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# Two contrasting principles, reductionist and systemic: Fundamentally separated or dynamically interacting?

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**Abstract** According to the intentions of the special issue "Advances in Philosophical and Theoretical Plant Biology" of the journal "Theoretical and Experimental Plant Physiology" plant biology is overviewed within the contrasting realms of natural science and metaphysics. Contrasting views in these realms are exemplified with modularity – emergence, reductionist – systemic, things – processes. Domains of diversity, serendipity, beauty and time are envisaged. It is concluded that separate work within these contrasting realms and domains has to be maintained for accumulating and specifying basic knowledge. However, this is not sufficient for advancing philosophical and theoretical plant biology towards an improved understanding of (plant-) life. It is shown that and how integration is possible. Integration must be approached and practiced for a better understanding of life.

**Keywords** Beauty · Diversity · Process · Serendipity · Time

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## 1 Starting points

What is a tree? Haukioja (1991) wrote: "a tree is not a tightly integrated organism but a by-product of its parts" (see also de Kroon et al. 2005). This is modularity and extreme reductionism towards isolated modules of trees, such as stems, leaves and roots. Similarly, modularity would reduce cells to isolated organelles, such as mitochondria and chloroplasts, and structures, such as the cytoskeleton, the endoplasmic reticulum and the nucleus. Mechanistic thinking associated with this reductionist view (mechanist-reductionist approach, MR) has led to the accusation that science of biology has nothing to do with the understanding of life (von Weizsäcker 1954). Such modularity is extreme thing-ontology to which we shall return below when we pronounce a plea for process-ontology in the sense of Nicholson and Dupré (2018). By contrast to Haukioja we may consider a tree a highly integrated, self-organized (Schmidt 2019) complex organism (systemic-complex approach, SC), i.e., as an emergence from assembling the modules in unitary organisms.

When we separate mechanistic-reductionism (MR) from systemic-complexity (SC), we ought to note, however, that we do not want to dismiss the study of mechanisms in biology. Here the term has a different affiliation regarding the empirical realization of functions driving living systems. For advancing to self-organization, integration and complexity, the basic outlines must be sufficiently secure. This implies

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that we must understand modules well, before we can move on to consider emergence from their integration. Both must interact. Reductionist modularity alone fails to understand life, as the above-mentioned critique of von Weizsäcker states well. Conversely, integration alone alights from the basic support. It does not mean that there is a "dualism". However, an intimate interaction is epistemologically important with integration, which shall become clear immediately when we turn to networks (Sect. 2.1).

Rebutting "mechanistic", of course, we mean refuting the consideration of organisms as machines. In his story writing E. T. A. Hoffmann (1776–1822) created the puppet Olimpia (Bertram 2004). The physicians Hermann Boerhaave (1668–1738) and Julien Offray de la Mettrie (1709–1751) considered the human body as a machine. Technology constructed an artefactual duck (Jacques de Vaucansons, 1709–1782), an automatic pianist (Pierre Jacquet-Droz, 1721–1790, and Henri-Louis Droz, 1752–1791) and trumpeter (Johann Friedrich Kaufmann, 1785–1866) (Schneider 2022). Such considerations in the eighteenth century are now ridicule. However, modern attempts of humanoid robot-technology and with neuro-technology expectations of trans-humanism (Weisman 2007; Alexandre 2015; Thivent 2015) are not far from disturbingly approaching them again.

With the distinction of the two principles, we arrive at the philosophy of metaphysics. As Dupré (2021) suggests and argues, in the case of the philosophy of biology it is naturalistic scientific metaphysics. It addresses reality with the most general and abstract truths. It is continuous with science. This mutual continuity is a leitmotif which means that there is not a separation but an extended effectivity. Actually, we really never know where technical development of methods still may advance us to for extending the hard empirical scientific bases. On the other hand, we are pretty sure that there are truths that will remain in the domain of metaphysics, such as emergence, processes, diversity, serendipity, beauty, time, which this essay shall address. But in fact, the origins of our universe and of life will remain myths. We believe in the big bang, but we cannot look into it, because we cannot look beyond the Planck time of the first $5.39 \times 10^{-44}$ s after the big bang. Regarding life, we have lists of basic properties explaining it, but we cannot define its origin.

## 2 Emergence

### 2.1 Creation of fundamentally new systems

A unitary whole is more than the sum of its compounds. This understanding of Aristotle leads us to the phenomenon of emergence based on much earlier thinking in plant biology (Lüttge 2012a, b, 2019, 2021, Souza and Lüttge 2015, Souza et al. 2016, Lüttge and Scarano 2019, Wegner and Lüttge 2019). Repeating the initial question "What is a tree?", we can see that it is composed of the modules stems, leaves, roots. We will not hesitate recognizing A in Fig. 1 as a tree, but we may have difficulties to accept other tall plants like B the cactus *Cereus* and C *Euphorbia* as trees. Looking at the tree as emerging

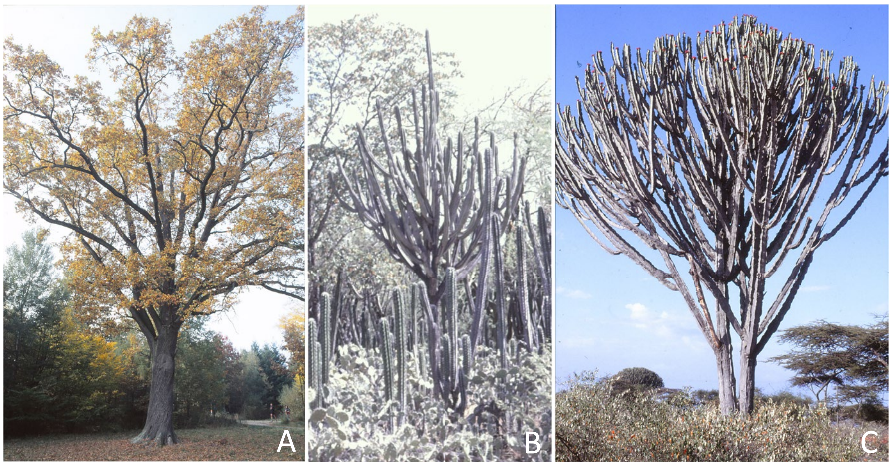



**Fig. 1** Are these all trees? **A** *Quercus* in Germany, **B** *Cereus* in Venezuela, **C** *Euphorbia* in Ethiopia

from integration of its parts, we see that it is something completely new and innovative unfolding new structures and functions not explained by the individual properties of its modules. Figure 2 shows how this happens, trying to assemble the various aspects of MR-modularity and SC-emergence and their possible interactions under one roof.

The unfolding of emergence becomes obvious when we envisage networks where modules are knots and the knots are connected via edges. By such integration a network is emerging from its knots. Now we can imagine such a network by being condensed as a whole, itself becoming a module or knot in a new network emerging at a higher level in a hierarchy of scaling. Our tree will then be a module in the emerging system of forest. Condensing again shall make forests to become modules in large habitats, habitats in ecosystems, ecosystems in biomes and finally biomes in the entire biosphere. Also going down scaling from organs to tissues and cells with their organelles similarly reveals emergence by passing through scaling levels. Overlooking the entire life of plants from photons and electrons in photosynthesis up to the biosphere, this covers in space 16 magnitudes in meters ($10^{-9}$ to $10^{7}$ m) and in time 32 magnitudes in seconds ($10^{-14}$ to $10^{18}$ s).

In forests the modules trees may all belong to the same species where we have monospecific stands, such as the *Picea* and *Taxus* forests in Fig. 3. In mixed forests they may represent a large species diversity like in the Atlantic rain-forest of Brazil also in Fig. 3. The various modules in forests also represent an array of levels because in addition to the trees there are shrubs, herbaceous understory plants, mycorrhizal fungi in the soil and many other organisms. This all results in a large biodiversity not only vertically but also horizontally in scaling levels.

## 2.2 Fostering processes

Modules are things. With the emergence after the condensation of networks to modules, we remain in the domain of thing-ontology. However, when we turn our attention to processes, we enter process-ontology, and we realize immediately that there is emergence not only when passing through scaling levels of the ontology of modules. With dynamics of thermodynamic instability and self-organization this becomes quite evident (Schmidt 2019).

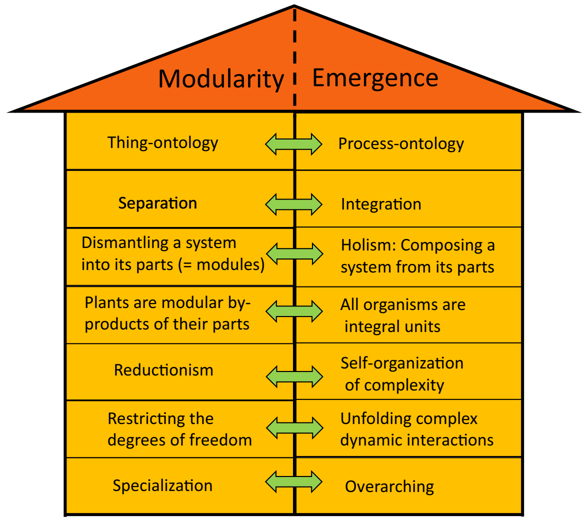



**Fig. 2** Features of modularity and emergence under a roof

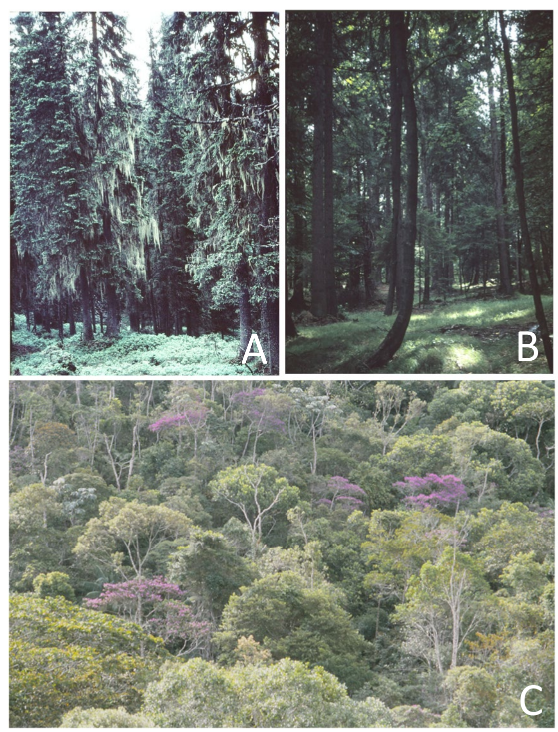



**Fig. 3** Monospecific forests of *Picea* **A** and *Taxus* **B** in Central Europe and mixed biodiverse Atlantic rain-forest in Brazil **C**

The most outstanding example is life itself. Explaining the origin of life remains philosophy and metaphysics. However, we can scientifically describe it. Life is high self-organized order. As such it apparently violates the second law of thermodynamics, where closed systems approach thermodynamic equilibrium with maximum entropy or disorder. Conversely, living organisms are open systems, which by translocation of substrates, energy and information and their metabolism keep entropy low. At the expense of their environment, they accumulate negative entropy (neg-entropy). They stay far from thermodynamic equilibrium, while overall in the sum of life and environment entropy keeps increasing and the second law is not violated. Life is a process or a bundle of processes. This applies to all living systems and all phenomena of their life (Nicholson and Dupré 2018; Dupré 2021; Lüttge 2023).

Thermodynamically equilibrium with high entropy means death. In this sense we may say that life emerges from the physical laws of thermodynamics. It is remarkable here, that the physicist Laughlin (2005, 2010) argues that all laws of physics are emergent. The laws govern processes and so the processes are emergent. The laws ruling the performance of integrated systems are independent of the laws applying to the individual processes underneath. An example is a gas made up of many molecules, that according to the emergent law

$$P \times V = R \times T \tag{1}$$

has a pressure (P) and a temperature (T), which an individual gas molecule does not have (V = volume, R = universal gas constant). As we recognize physical laws being emergent when describing processes, it is implied that processes are also emergent.

How can sugar-molecules emerge from the action of particles of quantum physics, such as photons and electrons? They do! The sugar molecules we have on the planet are emergent from actions of photons and electrons. This is not topical in quantum physics. In biology with these particles, we arrive at the finest pertinent scaling level, which we can reach and where we may turn from science to metaphysics. In photosynthesis absorption of photons is exciting electrons. The life-time of an excited state is $10^{-15}$ to $10^{-13}$ s in the chlorophyll. Studies of ultrarapid atto- to femto-second ($10^{-18}$–$10^{-15}$ s) physics of photons and electrons in biochemical phenomena using the sharp energy of coherent pulsed lasers, e.g., for the functioning of vision, are under way (Nicot 2023). In photosynthesis photons of visible, mainly blue and red light are absorbed by the chlorophyll molecules of the thylakoid membranes in the chloroplasts. This leads to excitation of electrons in the chlorophyll, which are then translocated via various molecular components within the thylakoid membranes. Excitation energy transfer results in splitting the molecules of water ($H_2O$) into electrons ($e^-$), protons ($H^+$) and oxygen ($O_2$). An electrochemical gradient of protons is built up across the thylakoid membranes. Its energy is transferred into the chemical energy of adenosine-tri-phosphate (ATP), which drives the biochemical fixation and reduction of carbon dioxide ($CO_2$) and its assimilation to sugars emerging from the entire process. Quantum processes of biological molecules and the questions of quantum physics of whether dynamic quantum effects can occur in vivo in incoherent sunlight and at steady state are explored (Caruso et al. 2012; Kassal et al. 2013). However, the link between quantum mechanics and photobiology remains entirely enigmatic.

Still more overarching and prominent examples of emerging processes of life are development and evolution. If the units developing and being selected in evolution (EVODEVO-theories) were things, the great problem coming up is the question of which are the stable units of substance, organism, system, individual, self, personality. The material of bodies of organisms is under continuous turnover, they do not remain constant. In development we have different stages, which are often particularly conspicuous among animals, where eggs – larvae – pupae – imaginae are appearing as quite different life forms. Are they all representing the same individual organism? This question is a continuous dominant issue in the entire debate between materialistic substantialism and dynamic processualism (Nicholson and Dupré 2018; Lüttge 2023). The problem dissolves when we move from thing-ontology to process-ontology. There is no stability. Self-organization of life is thermodynamic instability and emergent process (Schmidt 2019).

## 3 Casting bridges: metaphysics is continuous with science

Reminding to the statement of the philosopher Dupré (2021) that metaphysics is continuous with science (Sect. 1), it nevertheless remains clear that both are quite different fields of approach and thinking.

However, Dupré is right in that their borders are not sharp. Metaphysics continues explaining truths where scientific epistemology reaches its limitations. Science forces metaphysics into fights of retreat when unexpected advancements in development of methods allow empirical progress. The examples of the following subsections (Sects. 3.1–3.4) demonstrate the casting of bridges.

### 3.1 Biodiversity

Biodiversity is the biological manifoldness of living organisms, their habitats with vegetation mosaics, biotopes, ecosystems and biomes. It is expressed at these different and themselves diverse scaling levels. Remembering the modules in the hierarchies of networks, we recognize that there is **thing-diversity**. Species as modules are things, and the mixed forest has greater diversity than the monospecific stand (Sect. 2.1). Floristic diversity is the diversity of species and among them genomes as things. It carries morphological diversity. With its intrinsic esthetic, cultural and spiritual values philosophically we nevertheless enter the sphere of metaphysics. Biodiversity is severely threatened by decay through anthropogenic influence, including climate change. Since it is essential for the sustainability of life on the planet, it therefore is increasingly realized and penetrating public debate.

A paramount aspect of the diversity at the different scaling levels is functional diversity, which introduces **process-diversity**. Functional diversity of species is manifold comprising all their processes, such as.

- resource use,
- space occupation (Grams and Lüttge 2010),
- modes of photosynthesis ($C_3$- and $C_4$-photosynthesis, crassulacean acid metabolism; Sage and Stata 2015, Lüttge 2020),
- waste production,
- competition and facilitation (Lüttge 2020),
- regulating pathogenesis,
- reproduction,

and many more. They all are accessible experimentally and analytically.

However, with functions at higher integration and the bundles of processes, in addition we enter metaphysics. Diversity supports production of renewable resources regulating susceptibility to diseases and herbivory in plants and through the control of effects of environmental change. Via the control of environmental-change effects it is also beneficial for human health. According to the productivity hypothesis (Tilman et al. 1996, 2001, 2006) biodiversity increases the productivity of integrated systems. Diversity increases risk diversification (Knoke and Hahn 2013). Agricultural biodiversity supports crop yield, and it stabilizes and maintains sustainability (Tilman et al. 1996, 2001, 2006; Schläpfer and Schmid 1999; Lüttge 2016, 2020). Biodiversity thus, enhances ecosystem services affecting a suite of benefits provided to humanity.

The philosophical questions coming up are what are.

- stability,
- risk,
- sustainability,
- dangers of losses,
- esthetics,
- cultural and spiritual values.

Here we see again that science and metaphysics are continuous.

### 3.2 Serendipity

The king Giaffer of the island of Serendip (Sarandīp, later Ceylon, now Sri Lanka) had three sons. For acquiring experience to become kings he sent them on a prolonged journey. In their peregrination they made many unexpected observations, from which they drew unforeseen conclusions important for them and their social contacts. They arrived at the empire of Beramo. At last, they became rulers there and in two kingdoms. A book was published in 1557 in Venice and later translated into various European languages. The Persian tale of “The Three Princes of Serendip” was quite popular.

It was this fairy tale which led Horace Walpol, the Fourth Earl of Orford (1717–1797), to coin the term serendipity in a letter of 28$^{th}$ January 1754 to Horace Mann, an envoy of king George II in Florence. In the literature serendipity is often defined as an unforeseen favorable incident happening by chance and fortune. However, this is far from capturing its essence. From unplanned findings, i.e., when searching for something very different, a cognitive stream of consciousness leads to novel intelligent conclusions, where serendipity requires readiness to assess messages of unexpected observations and open-minded sagacity. Therefore, in the vein of the present essay we may view serendipity as a path from metaphysics to empirical science.

The most prominent examples of serendipity often quoted are the discovery of America by Christopher Columbus in 1492 and of penicillin by Alexander Fleming in 1928. Returning from a holiday to his laboratory in September 1928 Fleming found a left-over culture of the pathogenic bacterium *Staphylococcus aureus*. He saw that a *Penicillium* mold had intruded the sample and inhibited the growth of *Staphylococcus*. Instead of simply cleaning up, he reflected the unexpected observation and concluded that the mold had produced an antibiotic. So, discovery of the antibiotic penicillin is a typical example of serendipity. However, there are many more examples also from everyday experience of happenings in laboratories challenging the readiness to get their message and deduce novel interpretation. The progress of science is full of serendipities as a rule rather than exception.

An outstanding example in plant biology is the discovery of salinity-induced Crassulacean acid metabolism (CAM) in *Mesembryanthemum crystallinum* L. resulting from serial serendipities during travelling and then happening in the laboratory in the late 1960ies and early 1970ies (Lüttge 2016). In a sabbatical year in 1968/69 at the Research School of Biological Sciences (RSBS) of Australian National University (ANU) in Canberra, I had studied the salt accumulation in the large epidermal bladder cells of *Atriplex spongiosa.* On the way back from Australia to Germany I made a stop-over in California and also visited the laboratory of Andy Benson in La Jolla. At dinner in a Mexican restaurant, I spoke about the *Atriplex*-studies. Andy got excited, and in the darkness of this evening of 31 July 1969 he drove me to the beach and came up with *Mesembryanthemum crystallinum*. I should rather work on its leaves and stems, because they have really large, huge epidermal bladder with a volume of up to 2 $mm^3$. Seeds were taken back home. Plants were grown to get more seeds. For a small thesis of her college-teacher exam a student was asked in summer 1971 to check if the bladders accumulated salt. Plants were grown by watering with NaCl solutions of up to 500 mM, but she did not find NaCl concentrations in epidermal-bladder cell-sap higher than in the leaf mesophyll (Lüttge et al. 1978). The bladder cells of *M. crystallinum* by contrast to the salt hairs of *Atriplex* are just inflated epidermal cells, and there is no gland like stalk cell underneath for concentrating the salt. Having finished her work, the student had not cleaned up and left the plants in the greenhouse with their labels indicating irrigation with NaCl solutions of 0 to 500 mM. The serendipity arose because around this time Klaus Winter in an advanced course was supposed to perform gas exchange measurements. He had problems to allocate experimental plants until he found the left-over *M. crystallinum* plants. The gas exchange curves he obtained were unexpected. Some plants showed $C_3$ and others CAM-like patterns. The labels, however, resolved it. The plants with the labels of low NaCl showed $C_3$ patterns and those with high NaCl CAM-type gas exchange. Thus, Klaus Winter as a student discovered salinity induced CAM (Winter and von Willert 1972; Winter 1973a, b), which he subsequently subjected to in depth study (Winter 1975). Meanwhile *M. crystallinum* has developed to become one of the internationally most heavily used model plants for stress physiology and molecular biology. The work on *A. spongiosa* led to a serendipity which marked the starting point of a significant revolution in plant stress physiology with now of a global dimension.

Are spandrels a source of serendipity? Spandrels are seen especially in ecclesiastical architecture. They are functional elements. In a two-dimensional setting, arches are forming a linear row, or in a three-dimensional setting, hemispherical domes mounted on four rounded arches are forming a square by coming together at right angles. Unavoidably the two-dimensional arches leave triangular spaces between them, and similarly in the three dimensions curved triangular pendentives build up as a structurally necessary consequence under the arches supporting the dome. These spaces named spandrels arise as geometric byproducts entirely nonadaptive to the actual function. However, such forms, not explicitly chosen to serve a purpose, unexpectedly turn out to be essential for marvelous use. Recognizing the architectural spandrels and acquiring them as space for a most artistic ornamentation by mosaics or frescos was a process of serendipity.

Biology of evolution also has it. There are forms in organisms not explicitly selected as adaptations for a special purpose or function. They can be "structures co-opted for utility from different sources of origin... and not directly built as adaptations for their current function" (Gould 2002, p. 43) and are called exaptations (Lüttge et al. 2013). They are neither of disadvantage or lethal, and thus eliminated by selection, nor useful at the here and now, and thus not positively selected as adaptations. However, they may turn out to be useful in changed or new environments. Stephen Jay Gould (Gould 2002) with his favorite example of the dome of the Cathedral of San Marco in Venice uses architectural spandrels as a very poetic and esthetic metaphor for the exaptations.

## 3.3 Beauty

There is nothing that could embrace the continuity between science and metaphysics better than the mathematical beauty in the former and its counterpart of esthetics in the latter. There is much beauty in science (Lüttge and Souza 2019). A most remarkable one is the golden section. With a few rather simple operations with ruler and compass of Euclidian geometry we can cut a line between two points in a longer part (Φ) and a shorter part 1, where (Φ + 1) is the whole length, and where

$$(\Phi + 1) \ : \ \Phi \ = \ \Phi \ : \ 1, \tag{2}$$

i.e., the ratio of the whole length to the longer part equals the ratio of the longer part to the shorter part. This is the golden section. From Eq. 2 it follows that

$$\Phi \ = \ (1 + \sqrt{5}) \ : 2 = 1.6180339887. \tag{3}$$

The square root $\sqrt{5}$ is the most irrational number known by mathematical number theory, i.e., real number which cannot be expressed by the ratio of two natural numbers. Φ is the golden number, also called divine number.

From the one-dimensional golden section other golden geometries are derived. At two dimensions a golden rectangle is obtained when in a square with the length of Φ one length is divided into 1 and (Φ–1). Still at two dimensions a golden angle is drawn between two points on a circle when the total circumference is divided in two sections with the ratio of the whole circumference to the longer section equaling the ratio of the longer section to the shorter section. The golden angle is 137°30'. Golden spirals arise when quarter circles in golden rectangles of increasing size are attached to each other (Fig. 4), and these can be wound up higher in the third dimension of space.

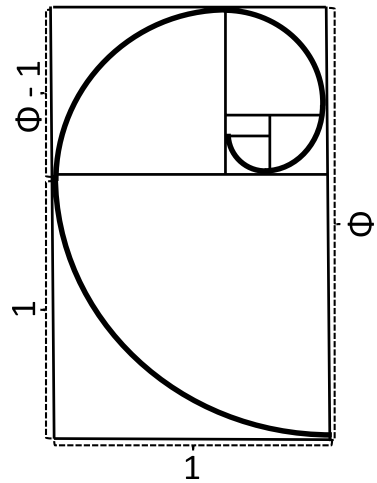
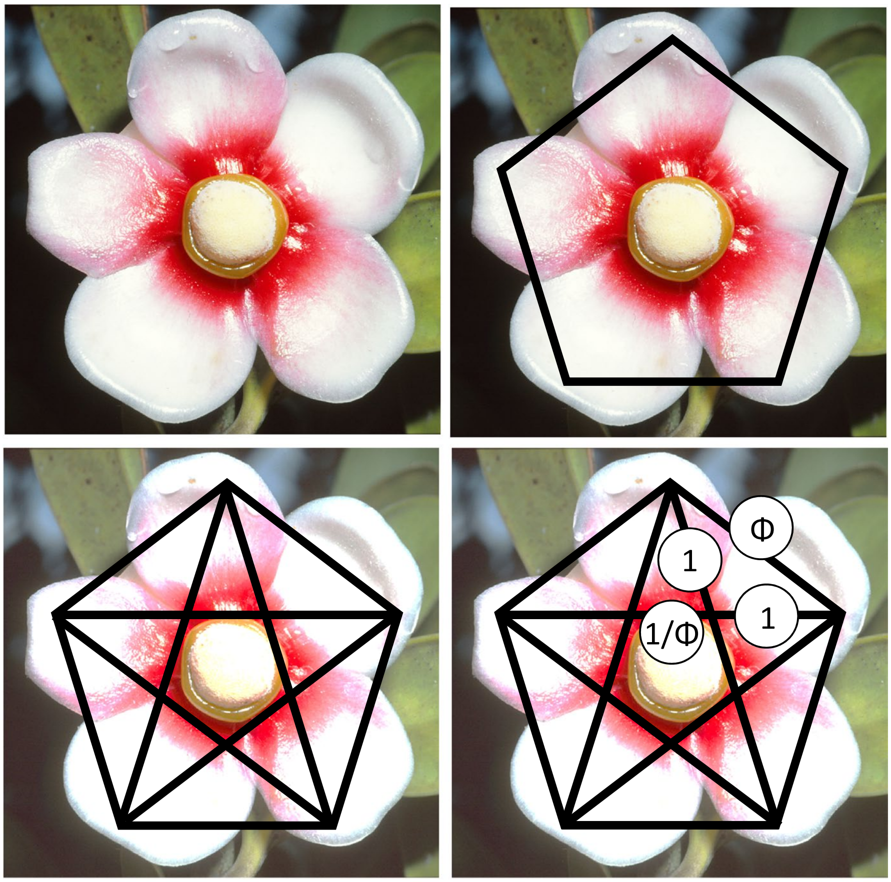



**Fig. 4** Golden rectangles with quarter circles in squares joining to a golden spiral

Examples of these golden geometries are ubiquitous in nature (Hemenway 2005, Lüttge and Souza 2019). Very many species of the dicotyledonous angiosperms have flowers with five petals. We can overlay a pentagram on them like in the female flower of *Clusia hilariana* in Fig. 5. When we draw lines between all the five points of the pentagram, we realize that they are cut in a way letting emerge the golden number Φ. This is in the one dimension of lines. With the golden angle we move into two dimensions. It determines the position of leaves on plant shoots, the scales of cycads and conifers and the seeds in the inflorescences of Asteraceae, like sunflower. So, we arrive at three dimensions. This is also given with the three-dimensional spirals in the shales of snails and the cephalopod *Nautilus pompilius*.

**Fig. 5** Female flower of *Clusia hilariana* with a pentagram showing the golden number Φ




The golden angle is particularly well studied in the leaf-rosettes of plants. The leaves form spirals. If we mark a leaf and count the number of turns made until we arrive at a leaf exactly above or below it and the number of other leaves touched in these turns, we obtain the so-called angle of divergence as follows

$$\text{divergence angle} = (\text{number of turns performed} : \text{number of leaves touched}) \times 360°. \quad (4)$$

When we list the leaf position ratios (turns made divided by leaves touched) of many plants we find that they follow a series of numbers according to the Fibonacci series, named after Leonardo Pisano or Leonardo Fibonacci (ca. 1180–1250), the Italian mathematician at the court of emperor Friedrich II. The Fibonacci-series is 1, 1, 2, 3, 5, 8, 13, 21 … …, i.e., each number following next is the sum of the two preceding numbers. The leaf position ratios found in nature have Fibonacci-series in both nominator and denominator 1/2, 1/3, 2/5, 3/8, 5/13, 8/21 … …. This series results in divergence angles asymptotically approaching the golden section but never reaching

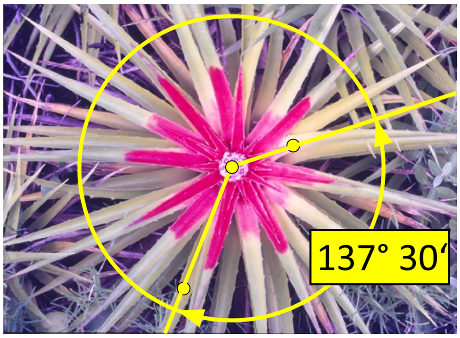



**Fig. 6** Leaf rosette of a flowering plant of *Bromelia humilis* showing the golden angle between two leaves marked by the yellow circles

the most irrational number. In *Plantago major* it is $3/8 \times 360° = 135°$, and in *Bromelia humilis* it is with $5/13 \times 360 = 138°28'$ still closer to the golden angle of 137°30' (Fig. 6).

Measurements of photosynthesis and semiempirical simulations have suggested that leaf position according to the golden angle optimizes light capture for photosynthesis, and a purely analytical model showed that it minimizes shading of lower by upper leaves (King et al. 2004; Lüttge and Souza 2019). Thus, the golden angle and the divine number Φ are seen to be an advantage in selection for photosynthetic productivity by evolution.

Expression of Φ has not only evolved as a selective advantage in nature, but the golden section and derivatives have been considered to be beautiful throughout the creative history of mankind. The golden section is used in architecture from the Egyptian pyramid of Gizeh to the Greek Parthenon of the Acropolis of Athens, to gothic cathedrals in Europe, e.g., the West façade of Notre Dame in Paris, and in our times the creations of Le Corbusier. In the renaissance Michelangelo has used it, and it is also realized in the Mona Lisa painting by Leonardo da Vinci. The book of Hemenway (2005) is full of these and further examples.

Objects of nature with their number of Φ and golden angles we also find beautiful (Figs. 5 and 6). By contrast to how easy it is to draw the golden section in the mathematics of Euclidian geometry and to explain the role of the golden angle in optimal packing of morphological structures of inflorescences and phyllotaxis in biological science, it appears impossible to explain WHY we find this beautiful. Regarding the question of why we find flowers beautiful, with the problem of psychology of perceptions of our esthetical sensations, natural sciences do not help us. We cannot explain our impression of beauty by evolution. The evolution of the flowering angiosperms with the Amborellaceae as their basal branch began $140 \times 10^6$ years ago. The selection pressure for the evolution of flowers was for pollination by animals and not for esthetical pleasure of man, whose evolution began much later with the genus *Homo* ($2 \times 10^6$ years ago) and the species *Homo sapiens* ($0.2 \times 10^6$ years ago).

Are we at this point at a cutting edge between science and metaphysics, where esthetics and beauty remain transcendental categories? At this stage I would like to suggest that we can cast a bridge. While at their cores science and metaphysics are epistemologically clearly separated, bridging them may be facilitated by the frequent observations that their borders a flawed. As we have seen from the examples above, the golden section is a universal principle of organization, and the golden number Φ is a natural constant. It is ubiquitous in the living and non-living nature and occurs even in the spirals of galaxies. Therefore, the evolution of our behavior may well have implied the selection of a sensation of beauty of this universal principle of optimization. We may follow Wilson (2002) thinking that these pleasant sensations are elicited by different stimuli to which our brain is adapted. In this vein particularly the golden section appears as a viable bridge between natural science and the metaphysical domain. A rose is an object of both scientific botanical studies and overwhelming emotional sensation of beauty.

### 3.4 Time

Time in this essay is a final multiplex topic, where we move between science and metaphysics. There are many orders of time reflected in philosophy and realized in the sciences of physics and biology.

In the philosophy of time there are (1) modal time versus location-time, (2) world-time versus personal time, and (3) cyclical time versus linear time (Sierioka 2018, 2020, Lüttge 2022a). In modal time only presence is existing, there are no past or future. In location-time there are always past, presence and future. World-time is measured by clocks, personal time is intrinsic time. Cyclical and linear time refer to respectively directed processes. All of these orders of time can be seen to be effective in both the empirical scientific and the philosophical domains.

In physics we have the Newtonian absolute time, a location-time from past via presence to future. It corresponds to our everyday-concept of time. There are many directed processes following physical laws which develop along arrows of time. However, the concept of absolute time is abandoned by the special theory of relativity where time became part of a four-dimensional continuum named spacetime, with the spacetime warp caused by gravity according to the general theory of relativity (Hawking 2001). Time arrows are remaining. But, the situation in quantum mechanics is different. Time is physically not observable and measurable. In basic equations time does not have a direction. There is no time arrow. The equations are time-reversal invariant. In the singularities of black holes and in the singularity of the universe before the big bang there is no time.

Much of this science goes beyond our actual everyday observations, the deviations from which we do not notice at these levels of experience. It is relevant as a background of the multiplex aspects of time and for metaphysical reflections. Plant biology covers the three philosophical orders of time (Lüttge 2022a, b). Although we mainly remain in the location-time order, we also see aspects of modal time of presence and individual time of organisms, although not consciously perceived. There are cyclical and linear orders of time, as seen in life cycles of organisms and linear processes including evolution. Time arrows always arise from non-equilibrium situations with the inherent drive to move to equilibrium. This is so in physics, where the most conspicuous non-equilibrium is the state of the big bang, or where we may consider the laws of heat conduction and diffusion in gases and solutions. Since all living organisms are open systems and determined by processualism (Lüttge 2023), they are following time arrows at all levels of organization from quantum levels to primary productivity of plants in the biosphere (Sects. 2.1 and 2.2). The questions are how the time is spent and thermodynamic equilibrium can be circumvented (examples in Lüttge 2022b), and if and when this equilibrium is attained with the arrows and time ceasing to exist.

## 4 Science and philosophy: integration

Between the faces of philosophical and theoretical plant biology we visualize the pairs of.

- modularity and integration in emergence,
- mechanistic-reductionist approach (MR) and systemic-complexity approach (SC),
- thing-ontology and process-ontology.

They appear to be contrasting each other. Nevertheless, for a real understanding of life they must be integrated in a certain continuity of science and metaphysics. Unplanned observations may direct us serendipitously to consciously develop novel intelligent conclusions. The knowledge of modules is important for comprehension of their integration by self-organization in emergence of systems of life. The MR is unavoidable for describing the modules, which per se without SC would remain isolated pieces. Modules locate in a static ontology of things and their integration is dynamic processuality. In science and metaphysics these approaches are realized in the vividness of biodiversity and the beauty of evolved principles of organization imbedded in an array of orders of time.

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