with the influential Human Problem Solving by Newel and Simon. In natural language understanding and multiagent systems, goals and intentions (pursued goals) are central in the agents theory. AI planning (finding the best sequence of actions to achieve a goal) arose from the practical needs of scheduling, robotics and other domains. The goal-oriented, learning agents are also classic in the machine learning literature.

4. Discussion

This paper reviewed the concept of teleology in Philosophy and Science (natural, biological and human sciences) and Artificial Intelligence. In order to make this review, I first introduced the mentality that shaped the search for knowledge in each period of human history in the scope of Philosophy of Science. Table 1 summarizes the main ideas and concepts related to the definition of teleology, divided by era and field. An integrative analysis of this table reveals a number of points that I enumerate in the remainder of this section.

In Philosophy of Science, the search for knowledge started with ancient greeks. Since these remote times, there is an idea that the universe is governed by an intelligent order that has some goals and purposes (telos). While platonic account for this intelligence is anthropomorphic and creationist (the Demiurge is the source), Aristotle argues that intelligence is an immanent property of universe and living beings. Both ideas persisted during Middle Ages.

With the arrival of modern times, physics and empiricism became the standard scientific paradigm. The requirement was to make Science empirical and verifiable as means of achieving objective justification for acquired knowledge. This principle led models of teleological explanations to start falling into disuse, and being replaced by explanations of cause and effect (mechanicist). This rationale was based on the impossibility to prove the methaphysical existence of a Creator or intelligent designer that assigns purposes for creation. As natural sciences were the standard paradigm, this way of thinking was also extended to Biology with Darwinism and Positivism in human sciences.

The tension between mechanicism, efficient causes vs. teleology, final causes prevails until nowadays. The discovery of relativity, quantum theory, complex systems and chaos challenged mechanicisms explanations, and teleological explanations started gaining new momentum. The tendency is then to assume an holistic perspective in the inquiry of physical systems and search for the teleological explanations for the functioning of the system globally. This is the approach taken in quantum theory that postulated the principle of least action, and in the theory of dissipative structures in non-equilibrium thermodynamics. In particular, Ilya Prigogine, the nobel prize winner in chemistry who studied the theory of dissipative structures, hoped to have formulated a theory of “critical phenomena” that explains self-organization in physical systems (e.g. chemical reactions) and biological systems. This theory would contain a "vocabulary of complexity” that consisted in a number of concepts that explain the mechanisms encountered in

Table 1
Summary of main ideas and concepts related to the definition of teleology, divided by era and field

Era	Definitions
Ancient Greece	**Physics** Plato follows an anthropocentric and creationist account Aristotle follows a naturalistic and functional account Four causes, potentiality and actuality
	Biology Plato: life is one of the good effects that comes from the Demiurge Aristotle: biological explanations in terms of functions and organisms
	Humanities Aristotelian ethics (goal-oriented behavior) Aristotelian politics (society is goal-oriented)
Medieval Era	Aquinas: universe has an order that comes from an intelligent source (God) God created nature, life and humans Humans strive for salvation rather than knowledge
(early) Modern Era	**Physics** Beginning of rupture between Philosophy and Science Causal, mechanicist explanations (teleological explanations are refuted)
	Biology Vitalism: biological systems are governed by a vital force Darwinism: natural selection is governed by causal forces Descartes: mechanicist explanations for organism functioning Kant: mechanicist vs teleological explanations for organism functioning
	Humanities Positivism: knowledge is acquired by observing phenomena (limited) Teleology, goals, values and hermeneutics are considered Philosophy of Mind and History: universe order follows a teleological structure
Relativistic Era	**Physics** Quantum physics and relativity: motion is governed by final causes
	Biology Modern synthesis (teleonomy) and Theory of autopoiesis
	Humanities Theory of autopoiesis: purposiveness and cognition
Artificial Intelligence	Cybernetics: biological systems have purposive, regulatory behavior GST: four types of teleology (static, dynamic, dynamic based on structure, Aristotelian teleology) Goal-based agents are a central in many fields (logical AI, robotics, multi-agent systems, (distributed) problem solving, natural language understanding, AI planning and machine learning)

complex systems, like teleology, nonequilibrium, stability, bifurcation and symmetry breaking, etc. However, as some of these theories are not fully understood yet (like the principle of least action), no mathematical theory of complex systems has been developed so far [11].

Advances in areas like GST and cybernetics shed some light over the controversy about mechanistic vs. teleological explanations. While cybernetics studied purposive, regulative behaviour, GST strived to develop a science with universal principles, with teleology being a property of "systems". Bertallanfy enumerated four types of teleology, being one of these types, the regulative mechanism adopted by cybernetics. Unfortunately, no mathematical basis exist [11] so far for cybernetics and GST, preventing a fully characterization of motion in complex systems.

Finaly, analysis of Table 1 allows us to integrate concepts of different areas using quantum physics. In quantum physics, systems have final states and an observer with a certain goal in mind (final cause in the Aristotelian sense) that directs its actions towards a future state. We can interpret that the observer is related to the final cause by determining the final point of movement (or change) [34]. In this way, the idea of order returns, but it is not divine, or metaphysical, it is the human which is part of the system that chooses the final state following an autopoietic imperative (to maintain life).

5. Conclusion

This paper reviews the concept of teleology in Philosophy, Science and Artificial Intelligence, providing an integrative overview of the concept and how it evolved along the centuries of scientific development. One can conclude that philosophers and scientists strived to define the principles of motion of the world (if based on causal or teleological principles) from the most remote times.

A number of other surveys [19, 35, 36] exist in the fields of Epistemology and Philosophy of Science, mainly concerning the validity and scientific status of the concept of teleology in different branches. In [19], the author discusses the dichotomy between mechanistic vs. teleological causation in natural sciences like mechanics and thermodynamics, and also Biology. Similarly, Woodfield [36] studies the different shades and uses of teleological explanations, discussing many concepts here presented like functions, final states, goal-oriented behavior, while Christensen [35] presents a discussion in the scope of cybernetics. The Teloi Project [37] discusses teleology within a religious and metaphysical background. Other words like [38, 39] proposes ontologies of complex systems. In [38], Heylighen outlines a long-term, transdisciplinary effort of such ontology, including the concept of “goal” as a final system state aimed by an agent, whereas [39] defines an ontology of complex systems with concepts like “system”, “emergence”, etc., but none of them include the teleological notions discussed in this paper that are a remarkable characteristic of such systems.

In contrast with such works, to the best of my knowledge, this is the first review of the concept of teleology in the field of AI, striving to define the dimension of natural intelligence connected to the pursuit of goals. By tracing back the idea of teleology, the paper represents a preliminary contribution towards defining a vocabulary or ontology for complex systems. As future work, other terms like emergence, self-organization, spontaneous order, criticality, etc. that are commonly found in the literature of complex systems, are still fuzzy and vague [11] needs to be incorporated into such ontology.

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