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Teleonomy as a problem of self-causation

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A theoretical framework is provided to explore teleonomy as a problem of self-causation, distinct from upward, downward and reticulate causation. Causality theories in biology are often formulated within hierarchy theories, where causation is conceptualized as running up or down the rungs of a ladder-like hierarchy or, more recently, as moving between multiple hierarchies. Research on the genealogy of cosmologies demonstrates that in addition to hierarchy theories, causality theories also depend upon ideas of time. This paper explores the roots and impact of both time and hierarchy thinking on causal reasoning in the evolutionary sciences. Within evolutionary biology, the Neodarwinian synthesis adheres to a linear notion of time associated with linear hierarchies that portray upward causation. Eco-evo-devo schools recognize the importance of downward causation and consequently receive resistance from the standard view because downward causation is sometimes understood as backward causation, considered impossible by adherents of a linear time model. In contrast, downward causation works with a spatial or presential time notion. Hybridization, lateral gene transfer, infective heredity, symbiosis and symbiogenesis require recognition of reticulate causation occurring in both space and time, or spacetime, between distinct and interacting ontological hierarchies. Teleonomy is distinct from these types of causation because it invokes the problem of self-causation. By asking how the focal level in a hierarchy can persist through time, self-causation raises philosophical concerns on the nature of duration, identity and individuality.

ADDITIONAL KEYWORDS: downward causation – duration – hierarchy – individuality – reticulate causation – time – upward causation – worldviews.

INTRODUCTION

Teleology is the cosmological study of *telos* or final causes, ends, purposes or goals in nature. It associates with ancient philosophical works of which the writings of Aristotle usually function as the exemplar (Hardie & Gaye, 1984). By adhering to a cyclic notion of time, Aristotle characterized the world in general and life in particular as undergoing an ever-repeating and everlasting cycle of coming and becoming. In this returning cycle of life, the end is known and foreseen before it is reached, and the path toward it is predestined and set to repeat.

Teleonomy instead is a concept introduced by Pittendrigh (1958). It refers to the study of goal or end-directedness, agency or overall motivation or movement in organismal behaviour (Corning, 2014; Vane-Wright, 2014). This is no coincidence, as any end-directed behaviour is behaviour that occurs over time. A goal or end is a future state anticipated or known in the present and determined, motivated or otherwise caused by past or present actions. As such, teleonomy brings forth a linear notion of time, one where the succession of events becomes causally correlated into means-end or cause-effect sequences.

Both the concepts of teleology and teleonomy thus advance a sense of finality that relies on notions of time and causality. In Aristotle's cosmology, matter is motivated or moved by final causes and the movement of matter is what defines time. In end-directed behaviour, what is needed to reach a future end are means or causes of movement toward that end. Such movement occurs over time, not in the least by the assumption that cause precedes effect.

While scholars today generally avoid questions on finality (for a discussion see Walsh, 2015), there continues to exist a correlation between causality and time thinking, and this correlation can be studied from within the genealogy of intellectual thought and the role herein played by hierarchy theory. Within the

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evolutionary sciences, the Neodarwinian synthesis endorses a notion of upward causation because it focuses on how genes bring forth organisms and how organisms underlie species formation, and with that, it adheres to a linear notion of time. Evo-devo schools investigate the possibility of downward causation or how species influence the evolution of organisms, and how organisms influence the evolution of genes. Ecological or reticulate evolution studies endorse a notion of reticulate causation that occurs between distinct hierarchies in spacetime.

Distinct from these types of causation, teleonomy raises the problem of self-causation. Self-causation can also be investigated from within hierarchy theory, as the question of how the focal level persists over time. Self-causation correlates with the problem of duration and it raises questions on individuality or how entities maintain identity over time.

Divided into three parts, this paper first addresses how, in intellectual history, different notions of time have brought forth different causality theories. Afterwards, it is investigated how causality theories are formulated from within hierarchy theories, and how hierarchy theories have helped evolutionary biologists in their understanding of upward, downward and reticulate causation. These two parts provide the background needed to subsequently, in part three, examine how teleonomy raises the problem of self-causation.

PART I: FROM TIME TO CAUSATION IN INTELLECTUAL HISTORY

Time is an important pillar of cosmologies. Cosmologies are worldviews that describe the nature of being by providing theories on matter, space and time (Gontier, 2016). Thinking on matter, space and time are conjoined because, time, in intellectual history, is defined as the movement of matter in space. How matter moves or changes in space defines the problem of causation (Gontier, 2018a). Consequently, changing notions of time correlate with changing notions of causality (Table 1).

Four major cosmologies and their typical cosmographies

This section exemplifies how time thinking has affected causality thinking in western intellectual history. Western cosmologies trace back to the cosmologies of the Ancient Greeks that are rooted in older Neolithic cultures. From there, western cosmologies transition, first into the Roman and Judeo-Christian cosmology, and later into the cosmology of classical physics and natural history research. Today, a new cosmology is emerging from modern physics and current evolutionary biology.

Although related by common descent, western cosmologies vary in how they understand matter, space and time. This variation can be studied conceptually through textual analysis, and visually, by analysing the cosmographies that accompany the great cosmologies. Cosmographies are typically hierarchical diagrams, found in books or on artwork, that capture the major tenets defended by cosmologies.

The cosmographies of Neolithic and Ancient Greek cultures depict and classify the nature of being into wheels of time and chains of being. Roman and Judeo-Christian cosmographies map the ontological state of the universe into scales of nature, chronologies, genealogies and pedigrees. The worldviews of classical physics and natural history research are depicted in seriations, timelines and phylogenetic trees. The cosmographies of modern physics and evolutionary biology often include networks drawn in graph theory and multidimensional vector space.

Correlations between time and causality thinking

How the four cosmologies understand causality correlates strongly with how they conceptually and diagrammatically understand and depict time (Gontier, 2016, 2018b). Ancient cultures developed cyclic time notions by studying planetary motions and life cycles. They also endorse a cyclic notion of teleology.

Romans and Judeo-Christians alter tradition and linearize time and causality. Judeo-Christians, in particular, endorse a worldview that is cosmogonic and eschatological, i.e. they assume that the world has a singular beginning and ending in time, and both are considered acts of voluntary creation and destruction by a deity. Causality becomes understood in terms of divine intervention that is non-uniform but nonetheless purposeful or teleological.

Classical physics and natural history research seek out natural rather than divine causal explanations for why matter changes through time. Phases of history steadily become equated with a uniform numerical timeline that reaches ever deeper to the beginning of cosmic time. Causation becomes defined as a uniform and predictable temporal relation between cause and effect.

Today, the assumed uniformity of cause is called into question. Evolutionary thinking proves that over time, a single evolutionary lineage can diversify into multiple lineages. In hindsight, scholars can point toward diverse and multiple mechanisms and processes that underlie this diversification, but they often find it difficult to predict the future from the present. Scholars nowadays also question the uniformity of time

Table 1. Time and causality in four major Western cosmologies (based on Gontier, 2016, 2018b)

Cosmology	**Late Neolithic cultures and Ancient Greeks**		**Romans and Judeo-Christians**		**Classical physics and natural history research**		**Modern physics and evolutionary biology**
Cosmographies	Wheels of time	Chains of beings	Scales of nature	Chronologies and pedigrees	Seriations, timelines	Phylogenetic trees	Vector spaces and graphs
Time depictions	Cycles	Strings	Stairs, ladders	Phases, series	Straight lines	Trees	Networks
Time directionality	Circular	Circular	Linear	Linear	Linear	Multilinear	Multidirectional or inexistent
Time concepts	(Once created) eternal true vs. relative time		Eternity vs. cosmogonic and eschatological, numerical time		Absolute (mathematical) vs. relative time		Spacetime vs. geo-logical, chronobiological, phenomenological or numerical time
Causality	Cyclical teleology		Religious, non-uniform teleology		Uniform and non-uniform teleology		Statistical probabilities and uncertainties
Phenomenology	Eternal returns, reincarnation, predictability, determinism		Providence, conceding to destiny, inevitability, having faith	The division into past, present and future, uniqueness of events	Progress, growth, advance, prediction	Physical and biological determinism	Uncertainty, indetermination, contingency, free will

because they continue to develop different techniques to measure and calculate change over time, and not all of these times are easily calibrated to a single numerical and universal timeline. Consequently, time and causation today are either studied as varied and multiple, or alternatively scholars argue that time and causation are unreal.

In sum, Western cosmologies can be studied for how they differentially understand causality, and how this correlates with varying phenomenologies of time (Gontier, 2018b). The following sections exemplify the transitions here listed.

Cyclic teleology, wheels of time and chains of being

Cyclic notions of time derive from the observation that stars and heavenly bodies rotate in the sky and correlate with seasonal changes in nature (Plato, 1960). An example of a celestial wheel of time is the zodiac that in Ancient Babylonian and Sumerian times was called a cycle, belt or chain of animal beings (King, 1902). An example of an earthly, seasonal cycle that accompanies the celestial cycle is the cycle of life and death. Common to all sunflowers, for example, is that they grow from seeds into seedlings and sprouts that develop into budding and full-grown flowers that eventually die and drop new seeds which enables the cycle to recommence (Fig. 1).

In line with older Neolithic cosmologies, Aristotle (Physics II, 3, in Hardie & Gaye, 1984) understood the cycle of life and death as demonstrative of the cycle of 'coming to be and passing away'. In this cycle of coming and becoming, unformed matter is moved or motivated by an inner wanting to become what it is destined to be by its form or essence. By running through the cycle, the potential inherent in all being reaches actualization. Typical for a teleological worldview, the actualization of the final form defines the *telos* or goal of all being.

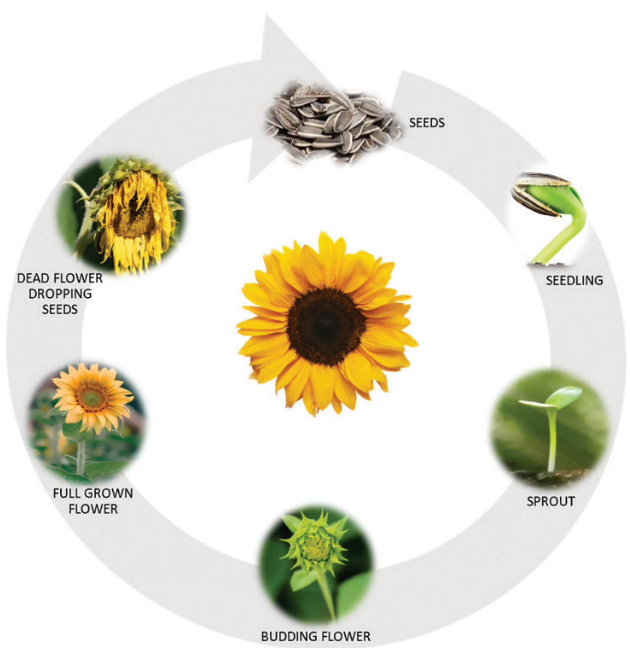

Figure 1. The life cycle common to all sunflowers (see text).

Innovative about Aristotle's work was that he additionally tried to find the reasons for the cycle of coming and becoming. He found four such reasons or causes (Fig. 2) that help explain how unformed matter reaches the actualization of its potential, or, how, in the example, the seeds grow into a sunflower. The material cause refers to unformed matter that has the inherent potential to become something. In the example, the unformed matter with potential is the sunflower seed. The formal cause refers to the form that unformed matter can take on, and this is defined by the essence of the substance that asks about the whatness of a thing (what a thing makes into what that thing is). In the case of the sunflower, Aristotle would say that sunflower seeds have the potential to grow into a sunflower, and because Aristotle assumes that like brings forth like, sunflower seeds can grow into nothing else but a sunflower. Their essence or what makes them into sunflower seeds also defines their final goal or wanting (their internal strive), i.e. to have their potential actualized. The efficient cause asks how this wanting is fulfilled. For Aristotle, this actualization of potential or the reaching of the final form requires external motivation. In the sunflower example, for the seeds to grow into the sunflower, they need water, sunlight and fertile soil. The final cause is the end or reason of becoming, which in the example is for the seeds to grow into a sunflower. The final cause asks about the why or what for of being which, over the course of intellectual history, has become understood as a question on final purpose. Here is how Aristotle described the causes:

> Now that we have established these distinctions, we must proceed to consider causes, their character, and number. Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the 'why' of (which is to grasp its primary cause). So clearly, we too must do this as regards both coming to be and passing away and every kind of physical change, in order that, knowing their principles, we may try to refer to these principles each of our problems. In one sense, then, (1) **[the material cause]** that out of which a thing comes to be and which persists, is called 'cause', e.g. the bronze of the statue, the silver of the bowl, and the genera

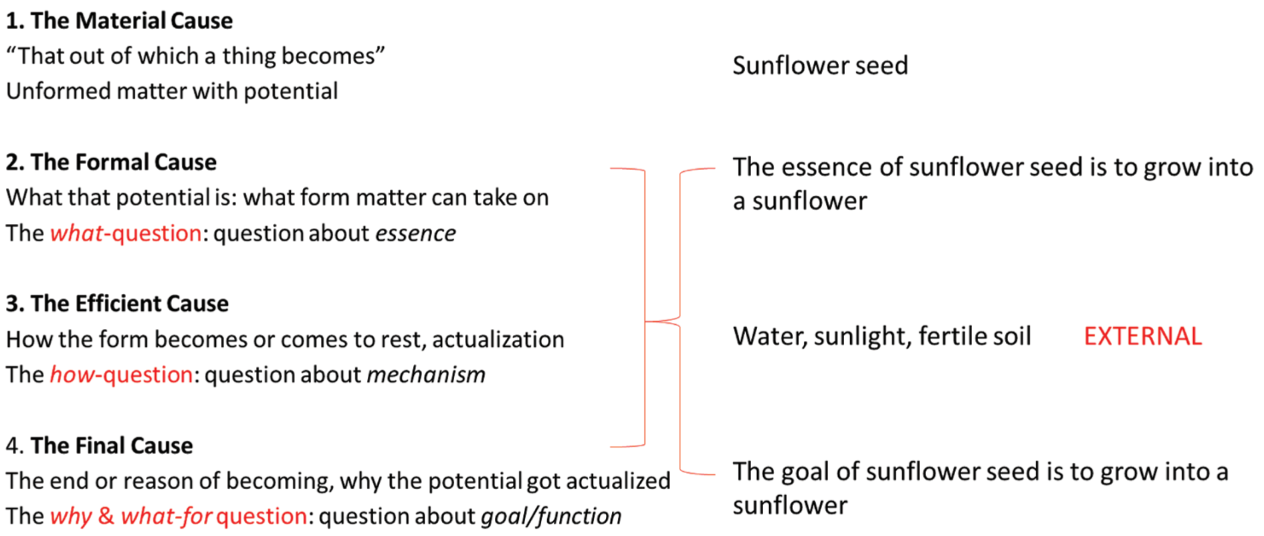

Figure 2. Aristotle's four causes that underlie all coming and becoming.

> of which the bronze and the silver are species. In another sense (2) **[the formal cause]** the form or the archetype, i.e. the statement of the essence, and its genera, are called 'causes' (e.g., of the octave the relation of 2:1, and generally number), and the parts in the definition. Again (3) **[the efficient cause]** the primary source of the change or coming to rest; e.g., the man who gave advice is a cause, the father is cause of the child, and generally what makes of what is made and what causes change of what is changed. Again (4) **[the final cause]** in the sense of end or 'that for the sake of which' a thing is done, e.g., health is the cause of walking about. ('Why is he walking about?' we say. 'To be healthy', and, having said that, we think we have assigned the cause.) The same is true also of all the intermediate steps which are brought about through the action of something else as means towards the end, e.g., reduction of flesh, purging, drugs, or surgical instruments are means towards health. All these things are 'for the sake of' the end, though they differ from one another in that some are activities, others instruments. This then perhaps exhausts the number of ways in which the term 'cause' is used.
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> Aristotle, Physics, Book II, part 3, 194b 24–194b, in Hardie & Gaye (1984); emphases added.

In Aristotle's view, the formal cause (the essence of matter or what something is) and the final cause (the goal or why something is) converge, and together with the material cause, they identify internal motivations and potentialities. The efficient cause is the only cause that identifies external motivation, and that explains how the potential of things becomes actualized.

The myth of the eternal return

But what then happens, in Aristotle's worldview, once the wanting becomes fulfilled? True to the older cyclic cosmologies, the cycle of life was thought to recommence. In the example, the seeds of the dying sunflower would have been understood as having the same wanting and the same essence to become the same sunflower. Such a view brings forth what Mircea Eliade (1954) called the 'myth of the eternal return'. The idea is typical for all ancient cultures that endorse a circular notion of time. Without the second law of thermodynamics, there is no permanent decay. Rather, once a cycle is completed, it repeats.

The appeal of such a worldview today remains obvious. Once spring has become summer, autumn and winter, the seasons recommence anew. Today, however, spring is no longer understood as causing or wanting to bring forth summer, autumn or winter. Rather, the causes for seasonal change are found elsewhere, outside the yearly cycle. Causation today is no longer understood as inherent to a cycle or as internal to being, but as something external to being, something that is imposed upon being from the outside. In association, the epistemic questions of what and what for that ask about inner wanting, essences and final goals are abandoned in favour of the how question that is understood as the only scientific question (Gontier, 2016).

Instead of repeating, today time advances. Although an hour comprises a cycle of 60 minutes and a year a cycle of 12 months, these cycles are nowadays considered to follow one another sequentially through time. An hour is no longer made up of 60 repeating single minutes, rather it is 60 new minutes. Inspired by Eliade's work, Gould (1987) already argued that in Western history, the notion of time's cycle became replaced by time's arrow. It can also be proven that the cyclic notion of causality has become straightened out throughout natural history. What are the reasons for this change?

Religious, non-uniform teleology and scales of nature, pedigrees and chronologies

Thinking about time changed with the introduction of the Roman and the Gregorian calendar (Samuel, 1972). Numbers have become attributed to the days, months and years (Richards, 1998), and the linear and sequential counting of the years underlies the formalization of time into a timeline (Rosenberg & Grafton, 2010). The adoption of a numerical timeline takes attention away from the older cycles of time. Now, a first year is followed by a second, the second by a third, and so on. This invokes the idea that a new year lies ahead in time, rather than that an old year is about to return.

The linearization of time helps the spread of Judeo-Christian thinking that understands all matter, space and time to have a single beginning and ending, both of which are conceptualized as acts of creation and intervention that follow a presumed divine plan. This plan is supposedly known and narrated in the scriptures as a series of events that have or will take place at irregular moments in time. Thus, causation, understood as the purposeful although non-uniform hand of the Judeo-Christian deity, remains teleological.

Linear and numerical time brings forth a growing sense for the uniqueness of history. This leads to the practice of timekeeping and recordkeeping (Gontier, 2011). Examples include familial pedigrees that keep track of the genealogies of individuals, and chronologies that record world history events (Burgess, 1999).

Examples of early genealogies include the Jesse trees that depict the historical ancestors of Jesus until King David and his father Jesse of Bethlehem, as well as the genealogical trees that depict Adam's descendants (Fig. 3) as recorded in the ancient scriptures. These trees are originally unilinear because the descent is traced patrilineally. But a person's familial history eventually becomes tracked both patri- and matrilineally (Bouquet, 1996; Gontier, 2011).

Examples of world history recordings are the *Chronicon* of Eusebius (Eusebii, 1866–1875), written in two volumes in 325, and the translation and adjustment thereof by Jerome around 380 and titled the *Book of Seasons/Times* (*Temporum Liber*). These chronicles compare the time reckonings of different ancient cultures including the Assyrian, Median, Lydian, Persian, Hebrew and Egyptian cultures by calculating the number of years their different kings reigned. Because these cultures vary in how they calculate the years, the scholars introduce comparative timetables that enable a conversion of the various times into their prevailing time reckoning. Scholars including George Syncellus, Joseph Scaliger and Isaac Newton would continue to revise the chronologies.

Chronological calculations of generations of kings enable scholars to situate and compare the different empires in time. Chronologies also start to list and position major events in time. In this regard, chronicles function as precursors of timelines that transform human history into a scale of events occurring in time. Newton's (1728) amended chronicle, for example, opens with *A short chronicle from the first memory of things in Europe to the conquest of Persia by Alexander the Great*, and it lists such major events, occurring at irregular moments in time, from 1125 BC onward, when Memphis reigned over Upper Egypt, until Darius Codomannus, the last king of Persia, flees in 331 BC.

In addition to genealogies and chronologies, also older chains of being and scales of nature become understood as depicting events in time. Aristotle had described nature as proceeding 'little by little from things lifeless to animal life in such a way that it is impossible to determine the exact line of demarcation, nor on which side thereof an intermediate form should lie' (*The History of Animals* 588b: 4–14 in Thompson, 1910). These ideas know a revival and expansion during the Middle Ages and the Renaissance. The Judeo-Christian god is depicted as standing above or as finalizing the old Aristotelian chain that is reconceptualized as forming a single 'great chain of being' (Lovejoy, 1936) that in turn is understood as a scale of nature (Barsanti, 1992), i.e. a ladder of perfection or stairway to heaven.

Following religious and romantic views, this chain of being or scale of nature is considered perfectly harmonious (Lovejoy, 1936), which provides the incentive to fill any gaps by finding intermediates. Together with genealogies and chronologies, research on scales subsequently gives way to natural history research.

Uniform teleology, from chronologies and pedigrees to timelines and trees

Scales originally show a hypothesized spatial distance that exists between the entities on the scale. This distance is measured by how close or far away the organisms are on the stairway to heaven which in turn is based upon the types of soul beings presumably have (Hicks, 1907). The spatial distance that exists between the rungs of the ladder later is interpreted as an indication of time. Religious scholars first reinterpreted the older scales of nature as chronologies that depict the order or phases wherein a presumed deity created the world. Later, natural history scholars

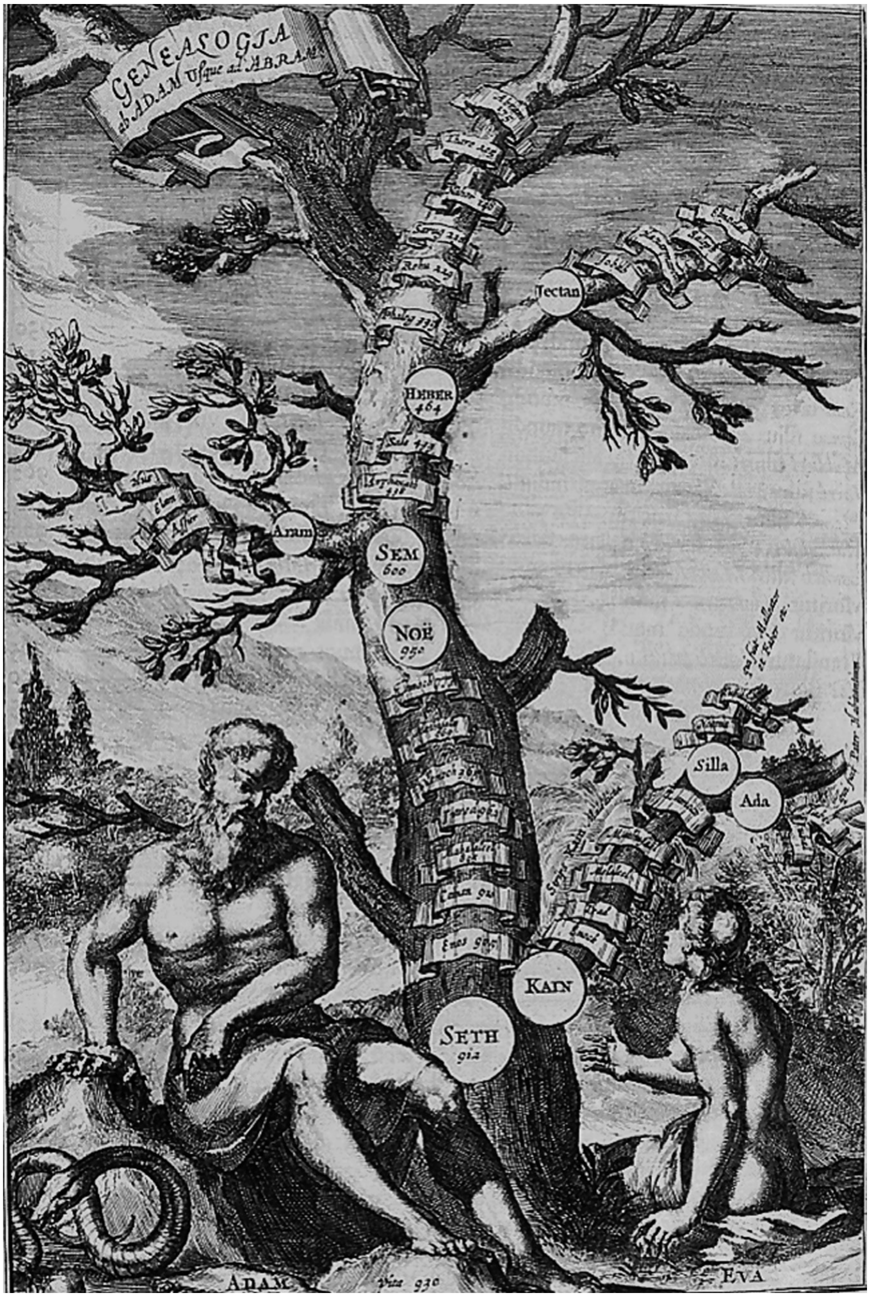

Figure 3. The genealogy from Adam and Eve to Abraham as drawn by Athanasius Kircher (1675: 237) in his work on the *Ark of Noe*.

interpreted the scales as depicting the actual natural history of the Earth, and scales become interpreted as seriations that depict the periods and 'natural' flow of time.

That spatial distance can measure time is exemplified by the geological timescale, where the different layers of the Earth represent different periods. Lyell (1830, 1832, 1833) demonstrated that although geological strata are non-uniform, with some layers being absent, thicker or thinner than others at different locations, their succession is orderly (Fig. 4). This successive order is identified through alphabetic numeration that enables uniformization. Just as in chronologies, time becomes a linear succession of events.

Lyell furthermore suggested that the causal explanations given for the formation of the different layers over time can also be made uniform, by arguing that the present explains the past. The subtitle of his

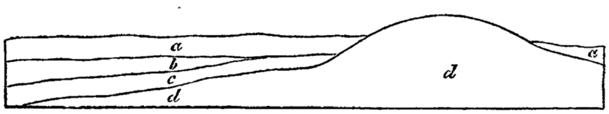

Figure 4. Idealized depiction of the 'order of succession of stratified masses' by Lyell (1833) in his *Principles of Geology*, Volume 3, p. 15.

Principles of Geology says just that, and reads as 'being an attempt to explain the former changes of the Earth's surface, by reference to causes now in operation' (this being an example of Whewell's 'uniformitarianism').

The geological strata become a means to track organismal change, and the geological timescale becomes a means to measure and found evolutionary time. Haeckel, in particular, would try to calibrate the genealogical tree of vertebrates with the geological timescale (Fig. 5).

At this junction in history, scholars sought to find the order or linear succession of various aspects of natural history (Gontier, 2015: 229). Developmentalists analysed the fertilized egg for how it transforms into an embryo, child and adult. Historians hypothesized that human history runs from the Bronze and Iron Ages to Antiquity, the Middle Ages, the Renaissance and the Modern Age. Moral philosophers and sociologists conjectured that Western societal history transitioned from hunter-gathering to farming to industrialized societies, and so on.

As denominations of specific periods in history, these scales lean toward chronologies that delineate non-uniform moments in time that are designated as eras, periods, epochs, ages, etc. But they also deviate from mere chronological recordkeeping in that the non-uniform moments together are thought to form a linear succession or series of events that necessarily follow one another sequentially in time. Particular time series are understood as natural seriations (Rieppel, 2010), i.e. as depicting a necessary and universal order. In this regard, scales of nature introduce the stadial phase thinking typical of early natural history research, where succession becomes understood as law-like, necessary, and inevitable. Humans, for example, are children for only a couple of years, while they are adults for the rest of their lifetime, and they inevitably have to pass the stage of childhood to reach adulthood.

Here is also where time's arrow (Gould, 1987) starts to show a curve toward racist and imperialist ideas of progress. Non-Western cultures that did not, like the Western world, organize into agricultural or industrial societies, for example, were falsely considered as 'stuck in time,' 'underdeveloped' or of 'lower rank' than those of Westerners.

With respect to causality, a shift takes place, from understanding the time differences or transitions between the eras of Earth or the ages of life as resulting from divine will and intervention, to understanding the phases of history as natural events occurring in time, to understanding the seriations or order of successions as necessary and again as teleological. This leads to natural causes becoming formulated as laws of nature, and these historicist laws, as Popper (1957) called them, are thought to give directionality to history. Examples include orthogenetic theories in biology and unilineal theories in anthropology. Both assume that history develops linearly and progressively according to a set of predefined stages. Time is thought to have directionality, and this gives a new interpretation to teleology.

However, if a distinction can be made between a time of the Earth, an age of men or different developmental sequences, then there exist multiple times, each of which runs in distinct directions. Straight-line seriation thinking, therefore, runs into the same problems as chronological research. The various times are either calibrated into a single universal timeline, or credibility is given to the plurality of time. The former also requires a grand theory of everything, that can explain all separate times and that can justify their grouping, whereas the latter requires epistemic pluralism, and a justification of why various times differ.

Here is where Newton enters the scene. Besides amending chronological thinking, in his *Philosophiæ Naturalis Principia Mathematica* published in 1687, Newton formulated the universal law of gravitation, and he thereby introduces a notion of universal or absolute time.

> Absolute true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.
>
> Newton in Chittenden (1846: 77).

Newton's absolute time, which equals a number line, provides a standard that enables the measuring of different times, as well as the incorporation of different times into a single universal timeline or a single historical or scientific narrative. Time becomes understood as a linear succession of events (of matter in motion), and causality becomes understood as a linear and timely relation between natural cause and effect. Because time becomes calculated in number, it becomes divisible into various parts or moments in

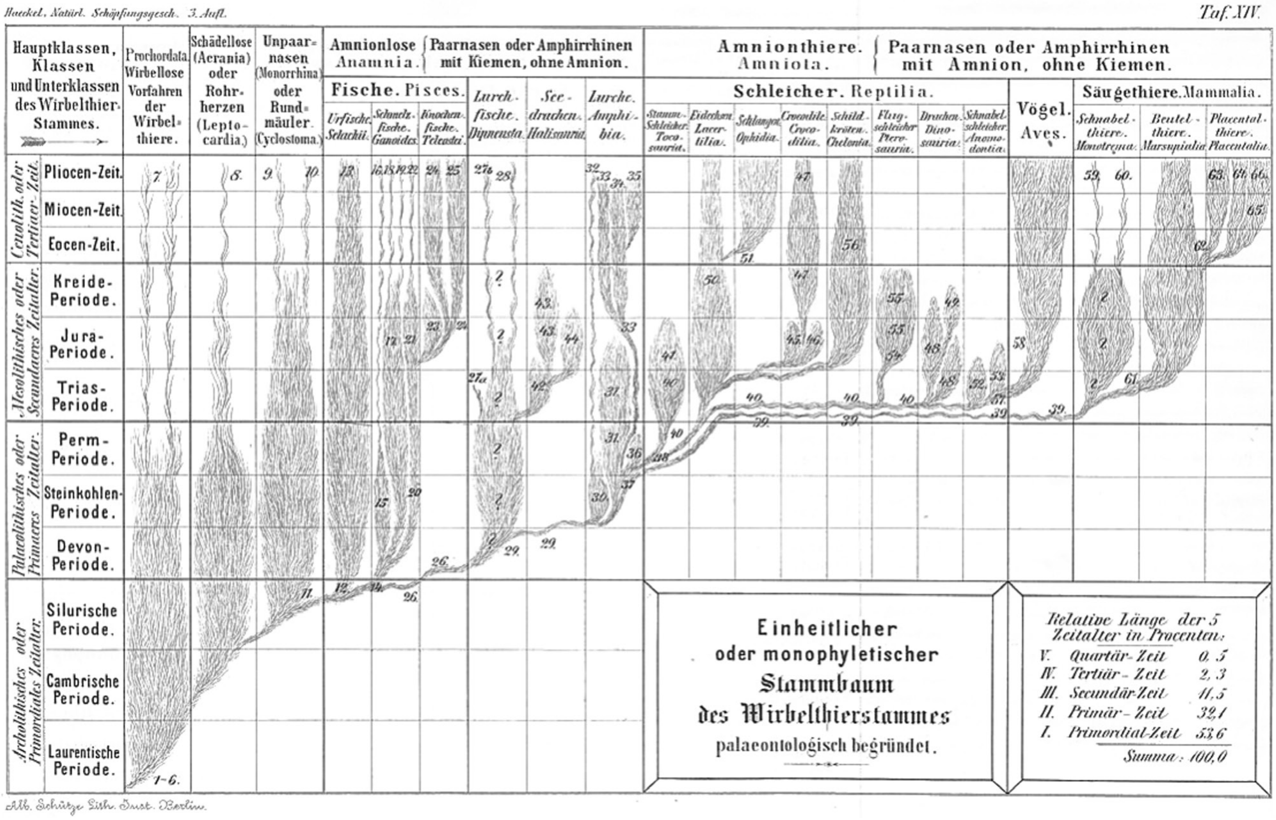

Figure 5. Haeckel's monophyletic genealogy of vertebrates as grounded in the geological timescale, first published on p. 288 of his 1872 book *Natürliche Schöpfungsgeschichte: Gemeinverständliche Wissenschaftliche Vorträge über die Entwickelungslehre* (Haeckel, 1872). Source: https://digital.sciencehistory.org/works/9k3l06g.

time (Heidegger, 1915), and causality becomes a study of how different moments in time follow one another sequentially according to natural law. The moment in time A is said to cause or bring forth another moment in time B, and A is argued to have precedence or contiguity over B. Such a view also implies that if there is a B, one can backtrack from there to an A. In other words, given an A, B will follow over time and given a B, one can backtrack to an A. Accordingly, the non-uniform teleology of before becomes naturalized, uniformized and linearized. This introduces the pinnacle of teleological thinking in science, because the assumption that unchangeable natural laws exist enables the predictability of future events.

The adoption of a numerical timeline to measure universal time is what enables the age of the Earth to grow from a couple of thousand years to millions and billions. The introduction of a numerical timeline enables the homogenization and incorporation of the different developmental, geological, historical and anthropological scales into a single historical narrative that is measurable by algebraic number. Causality theory becomes part of that narrative. Lumps of time or episodic events become joined, and the narrative serves as a way to homogenize the events as well as time into a seriation that has duration.

This narrative is also adopted by the developing evolutionary sciences. Multilinear phylogenetic tree thinking provides the example (O'Hara, 1996; Gontier, 2011; Tassy, 2011; Pietsch, 2012; Archibald, 2014; Fisler *et al.*, 2020). Tree models originate from genealogical thinking that map the historical descent lines of families. Evolutionary tree diagrams go beyond and map the genealogical descent of entire groups or species.

Rather than measuring the life cycles of individual organisms, Darwin (1859) studied generations of individuals that over time group into populations that then diversify into distinct species (Fig. 6). That this diversification occurs over generations in time is predicted by natural selection theory that becomes the unifying narrative. Generations of organisms will demonstrate variation over time, and they will gradually diversify into different species. The teleological aspect of the causal explanation given lies in the predictability of how evolution by natural selection will occur.

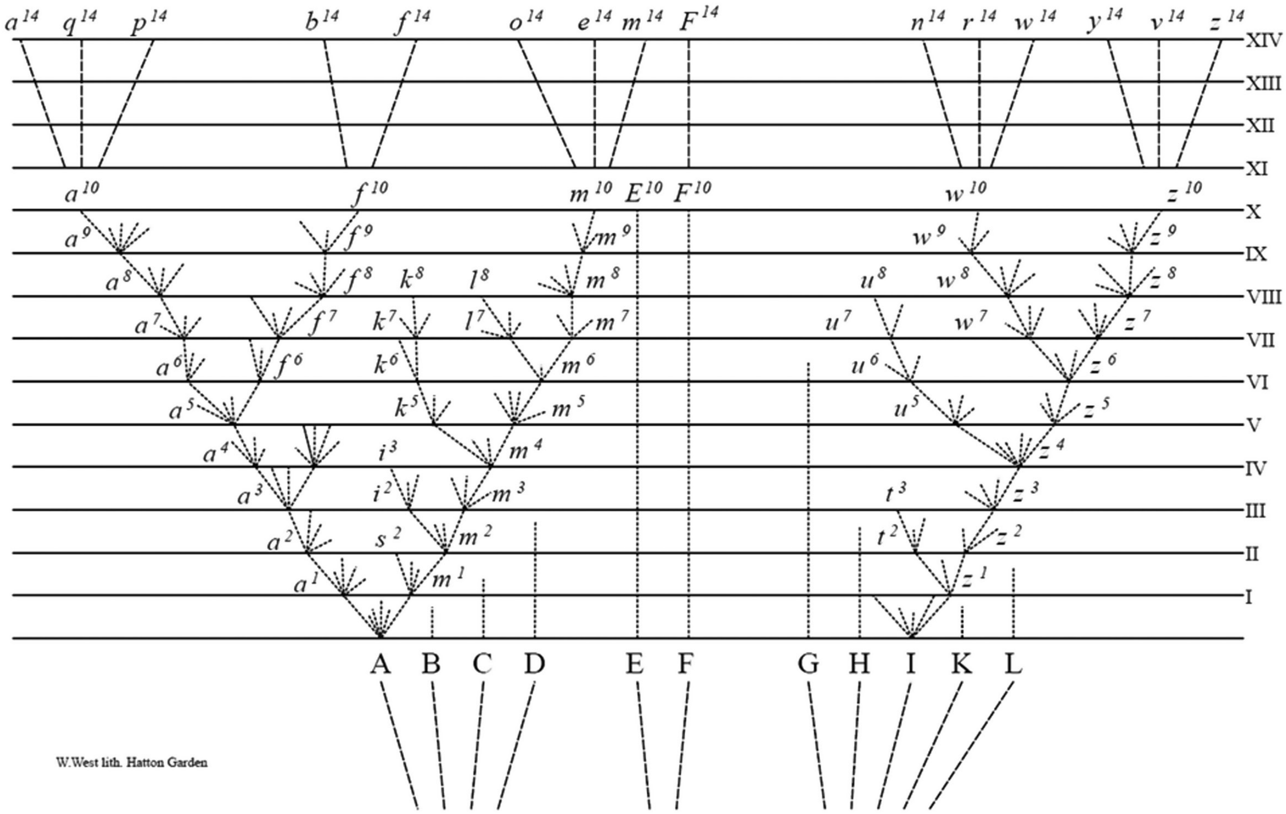

Figure 6. Darwin's (1859: 116–117) hypothetical speciation diagram. Organisms become lumped together into dotted lines that are tracked over generations for how they diversify. These branching lineages are then placed into a larger diagram consisting of horizontal lines. These horizontal lines, for Darwin, each represent a hypothesized number of generations. The uniform calculation of generations by number enables Darwin to add a linear timeline to an otherwise diversifying pattern of descent with modification. Source: Diagram of Divergence of Taxa, available at https://nl.wikipedia.org/wiki/Tree_of_Life_(Charles_Darwin)#/media/Bestand:Origin_of_Species.svg.

Darwin's diagram then functions as the basis for the development of phylogenetics. As phylogenetic trees evolve, the lineages lump together individuals into ever larger groups of species, genera and kingdoms. A branch in the gigantic tree of life then becomes a compressed lump of time, one that can diversify, but in so doing continues to follow the flow of linear time.

Absence of teleology, statistical probabilities and networks

Today, a lineage in an evolutionary diagram neither necessarily depicts a lump of time, nor does it necessarily depict the evolutionary path taken by a species. This is especially the case for cladograms (Hennig, 1950), that have 'no direct connotation of ancestry and the long axis does not connote time' (Vane-Wright, 2017). In fact, the majority of evolutionary diagrams stay uncalibrated in time. Unrooted, they depict statistical averages of likely evolutionary relations that are calculated based upon found genetic or other morphological similarities. In this regard, Rieppel (1988: 166) warned early on not to misunderstand cladograms for depicting lawful relations or actual evolutionary processes. In contrast to the older scales and chains of being, evolutionary diagrams today no longer try to miniaturize the whole of nature. Rather, they are understood as scientific tools that favour the most likely (highly probable relationships), parsimonious (with the least assumed changes), or optimal explanations (able to explain existing hypotheses) of how the elements depicted possibly relate. Models are thus recognized as approximations at best.

Beyond the study of natural history and evolutionary relatedness, scholars today in addition study how organisms develop during ontogeny, and how organisms interact with one another in the economy of nature. This brings forth studies of how distinct lineages interact horizontally, in space, and how these horizontal interactions affect the future course of evolution in time. These reticulate interactions are depicted in network diagrams. Examples include gene-regulatory networks,

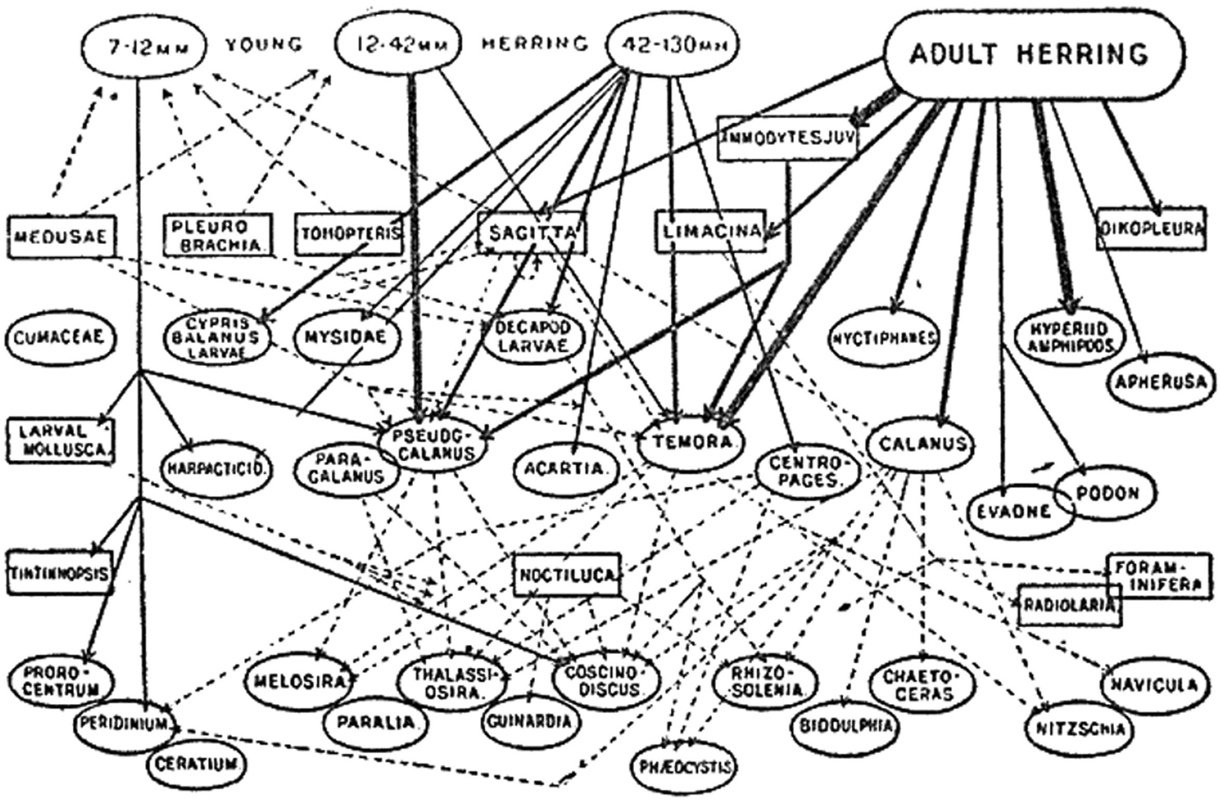

Figure 7. One of the first network diagrams introduced by Hardy (1924) to illustrate the ecological food interactions of the herring at separate phases during ontogeny. Source: Elton (1927: 58).

food networks (Fig. 7) or network diagrams that depict lateral gene transfer, symbiosis, symbiogenesis, hybridization (Fig. 8) or infective heredity. These diagrams have made scholars question and complement tree of life imagery and metaphors with web of life metaphors and diagrams (Reinheimer, 1915; Doolittle, 1999; Huson & Bryant, 2006; Carrapiço, 2015; Bechtel, 2019; Podani, 2019; Papale *et al.*, 2020).

Network diagrams demonstrate fundamental differences with evolutionary trees (Table 2). Evolutionary trees are classically drawn within Cartesian coordinate systems that track changes in space and over time. Such tracking is necessarily time consistent. Network diagrams enable the modelling of non-linear, horizontal and reticulate interactions that happen during lived time, in an extended present (Gontier, 2016). Both diagrams focus on distinct aspects of the evolutionary process.

Scholars today accept that there are different modes and tempos of evolution (Simpson, 1944). Regarding the mode of evolution, in addition to natural selection and drift, eco-evo-devo (Gilbert & Epel, 2008; Hall, 2012) and reticulate evolution schools (Margulis, 1998; Doolittle, 1999) have identified numerous different mechanisms and processes whereby evolution occurs. Evolutionary scholars today debate how these mechanisms and processes can be integrated into an extended synthesis (Pigliucci, 2007), or in the third way to evolution (Shapiro & Noble, 2021).

Regarding the tempo of evolution, beyond evolving gradually, evolving species or clades can show punctuated equilibria (Eldredge & Gould, 1972), i.e. long periods of stasis that are intermitted by short periods of rapid change. Reticulating evolutionary mechanisms and processes can also cause rapid evolutionary change (Sapp, 1994; Gontier, 2015). The study of deep time is complemented with research on the pace or rate whereby evolution occurs.

Scholars nowadays altogether distinguish between various kinds of time. Chronobiologists study circadian rhythms (Pittendrigh, 1958), molecular geneticists have introduced the notion of molecular clocks (Zuckerkandl & Pauling, 1965), and phenomenologists investigate lived or experienced time (Husserl, 1964). How these various times fit into a single universal numerical timeline remains a topic of ongoing study.

Newton's notions of absolute space and time that grounded modern physics and early natural history research have traded place with the notions of general relativity (Einstein, 1917) and a more dynamic and

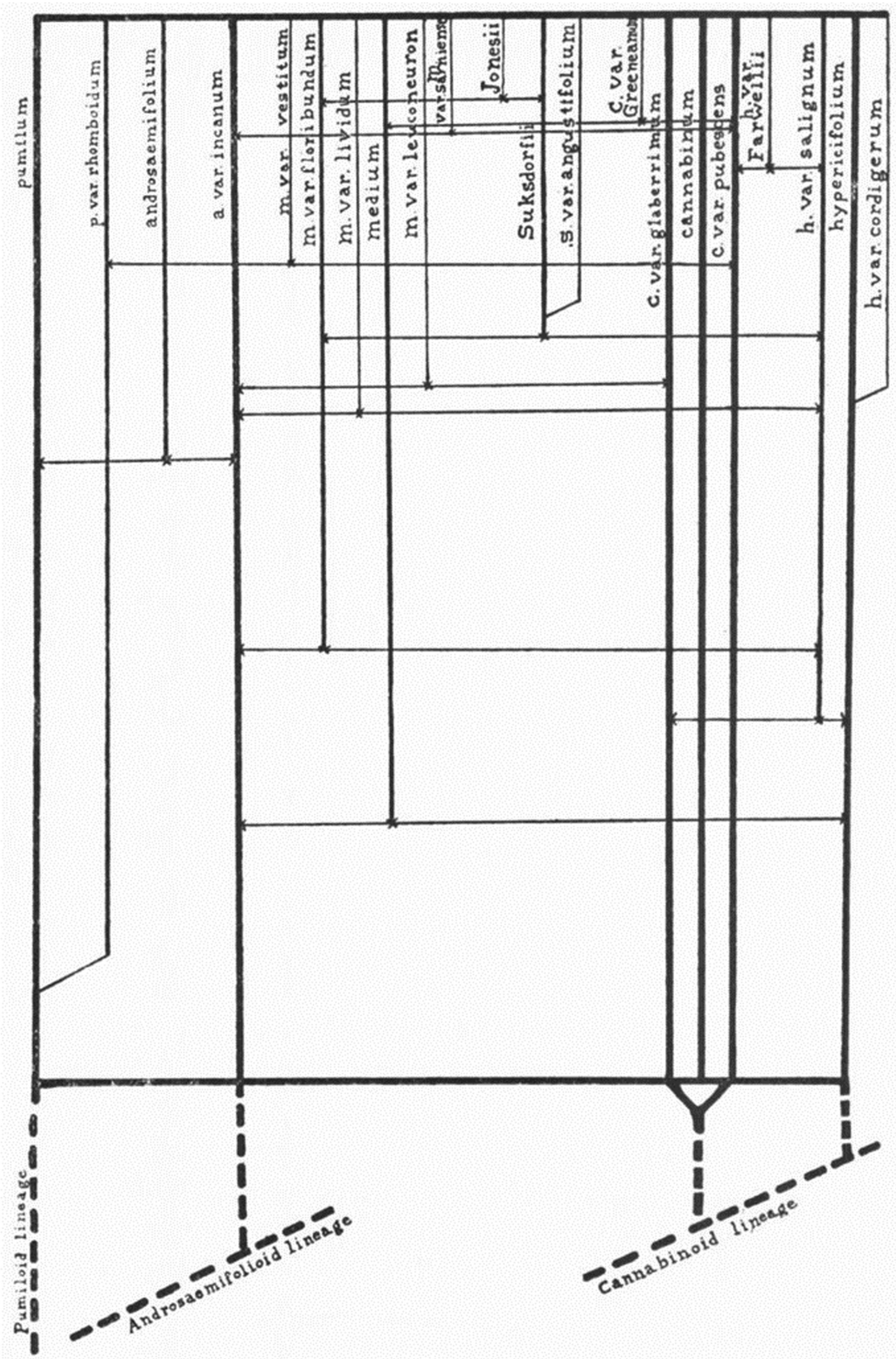

Figure 8. An early phylogenetic 'chart' or network by Woodson (1930: 75) depicting the assumed speciation of the genus *Apocynum* (flowering plants also known as dogbane or Indian hemp) through the hybridization of four potential ancestors. Broken lines represent hypothetical beginnings of the genus, solid lines stand for the relationships assumed to exist between the known species and varieties, the length of the vertical solid lines indicates the age of the lineages, the thickness depicts their relative abundance, and the horizontal lines illustrate hybridity. Horizontal lines are furthermore intersected with a vertical line with length and thickness proportional to the abundance and age of the hybrid lineage.

relative understanding of spacetime (Minkowski, 1908). In association, scholars have also started to question the existence of law-like, deterministic causality, and they have started to question altogether the succession and upward motion of cause-effect that they replace with concepts of biological relativity (Noble, 2016; Noble & Noble, 2022). Absolute determinism today trades place with chaos theory which proves that the same phenomena can have different causes, and the same causes can have different outcomes. Consequently, the world nowadays is understood through process accounts (Whitehead, 1929; Nicholson & Dupré, 2018) or probabilistic causalities (Walsh *et al.*, 2017).

These advances have made certain scholars question the reality of time (McTaggart, 1908). In place thereof, time is studied as a construct of the human mind, needed for navigating thoughts and actions (Varela, 1999) or of human culture, where time reckoning helps in sociocultural organization (Gontier, 2016, 2018b). Other scholars continue to consider time (Bechtel, 2011; Unger & Smolin, 2015) and causality (Machamer *et al.*, 2000; Levy, 2013) as singular and real and this brings forth the school of new mechanism (Levy, 2013). Still other scholars consider time and causality as real but not necessarily as universal or singular. The assumption that there can be different times and different kinds of causation brings forth ontological and epistemological pluralism (Braillard & Malterre, 2015; Gontier, 2018a). That means that scholars distinguish between distinct kinds of causation. Given the variability of circumstances, B can be caused by A or by C.

Table 2. Distinctions between evolutionary trees and network diagrams

Evolutionary trees	Evolutionary networks
Cartesian: tracking in space and over time	Multidimensional scaling
Linear, multi-linear	Non-linear, multidirectional
Time consistency	No necessary time consistency
Vertical descent	Horizontal and reticulate interactions
Phylogenetics: the study of the past or deep time	Ontogeny, ecology and reticulate evolution: the study of the extended present or lived time

Time, causality and teleology

In sum, cosmologies are foundational for ontologies which are theories on the nature of being, and these often become depicted into cosmographies. Causality theories in turn are formulated in epistemologies that explain the nature of being. Intellectual history teaches us that it is wrong to assume that only Ancient Greek or Neolithic cultures endorsed teleological views on causation. On the contrary, teleology also characterizes Judeo-Christian cosmologies as well as early natural history research, modern evolutionary biology and classical physics. In religious traditions the end is predestined according to the divine will, and in scientific traditions uniform laws ideally enable predictions on the beginning and end of the universe. Only now are teleological notions of causality becoming questioned in current evolutionary biology and contemporary physics. This questioning raises doubts about the existence of both absolute time and space. Accordingly, the certainty and predictability of the future or the past, as well as our ability to acquire knowledge thereof, are questioned in favour of research on contingency, uncertainty and probability.

PART II: FROM CAUSATION TO TIME VIA HIERARCHY THEORIES

Cosmographies are the intellectual forerunners of hierarchy theories, and today hierarchy theory serves as a means to conceptualize and depict causation. Causation is conceptualized as running up or down a single hierarchy, and more recently, also as running between distinct hierarchies (Table 3). This second part examines how the major paradigms within evolutionary biology have conceptualized and visualized causality by making use of hierarchy theory, how hierarchy theory in turn has expanded

Table 3. Causality as conceptualized from within different hierarchy theories and their associated notions of time

Paradigm	Natural history research	Neodarwinism	Eco-evo-devo	Current evolution studies
Hierarchy	Linear	Nested	Nested	Interactional
Causality	External to the linear hierarchy	Upward a nested hierarchy	Up- and downward a nested hierarchy	Reticulate, between interactional hierarchies
Outlook	Forces, laws	Affordances	Constraints	Interactions, processes
Orientation	Permanence	Temporal change	Spatial change	Spatiotemporal change

to accommodate different causality theories, and how both again correspond with different notions of time.

Epistemic questions in evolutionary biology

Classical physics has claimed, that for scientific analyses, it suffices to ask the how question, how external force underlies change (understood as the movement of matter). Evolutionary biologists instead have continued to ask the what and what for questions, by trying to delineate organism and species boundaries on the one hand, and by trying to understand goal-oriented behaviour and agency on the other.

Paraphrasing Ernest Nagel, Mayr (1961: 1501) in this regard wrote that causality traditionally '… is believed to contain three elements: (i) an explanation of past events ("a posteriori causality"); (ii) prediction of future events; and (iii) interpretation of teleological – that is, "goal-directed" – phenomena'. Mayr (1961: 1506) went on to note that causal reasoning in biology, and herein different from mechanical physics, has to make do with incomplete explanations of past events, and it can at most make statistical predictions of future events. Reasoning on teleology, however, is permitted when it asks about teleonomy or purposiveness. With these statements, Mayr was a transitional figure, and a crucial one, that made biology go from the causal reasoning typical of classical mechanics and natural history research, to modern evolutionary biology and modern physics.

Mayr (1961: 1502) distinguished functional biologists from evolutionary biologists. Functional biologists ask about the how of things. This how is a question of function ('the operation and interaction of structural elements') or what Mayr called proximate causation. It can be answered by research on genetics, ontogeny and ecology. Here, for Mayr (1961: 1504), there is room for teleonomy because 'the development of behaviour of an individual is purposive' (in the sense of Aristotle's formal cause, genes give structure to anatomy, and behaviour gives purpose to organisms).

By contrast, evolutionary biologists ask about the why of things, and he called this a question of ultimate causation. This why question, Mayr (1961: 1502) noted, can be directed either to the past or to the future. Directed to the past, the why question equals a 'how come', and it asks about how things came about during natural history. Directed to the future, the why question asks what things are for, and this is a finalistic question that raises the issue of teleology. Mayr reasoned that the why question in biology is a how come question that is directed, not to the future but to the past. Mayr (1961: 1504) found ultimate causation in the mechanism of natural selection, but 'natural selection is definitely not' purposive. Mayr reasoned that ultimate causes (natural selection operating on the organism at the level of the environment) do not necessarily converge with proximate causes (genetics, ontogeny and ecology that shape the organism in the sense of Aristotle's formal cause).

Inspired by Mayr, Tinbergen (1963) afterwards also distinguished between ultimate and proximate causes when he defined his four questions of ethology. The four questions respectively ask about the physiological (how), adaptive (survival value, what for), ontogenetic (how), and evolutionary (why) causes of behaviour. The physiological and ontogenetic causes correspond with the proximate causes and ontogenetic causes are again split into developmental and environmental causes. From these causes, only adaptive and evolutionary causes can be explained by natural selection, and these, for Mayr, define the ultimate causes.

The where of evolution

Dawkins (1976) broke tradition by asking whether ultimate causation can also explain proximate causation. Dawkins stated that both the what and the what for question can be explained by the how of evolution that asks about mechanism. He tried to explain genetic, developmental and even ecological aspects of life by how natural selection operates on genes and what he called extended phenotypes (Dawkins, 1982), which would found gene-reductionist views.

Debates on gene reductionism introduced a new epistemic question in evolutionary biology, namely, the question of where evolution occurs. Contrary to Darwin and adherents of the Modern Synthesis that understood natural selection to operate on the organism at the level of the environment, Dawkins, and herein following Williams (1966), raised the question of how natural selection can target genes directly, and where such selection would occur. Answers were sought on the one hand, in the units (Lewontin, 1970) and levels of selection debate (Brandon, 1982) and, on the other hand, in debates on the nature and universality of natural selection (Campbell, 1974).

Today, debates have somewhat settled on the consensus that selection operates on multiple units (Hull, 1980; Griffiths & Gray, 1994; Griesemer, 2000) at multiple levels (Gould & Eldredge, 1988; Wilson & Sober, 1989; Lloyd & Gould, 1993; Boyd *et al.*, 2011). Debates on the nature of an extended evolutionary synthesis (Pigliucci, 2007; Pigliucci & Müller, 2010), or third way of evolution (Corning, 2020, 2022a; Noble, 2021; Shapiro & Noble, 2021; Shapiro, 2022a, b) have moreover made it clear that evolution can altogether proceed by mechanisms and processes distinct from selection.

Common to all these debates is that they make use of hierarchy theory to make their claims (Simon, 1962; Lewontin, 1970; Pattee, 1973; Hull, 1976; Eldredge & Salthe, 1984). Evolution can even be defined as that which occurs universally when units evolve (change) at levels of an ontological hierarchy by mechanisms and processes (Gontier, 2021). The question that remains unresolved is the question of how evolutionary hierarchies can be adequately conceptualized.

Kinds of hierarchies in biology

Biological phenomena have been analysed from within four kinds of hierarchies: aggregational, linear, nested and interactional hierarchies (Gontier, 2021). Aggregational hierarchies are collections of non-interacting units that lack compositionality; examples are artificial classification systems such as the early chronologies of history. These arrange events according to how they occur over generations or over calendrical time, but the events themselves do not compose into a single narrative.

In linear hierarchies, units are arranged sequentially over time, and the sequence itself becomes understood as meaningful. Examples are the timescales and seriations where events become grouped into a narrative that becomes understood as directional and necessary.

In nested hierarchies, the units of a lower level are said to be arranged in such a manner that they actually bring forth a new level. The new level is said to be constituted by the lower levels. Examples are Mayr's (1982) developmental hierarchy where cells constitute tissues, organs and functional systems; and Hull's (1980) evolutionary hierarchy where genes bring forth organisms and organisms bring forth species that are depicted as lineages. Hull's scheme is therefore alternatively known as the replicator, interactor, lineage scheme.

Most evolutionary theories have been formulated from within nested hierarchies. Scholars today, however, question the nestedness of these hierarchies, whether these always bring forth new wholes, and they also ask about the existence of multiple hierarchies and how these interact with one another horizontally. These can be called interactional hierarchies (Gontier, 2021), and they are studied by ecologists and macroevolutionary scientists (Eldredge, 1985, 1986) as well as by scholars interested in reticulate evolution (Margulis, 1998; Doolittle, 1999; Morrison, 2016; Papale *et al.*, 2020; Haraoui, 2022).

Causation from within hierarchy theories

Hierarchies facilitate reasoning on causality, and this too has undergone conceptual changes over time. Aggregational hierarchies such as chronologies gather historical data into a single set for which no causal theories are formulated. They function merely as descriptions.

Causation in linear hierarchies such as scales of nature, timelines or seriations is sought outside the hierarchy and hypothesized as forces or laws that act upon the elements of the hierarchy. Early Darwinian thinking, for example, understands selection as occurring from the environment upon the organism, and selection is conceptualized as external to the organism.

Nested hierarchies are foundational for modern and extended synthetic views. Neodarwinians agree with Darwin that organisms are selected at the organism-environmental interface. Following the tenets of the Modern Synthesis and the advances made in molecular genetics, they furthermore recognize that organisms are constituted by genes. This expands older hierarchical thinking because it effectively brings causality inside the linear hierarchy that runs from genes to organisms to species. Lower levels of a hierarchy now not merely precede the higher levels in time, they actually constitute or cause the higher levels. Causality is understood as going upward in the evolutionary hierarchy, from genes to organisms to species. Upward causation theories continue to follow the flow of time, but scholars, in addition, examine evolutionary affordances or 'allowances' (Eldredge, 1989: 43), i.e. how genes afford or enable the formation of organisms, and how organisms enable or afford the evolution of species. This brings forth research on temporal change and it underlies reductionist approaches (Rosenberg, 2020).

In eco-evo-devo views that extend the Neodarwinian synthesis, causation is considered as running down the same nested evolutionary hierarchy, from species to organisms to genes (Campbell, 1974; Emmeche *et al.*, 2000; Okasha, 2012). Downward causation asks how species can influence how organisms evolve and how organisms can influence how genes evolve. This form of causation is therefore sometimes thought of as going against the flow of time, in which case it is considered a form of backward causation. But this is not necessarily the case. If organismal behaviour impacts the spread of genes, or if epigenetic changes occur due to information flowing from RNA to DNA, then such events occur during development or in the economy of nature. Downward causation theory is, therefore, better understood as concerned with research on spatial change. It investigates the problem of evolutionary 'constraints' (Eldredge, 1989: 43) imposed by spatial settings, i.e. how species constrain the evolution of organisms, and how organisms constrain the evolution of genes.

Downward causation requires consideration of development, or what Lewontin (1982) called the internal environment, as well as ecology, which encompasses the vast external environment. But this introduces a conceptual tension. Is causation internal or external to the nested evolutionary hierarchy? Eldredge (1985) has argued that it is both, and in this regard, he has argued that the problem needs to be considered from within a dual hierarchy. The dynamics of up- and downward causation have mostly been studied from within the same nested hierarchy that goes from genes to organisms to species. By way of an alternative, Eldredge has introduced a dual interacting nested hierarchy made up of a genealogical hierarchy, and an ecological hierarchy, both of which interact mostly at the organismal level. Following Mayr (1982) and Dawkins (1976), Eldredge's genealogical hierarchy is information or replicator-based. It depicts how genes bring forth organisms and higher levels in time, and this hierarchy is foundational for the tree of life. Following Hull (1980), who in turn was inspired by Lewontin (1970), Eldredge's ecological hierarchy is interactor-based, and it investigates how beyond genes, organisms and species exchange matter and energy in the economy of nature. This hierarchy is foundational for the biosphere. It is the combination of both hierarchies that for Eldredge enables an understanding of evolution. In his dual nested hierarchy, units at lower levels continue to be necessarily constitutive of higher levels, and lineages remain understood as monophyletic taxa, but horizontal interactions can occur between the distinct hierarchies (Tëmkin & Eldredge, 2015).

Matter and energy transfer and the ecological hierarchy

Eldredge developed the dual hierarchy in collaboration with Salthe (Eldredge & Salthe, 1984) and Vrba (Vrba & Eldredge 1984). Salthe (2015: 164), in particular, credits the Odum brothers for inspiration on the energetic aspects of the ecological hierarchy. In his textbook *Fundamentals of Ecology*, Eugene Odum (1953: 4–5) developed a 'layered cake' model of the biological sciences (Fig. 9) that detailed the place of ecology. The biological cake can be cut two ways. On the one hand, 'basic divisions', 'concerned with fundamentals common to all life', 'not restricted to particular organisms' are studied by the fields of 'morphology, physiology, genetics, ecology, and embryology'. On the other hand, 'taxonomic divisions' are concerned with problems of 'morphology, physiology, ecology, etc., of specific kinds of organisms'. This brings forth specialized fields such as 'zoology, botany, and bacteriology', that can diversify further into ever more specialized fields such as 'phycology, protozoology, mycology, entomology, ornithology, etc.'.

The first division brings to light the need for research on general principles of biological structure and change, and this would prove foundational for Odum's work on biological organization and energetics (matter

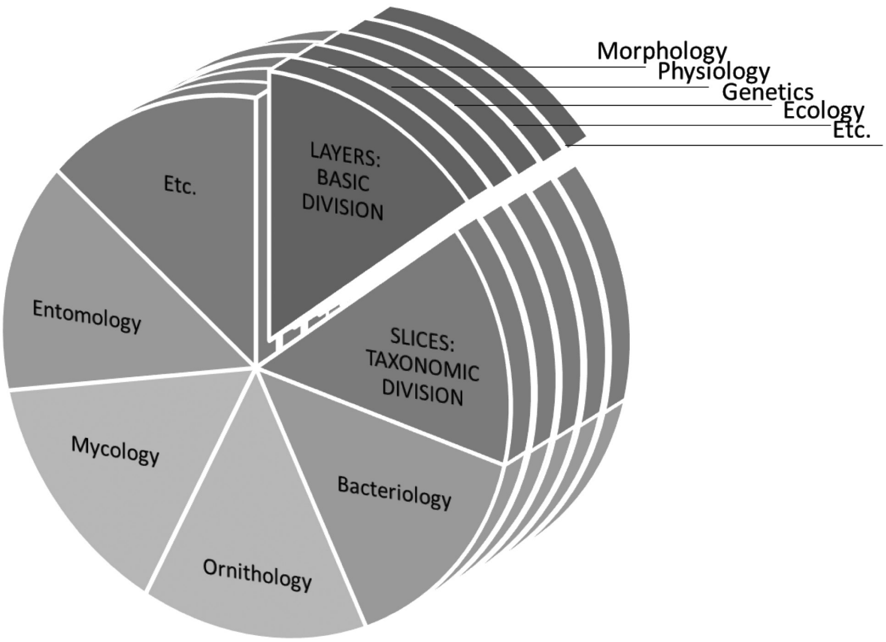

Figure 9. Schematic interpretation of Odum's (1953: 4) layered cake model of biology that distinguishes basic divisions of the field from specialized fields based on taxonomy.

Protoplasm - Cells - Tissues - Organs - Organ Systems - Organisms - **Populations - Communities - Ecosystems – Biosphere**

ECOLOGY

Figure 10. Schematic interpretation of Odum & Odum's (1959: 6) biological spectrum of biological organization where above-organismal levels (in bold) are considered of particular relevance for ecology.

Biotic components	Plus	Abiotic components	Equals	Biosystems	
Genes	=> <=		=	Genetic systems	
Cells	=> <=	Matter	=	Cell systems	
Organs	=> <=	~~~~~~~~~~ ~~~~~~~~~~	=	Organ systems	
Organisms	=> <=	Energy	=	Organismic systems	E C
Populations	=> <=		=	Population systems	O L
Communities	=> <=		=	Ecosystems	O G Y

Figure 11. Schematic interpretation of Odum's (1971: 5) levels of organization spectrum that now also includes the abiotic interactions that underlie biosystems formation.

and energy transfer) later co-opted by Salthe and Eldredge. In the second edition of the *Fundamentals of Ecology*, edited by Odum & Odum (1959), the scholars introduce a 'biological spectrum' that depicts ten levels of biological organization (Fig. 10). The spectrum goes from 'protoplasm' to 'cells', 'tissues', 'organs', 'organ systems', 'organisms', 'populations', 'communities', 'ecosystems', to the 'biosphere', and according to the classification of hierarchies given above, the spectrum can be understood as a linear hierarchy. The right part of the spectrum that, for the authors, starts above organisms, is of relevance for ecology, while the left part, below organisms, concerns questions of genetics, physiology and morphology.

In the third edition (Odum, 1971: 5) that inspired Salthe, this biological spectrum transforms into a spectrum with six levels of organization (Fig. 11). The older biological spectrum is now recognized to interact with the physical environment, through matter and energy transfer, and this underlies functional systems called 'biosystems'.

In later works (Barrett *et al.*, 1997; Odum & Barret, 2005: 7), and perhaps inspired by earlier work by Eldredge and Salthe, this biological 'levels-of-organization hierarchy' becomes interpreted as an ecological nested hierarchy and the biosphere becomes further divided into the biome and the ecosphere. Odum and collaborators credit Novikoff (1945) and Simon (1962) for their evolving ideas on the spatial and temporal aspects of biological organization, and Novikoff (1945) opposed Lillie (1938) for associating hierarchy thinking with vitalism.

Causation from within hierarchy theories continued: the importance of reticulate causation characteristic of interactional hierarchies

By combining the genealogical and ecological hierarchy, Eldredge has opened a path toward understanding evolution as resulting from different hierarchies. In particular, reticulate evolution brings to light that there are many more hierarchies than two and they interact at various levels. Reticulate evolution is evolution as it occurs by means of lateral gene transfer, infective heredity, symbiosis, symbiogenesis and hybridization (Gontier, 2015). Typical of these forms of evolution is that they occur between distinct evolutionary lineages. Bacteria can exchange antibiotic resistance genes amongst different taxa; species belonging to different

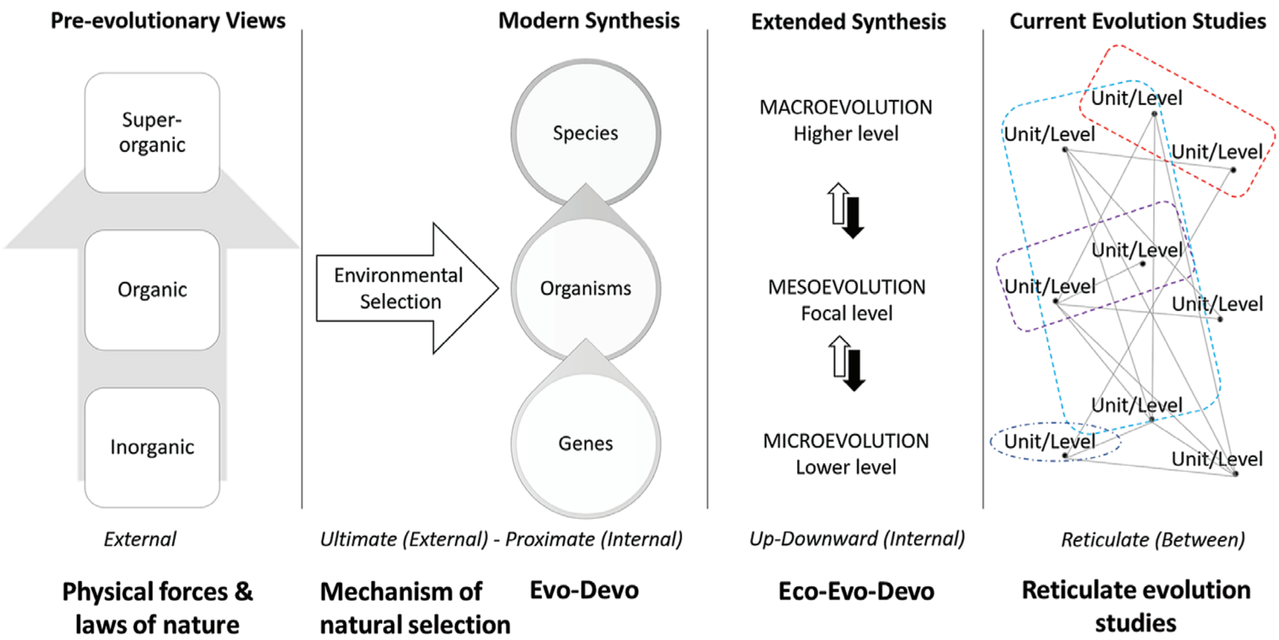

Figure 12. Shifting views on causation (expanded from Gontier, 2021).

genera, families and orders can hybridize; viruses can jump between species; and symbiosis occurs amongst a myriad of organisms belonging to different domains of life. Different evolutionary lineages each form their own hierarchical system or bioreality (Gontier & Bradie, 2017), and these lineages then interact reticulately, thereby bringing forth interactional hierarchies (Gontier, 2021).

Beyond constraints and affordances, interactional hierarchies focus on the interactivity occurring between distinct lineages, and this interconnection is characterized by reticulate causation (Gontier, 2021). Reticulate causation is causation that occurs between genes, organisms and species belonging to different hierarchies/lineages and this necessitates a spatiotemporal outlook. The new question that arises from this is whether these interacting hierarchies together bring forth higher-level hierarchical wholes.

The shifting locus of causation

The different hierarchies each define causation differentially. Accordingly, the locus of causation has shifted over time (Fig. 12). In pre-evolutionary worldviews, causation is defined as external to the living world. In these accounts, the world is subjected to eternal forces, laws or divine will, and these induce change from the outside.

The Modern Synthesis partly continues this line of reasoning when it understands natural selection as acting upon organisms at the level of the environment. Selection here is understood as a force that is external to organisms.

With the rise of molecular genetics, multilevel selection theory, and later eco-evo-devo, natural selection becomes internalized (Lewontin, 1982), and understood as operating within the organism, and within the genealogical hierarchy that runs from genes to organisms to species. Similarly, proximate causation is conceptualized as internal to the organism, and ultimate causation as external to the organism.

With the introduction of eco-evo-devo schools, scholars distinguish between micro-, meso- and macroevolution, and they investigate up and downward causation from within a single nested, gene-based hierarchy. This hierarchy was called the developmental hierarchy by Mayr, the evolutionary hierarchy by Hull, and the genealogical hierarchy by Eldredge. Up and downward causation is understood as internal to a single genealogical or replication-based hierarchy. This hierarchy, however, loses sight of the ecological interactions that occur in the economy of nature. The genealogical hierarchy, therefore, becomes complemented by an ecological hierarchy.

Genes, organisms and species are not only selected by means of natural selection, they also engage in all sorts of reticulate interactions within the economy of nature. Reticulate causation occurs between units and levels belonging to multiple hierarchies, many more than two. Each of these lineages has its own history in time, each occupies its own space, and they interact reticulately in spacetime.

PART III: TELEONOMY AS SELF-CAUSATION

Beyond up, down and reticulate causation, another question relevant to the study of causation is the question of self-causation. Understood from within hierarchy theory, self-causation asks whether a level in a hierarchy, the focal level in particular, can bring forth itself.

In the previous part it was discussed how levels of nested hierarchies are understood as made up of units at lower levels. Organisms are brought forth by genes, species are groups of organisms. The question of self-causation instead asks whether the focal level is caused, not by the lower units of a hierarchy, nor by the higher levels, but by itself. In other words, self-causation asks how the focal level can generate itself. If that is possible, then the focal level is its own cause or *causa sui*. When self-caused, it could also be *sui generis* or '*in a class by itself*', and it would not necessarily be part of a nested hierarchy made up of lower or higher levels.

The problem of self-causation provides a mind twist that has often been dismissed as impossible. That a focal level such as the organismal level can cause itself, *sui generis* is generally considered false. Organisms are the offspring of their parents; they did not make themselves. Causality-wise, a human child, for example, is determined upwardly by its genes, and these genes were acquired reticulately, during the reproductive act of its parents. But once the child exists, do the parents determine its life? Or does the child cause itself, is it *causa sui*? An answer to where to localize causation for current actions becomes much less straightforward, and it requires a referral to up, down or reticulate causation. But is that sufficient to explain the current actions of the focal level and its persistence through time?

One thing is certain, by raising the above question, the problem of time is encountered once more. In the example, the focal level, i.e. the organism or the self, is either considered from within its natural history, as being brought forth by (the genes of) its parents; or from within its present or its future, by asking if it can act and self-persist in the present, and as such determine its future.

In this part, teleonomy is analysed as a problem of self-causation over time.

Self-causation in history

Throughout intellectual history, the problem of self-causation has been approached by different scholars under different names, with or without time. The idea of the eternal return (Eliade, 1954) of the grand cycle of generation and decay, for example, is *sui generis*. It is always the same returning cycle, and every repetition is identical to the first, which therefore associates with the idea of reincarnation typical of many Eurasian religions and worldviews.

Aristotle stands at the end of this intellectual history, and he commences a search for the causes of the cycle. In Aristotle's doctrine, the cycle of coming and becoming is ultimately motivated by the unmoved mover, which is its own cause or *causa sui*. As pure act, the unmoved mover does not cause the four causes, but it does provide the motivation or wanting of all movement. With no potential to actualize, and never having had to, the unmoved mover has permanence and just is (by, according to Aristotle, thinking a thinking of its thinking). As such it becomes the longing for those in eternal motion (comparable to the nirvana in Eurasian religions). Here it becomes clear why the notion of a *causa sui* often underlies how deities are conceptualized. In this regard, the unmoved mover is often interpreted as the prime mover of the cycle, but that is already a linearized interpretation that assumes an initial beginning of the cycle in time. This interpretation is typical of the Middle Ages, but it is not how Aristotle saw it.

In less obscure jargon, and in many ways, this unmoved mover is comparable to what Newton defines as absolute time or duration (citation above). Unmoved or unaffected by the different speeds it measures, for Newton there exists an absolute time that is different from relative time. Absolute time, in itself and by its own nature ('*in se & Natura sua*' in the original Latin but see citation above) 'flows equably' without regard to anything external. Absolute time cannot be changed. But, also for Newton, this absolute time is mathematical, and it is number that 'flows equably', with one standing at a uniform distance from two, and three following at an equal distance from two, etc. As such, he considers time as having self-causing continuity. This self-perpetuation Newton calls duration.

In sum, Aristotle's unmoved mover that is its own cause or the eternal return has permanence (as an absolute unmovable time), while Newton's absolute time, in itself and by its own nature, has duration (an absolute self-perpetuating time).

Visualizing self-causation

The above can be visualized. Illustrating how a focal level causes itself seems possible only by drawing a circular diagram. This diagram however changes depending upon whether and how time is included (Fig. 13).

Generations of different sunflowers over time

This shift is illustrated once again with the example of the sunflower. Ancient scholars examined the cycle of

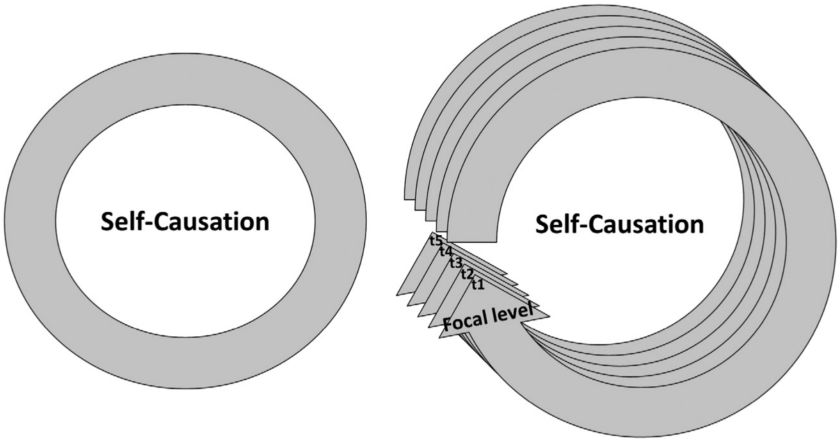

Figure 13. Diagrammatic interpretations of self-causation, without and with time. From the view of permanence, self-causation can be depicted as a single, and indivisible closed loop. From the view of duration, self-causation asks about the continuity of the focal level over time. This can be depicted as the focal level (re)generating or perpetuating over a linear timeline. The addition of time thereby induces a shift in how self-causation is understood.

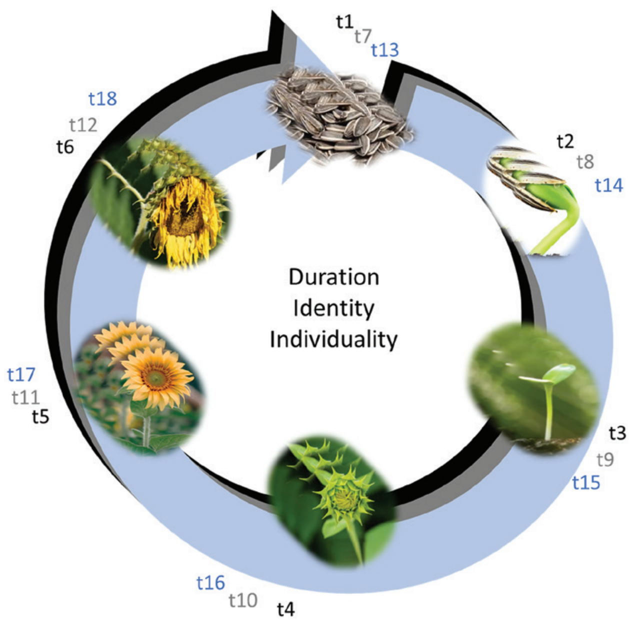

Figure 14. The regeneration of different sunflowers over time.

life and death that is common to all sunflowers. This cycle was understood to have permanence meaning that each cycle saw the return of the same sunflowers. Today, this cycle instead is understood to have duration, and scholars examine the (re)generation or perpetuation of different sunflowers over time, from a single root onwards (Fig. 14).

Trying to understand the perpetuation of different sunflowers over time, scholars investigate how seeds bring forth seedlings in one moment in time, how in the following moment, the seedling brings forth the sprout, how in the following moment, the sprout brings forth the sunflower, that, in a later moment in time dies and drops new seeds that, in a still later moment in time, bring forth new seedlings, and so on.

This brings to bear the paradox of self-causation. When time is added to the equation, rather than investigate a self or how a single focal level regenerates, the investigation revolves around how different entities of a hierarchy bring forth one another at different moments in time. The question brings forth a linear causal hierarchy that goes from t1 to tx.

Problems of identity in evolutionary worldviews

In an evolutionary worldview, different entities bring forth new entities over time. Time thereby is at most a medium, no causality can be attributed to it. Rather, it is the entities that bring forth new entities over time. Evolution brings forth new entities that are similar to the older entities, genetically, morphologically, etc., but that are not identical.

Self-causation over time understood as a problem of duration of the same or similar entities raises questions of identity. Is there continuity from the seed to the seedling over time? Are the seedling and the sprout the same individual? Is there some kind of identity, either during the generation process of one sunflower or over generations of different sunflowers?

Here, modern-day evolution theory grounds much of these questions in genetics and developmental programs (Oyama, 2000). Genetic replication or developmental programs are semi-conservative yet

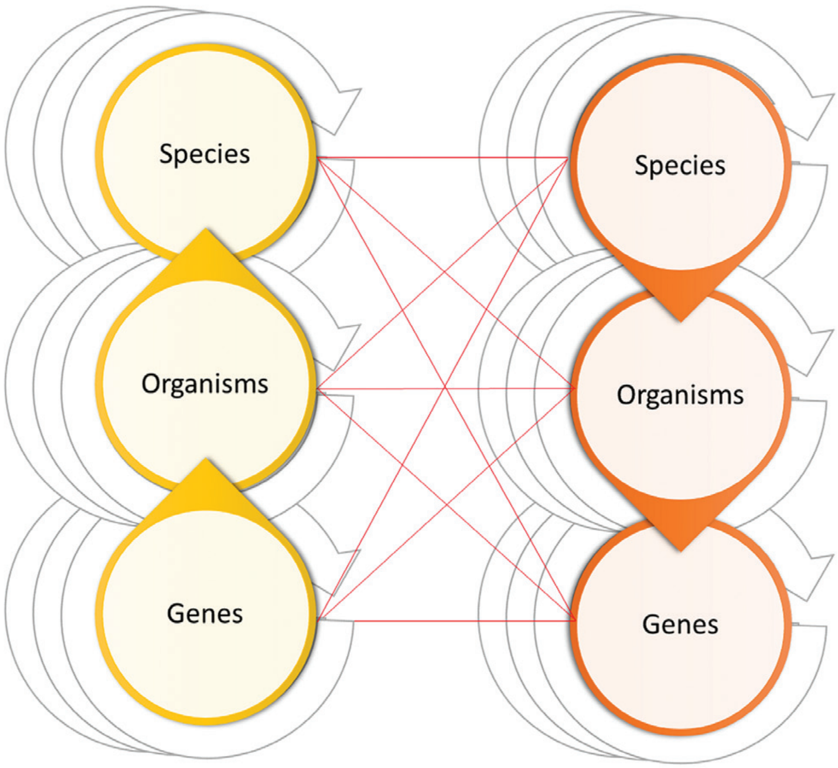

Figure 15. Schematic of upward (in yellow on the left), downward (in orange on the right), reticulate (in red in the middle) and self-causation over time (the repeating circles in grey).

fallible, and replication or reproduction consequently introduces new variations. Rather than bring forth the identical, there is change over time. In an evolving worldview, duration does not require identity. A current gene might have a natural history in an older gene, but at a later moment in time, it becomes a different gene.

Linearized self-causation or perpetuation in evolutionary biology

There is no need for identity. But there can be continuity. Self-causation can be linearized over time and as such, it looks into the problem of continuity or the persistence of a level over time. Is there room for such a linearized notion of self-causation in biology? I think there can be, and not merely at a focal level but at any level of a hierarchy. Genes can bring forth genes over time, an example being genetic replication; organisms can bring forth organisms over time through reproduction; species can bring forth species over time through speciation. The perpetuating entities are not identical, but they have continuity. This continuity can be explained by current evolutionary biology that besides natural selection theory includes eco-evo-devo and reticulate evolution studies (Gontier, 2021).

A critical scholar might object and say that there never really exists self-causation and that self-causation can be explained by referral to the other types of causation. During DNA replication, for example, DNA does not replicate 'itself'. The execution of the process requires entities such as enzymes and nucleotides operating on a lower level. For a sexually reproducing organism to bring forth new organisms, for example, in addition to 'itself', the reproducing organism needs to find a sexually compatible partner in the economy of nature. During reproduction, these partners pass on genes to the offspring they received from their parents. Or species, for example, only diverge when organismal (gene-based) and ecological diversification occurs.

A reply is that the problem of self-causation over time understood as a problem of perpetuation, needs to be understood from within interacting hierarchies where causation occurs upward, downward or reticulately (Fig. 15). During perpetuation, what persists through time is the combination of these numerous causal interactions.

That means that numerous mechanisms and processes need to be repeated over time for a focal level to persist. This process too is fallible, and that is what explains evolution. Is the focal level then somehow able to regulate the process or to give directionality to the process, by somehow taking control over the different types of causation that enable its existence? If so, might this be understood as establishing the self-perpetuating entity or self?

Individualizing causation or the question of control

Recognizing self-causation as perpetuation over time, there is a final problem that pertains to the issue of self-causation, namely the problem of what Driesch (1914) called 'individualizing causality'.

Asking whether a focal level in a hierarchy brings forth the focal level over time (with or without considering that the focal level in addition results from up, down and reticulate causal processes), brings forth a duality because, in addition, it asks whether that focal level has a steering capacity, as Plato would have called it, to organize and control the process of self-perpetuation.

This is the most controversial aspect of teleonomy debates because it asks about how, in Driesch's terms, an 'individualizing agent' can act upon natural processes, and such an agent, in intellectual history, has often been equated with a soul, the unconscious, the ego, the self, etc.

Assuming that any such individualizing agent must also be natural already helps in demystifying the problem. The question then becomes how natural entities act upon other such natural entities in such a way that they form a unity or a whole able to influence the future state of the entities involved. A quick answer to this would be through upward, downward and reticulate causation, but here, that is missing the point.

There is more to it. This brings forth the same problem Newton faced when he lumped all relative times into an absolute time, and the same problem Darwin faced when he lumped organisms into single lineages. This is a question about individuality formation. Natural entities group into larger entities, and into entire ontological hierarchies that underlie biorealities. Many of these persist over time, more or less in the same way as their progenitors did.

Do any or all of the units and levels of those hierarchies have the same causal power or do some units and levels have more control than others? Alternatively, do none have causal power, and are they acted upon from lower or higher levels of the same hierarchy, or units and levels of different hierarchies? Or do some obtain autonomy, and function as individuals or agents able to regulate and control their 'own' persistence, thereby giving directionality to the emerging system over time?

Driesch noted in this regard, that for causation to become individualizing, unifying causality is required, and such can be "purposive or teleological".

> If a system passes through several phases of becoming in succession, all controlled by unifying causality, we may speak of the evolution of the system: and every singularity of becoming that leads to the unity as the final end may be called purposive or teleological.
>
> Driesch (1914: 202).

The question of individualizing causality is a question of individuality formation over time, and such is a question that asks about the future of a system. Once a system evolved, does it have autonomy and control, over its own future, and over everything required to bring forth its future? A visualization of the problem is depicted in Fig. 16.

Individualizing causation in the sciences

Several sciences have commenced to find answers to the questions raised. The concept of autopoiesis that was introduced in the cognitive sciences by Maturana & Varela (1980) and later extended to the biological sciences, recognizes that cognitive and biological systems can self-regulate and self-organize. In the cognitive sciences, the problem is formulated as one of free will, but self-organization can also be found at a behavioural (Corning, 2014; Vane-Wright, 2014, 2019) and social or cultural level (Igamberdiev, 2017; Corning 2018, 2022b). The behaviour of organisms, as well as their sociocultural situatedness, is recognized to give directionality to the future course of evolution.

In the political sciences, the problem of individualizing causality underlies notions of accountability, intentionality and responsibility in law systems. When a delinquent, for example, has committed a crime, one might say bad genes, a bad upbringing, or bad peers are responsible, but it is the delinquent that commits the crime, and the delinquent is considered responsible and prosecuted as such. Circumstances are considered circumstantial. Law systems and penal codes work under the assumption that there is autonomy, agency and free will at the focal level, and that organisms are responsible for their actions which are considered their own.

Also in reticulate evolution studies, concepts such as holobionts (Margulis, 1991) or the Gaia hypothesis (Lovelock, 1979) work based upon the idea that there can be individualizing causation and regulation of the higher-level entity. In this regard, the living world can be understood as recycling an older world over time (Gontier, 2018a).

These different sciences provide promising avenues wherefrom the problem of self-causation can be analysed further.

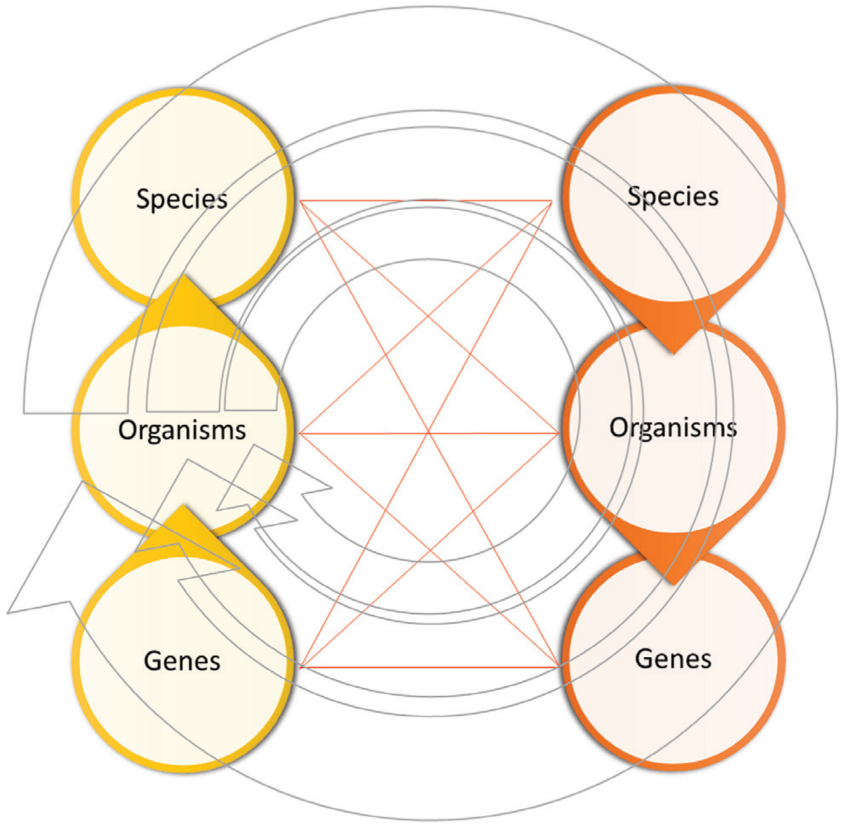

Figure 16. The problem of individualizing self-causation: is a level in a hierarchy able to control the regeneration or perpetuation of a multi-hierarchical system?

CONCLUDING REMARKS

The genealogy of intellectual thought demonstrates that how human cultures conceptualize and depict hierarchies and causality varies significantly in correlation with changing notions of time. Cyclic notions of time and causality, typical of ancient cultures, have traded place, first with linear, and then with multilinear notions of time that define causation as an up- or downward movement along the rungs of a (multi)linear nested hierarchy. Reticulate causal theories break with this tradition by investigating how different hierarchies interact spatio-temporally, during an extended present.

Distinct from up, down and reticulate causation, teleonomy can be understood as a problem of self-causation. Research on self-causation has a dual outlook. On the one hand, it asks about self-perpetuation or how a system can continue to exist over time. Evolution teaches us that there can be continuity, but there need not be identity of a system over time. On the other hand, it asks about how systems individualize and demonstrate agency that can provide directionality to their future (Table 4). Such would require control over multiple interacting systems.

Table 4. Particularities of self-causation

Time	Duration
Hierarchy	Linear, consecutive
Outlook (dual)	Identity (self-perpetuation) Individuality (agency)
Spatiotemporal orientation	Continuity

This individualization can concern a focal level, a hierarchy or a multi-hierarchical system, and it asks about the persistence of this system over time. With that, I hope to have contributed to the anatomy of the debate on teleonomy.

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DATA AVAILABILITY

This article is based on concepts and data available in the published literature.

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