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The Contemporary Legacy of Goethean Morphology: From *Anschauende Urteilskraft* to Algorithmic Pattern Recognition, Generation, and Exploration

This article offers a new interpretation of Goethean Morphology, that reads it not so much as an anti or pre-modern methodology than as a late modern one. Indeed, based on the analysis of the specificity of the visual and computational techniques that ground Goethe’s approach to natural phenomena, the paper suggests to look at Goethean Morphology as an original practice of reduction. The latter does not simplify complexity, as is usually the case in modern natural sciences, but rather aims at intuiting the ways in which nature’s technique generates complexity itself. Consequently, the article understand the work of Goethe qua naturalist as an innovative answer to Kant’s antinomy of teleological judgment, namely as an attempt to comprehend the logic of nature from within, instead of merely trying to represent or mimic it. In this context, the article presents the Urtyp, the key-feature to Goethean Morphology, as a proto-algorithmic matrix capable of identifying and/or visually generating and exploring the structures of both actual and virtual morphologies. Finally, the article indicates how this very gesture paved the way to contemporary techniques of pattern recognition, generation and exploration via natural computing, developmental algorithms, fuzzy logic and computer graphics.

Key words : Goethean Morphology, structuralism, generative algorithm, pattern recognition, fuzzy prototype, artificial life, computational arts.

Though there have been numerous studies on Goethean morphology, most employ a history of philosophy approach rather than address the topic at the conceptual level – and thus tend to overlook the remarkable contemporaneity of the methodological innovations advanced in the corpus of Goethe’s scientific writings.ⁱ Indeed, the manner in which Goethe formulates the main problem faced by naturalists – how best to uncover the invisible laws driving the morphogenesis of natural products – is strikingly close to how contemporary computational crafters and artists explore the virtual potentialities of the materials with which they work. In his “Excerpt from Studies for a physiology of plants,” for instance, Goethe notes: “Wenn ich eine entstandne Sache vor mir sehe, nach der Entstehung frage und den Gang zurück messe, so weit ich ihn verfolgen kann, so werde ich eine Reihe Stufen gewahr, die ich zwar nicht neben einander sehen kann, sondern mir in der Erinnerung zu einem gewissen idealen Ganzen vergegenwärtigenⁱⁱ” (If I look at the created object, inquire into its creation, and follow this process back as far as I can, I will find a series of steps. Since these are not actually seen together before me, I must visualize them in my memory so that they form a certain ideal whole). The generative processes responsible for the growth and transformation of natural products thus are not empirically given as such, or in Goethe’s words, “der Beobachter nie das reine Phänomen mit Augen sieht” (WA, 11, 38; the observer never sees the pure phenomenon with his own eyes, 24). Similarly, prominent contemporary computational architect Jane Burryⁱⁱⁱ states:

Over the last half century, architecture has been slowly adapting its representational practices from the conception of objects of sensory engagement to the construction of systems of formally described relationships. This shift from object description to definition of a dynamical space of design possibilities (...) we call “computational design” (...) it is potentially invisible, seen only through its instances (...) it is these traces that are seen, not the model itself, which must be understood through more abstract, linguistic, mathematical, diagrammatic and perhaps logical means.^{iv}

Following this preliminary observation, this article offers a new approach to Goethe’s scientific writings by setting up a dynamic and retroactive dialogue between Goethean morphology and contemporary innovations in morphogenesis. I argue that, like the methodological gesture grounding it, Goethean science should not be understood as anti-modern, pre-modern, or unconventional as Goethe scholars often portrayed it,^v but rather as *late modern*. In fact, by disentangling morphology from its ancillary roles in other sciences such as biology, physics, or chemistry, and singling it out as a new science which “kann als eine Lehre für sich (...) gesehen werden” (WA, 6, 292; can be viewed [foremost] as a theory in and of itself, 57), Goethe’s approach produced a perspectival shift in the natural sciences – turning naturalist attention away from emphasis on contingent natural products towards investigation of nature’s ways of producing them. It is this methodological impulse, I contend, that opened pathways leading to contemporary innovations in morphogenesis and developmental biology which are grounded in techniques of automated pattern recognition, generation, and exploration. Such innovations are becoming increasingly important to the contemporary techno-intelligence landscape, fuelling a wide variety of cross-fertilizing fields, including theoretical biology and Artificial Life and Intelligence, as well as scientific imagery, data-mining, and computational arts and crafts.^{vi}

This current revival of Goethean morphological intuitions is unfolding in a context characterized by the accelerating automation of automation and attempts to free computational and technological media from anthropocentric capture in order to enable development of endogenous forms of reasoning, cognizing, and exploring. Such phenomena urge us to re-evaluate Goethe’s late-eighteenth-century research program in light of its late modern legacy and to develop a richer, more interdisciplinary, and critical reading of past, present, and future uses of morphogenetical tools.

In what follows, I attempt to contribute to this renewed line of research by offering an updated account of Goethe’s most iconic morphological tool: the *Urtyp*. I argue that the latter should be understood as a *computational* device explicitly designed to formulate open-ended classification rules via proto-pattern recognition and data-mining techniques, in order to facilitate the definition of natural domains, and, in a subsequent step, to explore the invisible model space of such domains. Here, I use the term “computation” in the specific sense developed by contemporary algorithmic architecture theorist Kostas Terzidis, as a “procedure of calculating, i.e. determining something by mathematical or logical methods.”^{vii} In fact, in his theoretical work, Terzidis helpfully differentiates between computation and computerization, defining the latter as a mere “act of entering, processing, or storing information in a computer or a computer system.”^{viii} Consequently, while computer systems are prone to accelerate computational acts, overlooking the distinction in function between the two terms risks eliding the creative potentialities located within computational processes. In fact, for at least two decades, numerous scholars, ranging from N. K Hayles^{ix} and John Johnston^x to Luciana Parisi^{xi} and

Kostas Terzidis,^{xii} have insisted that a shift occurred in the techno-intelligence field in the 1980's, which entailed a move from a first generation of algorithms, usually seen as a pre-defined set of procedures facilitating the processing of large sets of data to solve well-defined problems, toward "a certain category of algorithms [whose] inductive strategy is to explore generative processes or to simulate complex phenomena" and which "can be regarded as extensions to human thinking" that "may allow one to leap into areas of unpredictable, unimaginable and often inconceivable potential."^{xiii}

Building upon such insights, this article aims to excavate the proto-algorithmic nature of Goethe's *Urtyp* by taking this second sense of algorithm as a point of reference. To do so, in the first section I present Goethean morphology as a solution to Kant's antinomy of teleological judgment that aims to uncover nature's inner techniques of production. Then, in the second section, I show how this original response remains somewhat vague if not connected to the specific visual devices Goethe saw mediating judgment through intuitive perception. Carefully analyzing those complex visual processes, I highlight their diagrammatic and algebraic characteristics. In the third and final section, I show how Goethe's methodological innovations opened pathways that are now being mobilized in forms of late modern pattern recognition, generation, and exploration techniques that are increasingly grounding contemporary innovations in the techno-intelligence field.

Goethean Morphology: (Human) Access to Nature's Technique

Following the insights of a number of studies^{xiv} begun in the early 2000s that cast new light on Goethean science by relocating it within post-Kantianism, I argue that understanding the originality of Goethe's scientific method requires situating it in relation to Kant's Third Critique. Indeed, in his 1822-1824 notebook, Goethe claims, alongside a set of experimental studies of botany, zoology, and geology, that "Nun kam die Kritik der Urteilskraft mir zu handen und dieser bin ich eine höchst frohe Lebensperiode schuldig" (WA, 11, 50; with the reading of the Third Critique, a wonderful period arrived in [his] life, 29). The source of this enthusiasm was Kant's elaboration of a profound solidarity between the teleology of nature and the domain of aesthetics – two of Goethe's greatest interests. These comments underscore the extent to which Goethe's artistic practice and study of natural science were conceived in dialogue with the Third Critique. In this section, I thus present Goethean morphology as an innovative solution to Kant's antinomy of teleological judgment. However, my approach differs from existing scholarship on the subject in its insistence on the *visual* aspects of Goethe's response to Kant. In fact, I argue that it is precisely through the development of visualization techniques diverging from Kant's projective paradigm^{xv} that Goethe attempted to overcome it.

The second part of the Third Critique famously addresses an issue arising from the structure of the First Critique: nature exists for us only so long as what manifests in the natural world fits the categorical projections of our understanding. In this sense, nature is denied any type of freedom – or, in more contemporary terms, agency. Kant notices, however, that this results in an inability to explain a certain category of natural phenomena, namely the living organism, which displays a form of purposiveness external to the constructions of the human mind. This antinomy highlights the limits of the mechanistic model of cognition at stake in the First Critique and its claim to account for all visible phenomena. Kant famously tried to resolve this problem with a contradictory move: on the one hand, he recognised that "some production of material things is not possible on mere mechanical law"^{xvi} and that "we may, in our reflection upon them, follow the trail of a principle which is radically different from explanation by the mechanism of nature, namely the principle of final causes." (CJ, 215) On the other hand, Kant also

rejected the possibility that the finite human understanding could access the intrinsic, self-sufficient principle generating nature, or what he calls “the technique of nature.” (CJ, 241) The latter, according to Kant, is located in a supra-sensible stratum that takes the form of a guiding thread for the finite human understanding, or at best, becomes the subject of aesthetic contemplation through the use of reflective judgment.

It is within this problematic field that Kant, in paragraph 77 of the Third Critique, discusses the peculiarity of the human understanding, which he opposes to the “distinct cognitive faculty” (CJ, 234), seemingly divine, that he calls the “intuitive understanding” (CJ, 234) or “archetypal understanding” (CJ, 235). As we shall see, it is at this crucial point that Goethean morphology intervenes in the legacy of the Third Critique and resonates beyond it. According to Kant, the main characteristic of the finite (human) understanding is its specific cognitive movement: it proceeds from the universal – supplied by concepts – to the particular. The particular comes to be located under the universal through a process of formal subsumption described as “the harmonizing of the feature of nature with our faculty of concepts – a most contingent accord” (CJ, 234). This represents the problematic core of his model of cognition: the human understanding relates to nature only as a series of appearances produced by the mind’s representational techniques, sidelining the possibility of a genuine connection between the mind and nature. Archetypal understanding, on the other hand, functions quite differently: it moves from intuition of the whole as a whole to deduction of the particular, thus avoiding the problem of a contingent relationship between mind and nature.

It is important to underscore that Kant discriminates between the cognitive processes of the human understanding and the processes entailed in archetypal understanding through reference to the human’s dependence on a kind of visibility he characterizes as empirical realism.^{xvii} Kant’s argument runs as follows: “It is sufficient to show that we are led to this idea of an *intellectus archetypus* by contrasting with it our discursive understanding that has need of images (*intellectus ectypus*) and noting the contingent character of a faculty of this form, and that this idea involves nothing self-contradictory” (CJ, 236). In other words, the projective and representational paradigm grounding Kant’s model of cognition is mainly responsible for the production of his “two world metaphysics”^{xviii} and problematic division between the *mundus intelligibilis* and the *mundus sensibilis*. This is the point emphasized by Constantin Rauer in his remarkable study *Kant’s Philosophy of Projection: The Camera Obscura of the Inaugural Dissertation*, which stresses how Kant’s empirical realism – or rather, his idea that “there is no way to get from being to appearance or to get from appearance to being since the two are of two completely different origins”^{xix} – results from the optical apparatus (or *camera obscura*) that informed his projective paradigm from the period of his pre-critical writings onward. Rauer notes,

Yet we can already indicate that the determination of this limit {between being and appearance} is a logical consequence of the idea of *projection* itself, as soon as the subjective projection apparatus of the observer is taken into account (...) For there could be an understanding, though certainly not a human understanding, which might distinctly apprehend [an infinite] multiplicity at a single glance.^{xx}

As a matter of fact, according to Kant, each type of understanding involves a specific kind of gaze. The (human) finite understanding is trapped in a subjective framework, whose mode of securing an objective representation of empirical reality is reminiscent of the way realist painters use the *camera obscura* technique to faithfully reproduce reality.

Art Historian Svetlana Alpers has described this approach: “[t]he attitude is conditional on a double fragmentation: first, the viewer's eye is isolated from the rest of his body at the lens; second, what is seen is detached from the rest of the object and from the rest of the world.”^{xxi} Similarly, in his first paragraph discussing the transcendental aesthetic in the First Critique, Kant highlights the separation of the material aspect of a phenomenon from its unalloyed form as enabling easier and more fitting elaboration by the categories of the understanding. Conversely, the kind of looking Kant associates with (divine) archetypal understanding is the single glance: immediate visual grasp of a totality reminiscent of pre-modern claims to accessing the whole. However, this empirical realism denies the modern (finite) observer access to nature's ultimate ground (the *in sich*), a disavowal that Goethean morphology intends to confront and overcome in a late modern way. Indeed, as we shall see in the next section, unlike Neoplatonic approaches, Goethe's gaze is neither mystical nor subjective but *technologically mediated*. In fact, in his famous essay “Der Versuch als Vermittler zwischen Objekt und Subjekt” (WA, 11, 21; The Experiment as Mediator between Object and Subject), Goethe insists on the key role played by a certain form of visual attention in the morphological approach to nature. He writes,

Ein weit schwereres Tagewort übernehmen diejenige, deren lebhafter Trieb nach Kenntnis die Gegenstände der Natur an sich selbst und in ihnen Verhältnissen unter einander zu beobachten strebt: denn sie vermissen bald den Massstab, der ihnen zu Hilfe kam, wenn sie als Menschen die Dinge in Bezug auf sich betrachten (...) Sie sollen als gleichgültige und gleichsam göttliche Wesen suchen und untersuchen was ist und nicht was behagt. (WA, 11, 22)

A far more difficult task arises when a person's thirst for knowledge kindles in him a desire to view nature's objects in their own right and in relation to one another. On the one hand he loses the yardstick which came to his aid when he looked at things from the human standpoint; i.e., in relation to himself (...) as a neutral, seemingly godlike being he must seek out and examine what is, not what pleases. (11)

In contemporary terms, Goethe thus seeks a way of accessing a non-human kind of gaze that is able to explore “die geheimer Naturverhältnisse” (WA, 11, 23; the hidden relationships in nature, 12) without projecting the categories inherent to the human cognitive apparatus. In the next section, I outline the proto-machinic aspects of this gaze by identifying the specific visual techniques Goethe used to build the Urtyp and explore what Christopher Langton, a pioneer in the field of Artificial Life, has called “the entire space of [potential] biological structures.”^{xxii}

Building the Urtyp: Goethe's Visualization Techniques

In *Objectivity*, Lorraine Daston and Peter Galison identify Goethe as belonging to the “truth-to-nature”^{xxiii} episteme. Their work argues that while the sixteenth and seventeenth centuries were characterized by fascination with nature's oddities, monstrosities, and excesses, thinkers in the eighteenth century turned away from the particular in order to find the “idea in the observation”^{xxiv} and uncover nature's recurring features. Although this framework is useful, I agree only partly with its applicability to Goethe, whose original methodology differs substantially from those of other eighteenth-century naturalists. Goethe himself underscored the novelty of his morphological approach: “Ich erwiderte darauf, dass sie [die Morphologie] den Eingeweihten selbst

vielleicht unheimlich bleibe und dass es doch wohl noch eine andere Weise geben könne, die Natur nicht gesondert und vereinzelt vorzunehmen, sondern sie wirtend und lebendig aus dem Ganzen in die Theile strebend darzustellen" (WA, 11, 17; I replied that this method would probably disconcert even the initiated, and that a different approach might well be discovered, not by concentrating on separate and isolated elements of nature but by portraying it as alive and active, with its efforts directed from the whole to the parts, 20).

The key faculty Goethe mobilizes to fulfil his research program is "anschauende Urteilskraft" (WA, II, 11, 54; judgment through intuitive perception, 31), which is dedicated to grasping nature's inner morphing principles. However, it is not possible to understand how Goethe conceived of this faculty without taking into account his appeal to a specific visualization technique that made access to nature's inner modes of production possible: the intuitive glance of an expert eye trained through intensive practice with observational drawings of natural products such as plants, bones structures, or clouds to "schliesst das Zufällige aus, fordert das Unreine, etnwickelt das Berworrene, ja entdeckt das Unbekannte" (WA, 11, 40; exclude the accidental, set aside the impure, untangle the complicated, and even discover the unknown, 25).

Though appeal to a practised eye performing classification tasks is not specific to Goethe – Daston and Galison even describe it as one of the practical requirements of the truth-to-nature episteme – the aim of Goethe's quasi-automated gaze is quite singular and specific. In fact, more than statically defining the idealized features of a given set of specimens, Goethe's proto-machinic gaze aims to grasp the generative dynamic of "reine Phänomen" (WA, 11, 40; pure phenomenon, 25) that are not visible as such in the *empiria*. Properly understanding the mode of operating of such a gaze requires retracing Goethe's claims about the role of visualisation in scientific work, which are scattered throughout his writings. In fact, on several occasions, Goethe valorises synoptic vision^{xxv} and drawing practices as particularly important tools for grasping the virtual domain in which forms of given natural phenomena manifest and are partially actualised. For instance, in the *Metamorphosis of Plants*, Goethe notes,

Da nun hierbei viel darauf ankommt, dass man die verschiedenen Stufen, welche die Natur so wohl in der Bildung der Geschlechter, der Arten, der Varietäten, als in dem Wachstum einer jeden einzelnen Pflanze betritt, genau beobachte und mit einander vergleiche: so würde eine Sammlung Abbildungen zu diesem Endzwecke neben einander gestellt, und eine Anwendung der botanischen Terminologie auf die verschiedenen Pflanzenteile bloss in dieser Rücksicht, angenehm und nicht ohne Nutzen sein. (WA, 6, 79)

Here it is crucial that we thoroughly observe and compare the different stages nature goes through in the formation of genera, species, and varieties, as well as in the growth of each individual plant. For this reason alone, it would be both pleasant and useful to have a collection of properly arranged illustrations labelled with the botanical terms for the different parts of the plant.^{xxvi}

The text also specifies how such illustrations should be "properly arranged": the naturalist should place them side by side (*neben einander gestellt*). This layout will help her grasp the structural homologies of a given set of (in this case) manifest vegetal forms, enabling her proto-machinic gaze to compare the samples in a quasi-automated way. The

main outcome of this process is the creation of an Urtyp or *Urphänomen*, whose mode of constructing and operating Goethe describes as such:

Da man nun auf solche Weise alle Tiere mit jedem und jedes Tier mit allen vergleichen musste; so sieht man die Unmöglichkeit ein, je auf diesem Weg eine Bereinigung zu finden. Deshalb geschieht hier ein Vorschlag zu einem anatomischen Typus, zu einem allgemeine Bilde, worin die Gestalten sämtlicher Tier, der Möglichkeit nach, enthalten wären, und wonach man jedes Tier in einer gewissen Ordnung beschriebe. Dieser Typus müsste so viel wie möglich in physiologiker Rücksicht aufgestellt sein. Schon aus der allgemeinen Idee eines Typus folgt, das sein einzelnes Tier als ein solcher Vergleichungskanon ausgestellt werden könne; kein Einzelnes kann Muster des Ganzen sein (...) die Erfahrung muss uns vorerst die Teile lehren, die allen Tieren gemein find, und worin diese Teile verschieden sind. Die Idée muss über den Ganzen walten und auf eine genetische Weise das allgemeine Bild abziehen. Ist eine solches Typus auch nur zum Versuch ausgestellt, so können wir die bisher gebräuchlichen Vergleichungsarten zur Prüfung desselben sehr wohl benutzen. (WA, 8, 10)

It was found necessary to compare all animals with every animal and every animal with all animals—and we can see the impossibility of reconciling things in this manner. Hence, an anatomical *Urphänomen* will be suggested here, a general picture containing the forms of all potential animals, one which will guide us to an orderly description of each animal. As much as possible, this archetype must be established physiologically. The mere idea of an *Urphänomen* in general implies that no particular animal can be used as our point of departure; the particular can never serve as a measure for the whole (...) Empirical observation must first teach us which parts are common to all animals, and how these parts differ. The idea must govern the whole, it must abstract the general picture in a genetic way. Once such an *Urphänomen* is established, even if only provisionally, we may test it quite adequately by applying the customary methods of comparison.

Here, the Urtyp's *modus operandi* can be described in contemporary terms as a dynamic data-mining tool. In fact, according to the quotation above, the Urtyp clearly displays a crypto-machine-learning behaviour open to reconfiguration through encounter with empirical data that brings forth new information (I will discuss this in more detail below). It thus resembles the behaviour of some of the most cutting-edge algorithms used by computational arts and crafts practitioners, which, as STS scholar Luciana Parisi notes, display an “inductive reasoning rel[ying] on the computational capacity to gather information from the physical world and thereby generate dynamic spatio-temporal structures that are derived from matter.”^{xxvii} As we shall see below, Goethe seems to go a step further, envisioning dynamic structures generated by the morpho-*logical* medium itself, without any further reference to external material reality.

Before addressing this move, however, I want to underline the proto structuralism^{xxviii} of Goethe's approach to nature, thus extending a line of interpretation initiated by French mathematician and philosopher Jean Petitot. Indeed, metamorphosis – the core concept of Goethean science – entails identifying the rules governing the dynamics transforming a given set of actual or virtual natural products.^{xxix} For example, in paragraph 84 of the *Metamorphosis of Plants*, Goethe writes, “Und so wären wir der Natur auf ihren Schritten so bedachtsam als möglich gefolgt; wir hätten die äussere Gestalt der

Pflanze in allen ihren Umwandlungen (...) wir hätten (...) auf Äusserung der Kräfte, durch welche die Pflanze ein und eben dasselbe Organ nach und nach umbildet, unsere Aufmerksamkeit gerichtet" (WA, 6, 71; Thus we have sought to follow as carefully as possible in the footsteps of nature. We have accompanied the outer form of the plant through all its transformations (...) we have investigated the outer expression of the forces by which the plant gradually transforms one and the same organ).^{xxx} What is at stake here is a specific kind of structuralism that can be labelled "dynamical."^{xxxi} It fuses the notion of structure together with the problem of its genesis and offers a path away from hegemonic pre-formative structuralism, which views structure as a static, pre-determined, and atemporal entity, by opening it to becoming and exploration. Only by situating Goethean morphology within a dynamical proto-structuralist framework can we make sense of the peculiar relation Goethe tries to articulate between the universal and the particular. More precisely, I contend that the notion of the virtual is the "etwas Vermittelndes" (WA, 11, 18; mediating element, 20) Goethe was seeking as a means of connecting experience with idea in his famous debate with Schiller on the nature of the Urtyp.^{xxxii} In this sense, Deleuze's reconstruction of structuralism and its main characteristics is particularly illuminating for our argument:

We will say of structure: real without being actual, ideal without being abstract. This is why Levi-Strauss often presents the structure as a sort of ideal reservoir or repertoire, in which everything coexists virtually, but where the actualization is necessarily carried out according to exclusive rules, always implicating partial combinations and unconscious choices. To discern the structure of a domain is to determine an entire virtuality of coexistence which pre-exists the beings, objects and works of this domain. Every structure is a multiplicity of virtual coexistence.^{xxxiii}

In trying to build the Urtyp of mammalian anatomy, this is precisely what Goethe does: he sketches the virtual structure of the mammalian domain and, in a subsequent step, deduces actual forms of anatomical organization. From this perspective, the concept of the Urtyp can be recoded as a structural matrix enabling the exploration of nature's virtual realm. This point is what distinguishes Goethe from other eighteenth-century naturalists such as von Martius or Linnaeus. Indeed, the latter develop an additive, analytic classificatory method, producing "a kind of mosaic, in which one completed block is placed next to another, creating finally a single picture from thousands of pieces; this [is] somewhat distasteful to [Goethe]."^{xxxiv} In other words, Linnaeus is mainly committed to investigating *genera* based on their particular exemplifications in a static, bottom-to-top way, while Goethe is less interested in classification of natural products *per se* than in discovering the underlying rules governing their generation and transformation. This represents a considerable logical jump with respect to the classic truth-to-nature episteme. Indeed, Goethe's classification process is intimately connected to his goal of comprehending the logic of nature from within, rather than merely mimicking or representing it from the outside. He thus departs from empirical realism in order to have freedom to explore nature as *it could become*. This emphasis on *genesis*, rather than *genus*, is so strong that Goethe seriously flirts with the idea of virtually producing plant structures that exist only on an abstract plane.^{xxxv} He writes that "mit diesem Modell und dem Schlüssel dazu kann man alsdann noch Pflanzen ins Unendliche erfinden, die konsequent sein müssen, das heist, die, wenn sie auch nicht existieren, doch existieren könnten und nicht etwa malerische oder dichterische Schatten und Scheine sind, sondern

eine innerliche Wahrheit und Notwendigkeit haben" (WA, 31, 240; with this model [the *Urpflanze*] and the key to it, one will be able to invent plants without limits to conform to, which is to say, plants which even if they do not actually exist nevertheless might exist and which are not merely picturesque or poetic visions and illusions, but have an inner truth and logic).^{xxxvi} In the next section, we will see how this fundamental transition from a representational approach to a generative one, which extends the scope of the actual, paved the way for contemporary techniques for generating unexpected morphologies via computational tools such as inductive algorithms and computer graphics.

However, before reconstructing the Goethean legacy at work in such late-modern technological innovations, it is first crucial to note how Goethe located both the Urtyp and the visualization techniques grounding it in the lexical field of mathematics, and more precisely, the domain of algebra – or rather, in abstract relationships dissociated from spatio-temporal (human) intuition.^{xxxvii} For instance, in the *Metamorphosis of Plants*, Goethe compares the Urtyp – which, according to Goethe scholar Elizabeth M. Wilkinson, serves as a "regulative organ of perception in the comparison and ordering of further forms"^{xxxviii} – to an algebraic formula. He writes,

Wir sind überzeugt, das smit einiger Übung es nicht schwer sei, sich auf diesem Wege die mannigfaltigen Gestalten der Blumen und Früchte zu erklären; nur wird freilich dazu erfordert, dass man mit jenen oben festgestellten Begriffen der Ausdehnung und Zusammenziehung und Anastomose, wie mit Algebraischen Formeln bequem zu operiren. (WA, 6, 79)

We are convinced that with a little practice the observer will find it easy to explain the various forms of flowers and fruits in this way. To do so, however, requires that he feels as comfortable working with the principles established above—expansion and contraction, compaction and anastomosis—as he would with algebraic formulas.^{xxxix}

In other writings, Goethe describes the Urtyp as "die Formel [die vorstellt] unter welchen unzählige einzelne Rechnungsexempel ausgedrückt worden" (WA, 11, 33; the general formula, so to speak, that overarches an array of individual arithmetic sums, 16.) He notes that:

Diese Bedächtlichkeit nur das Nächste an's Nächste zu reihen, oder vielmehr das Nächste aus dem Nächsten zu folgern, haben wir uns seiner Rechnung bedienen, müssen wir immer so zu Werte gehen, als wenn wir dem strengsten Geometrer Rechenschaft zu geben schuldig waren. (WA, 11, 33-34)

From the mathematician we must learn the meticulous care required to connect things in unbroken succession, or rather, to derive things step by step. Even where we do not venture to apply mathematics we must always work as though we had to satisfy the strictest of geometers. In the mathematical method we find an approach which by its deliberate and pure nature instantly exposes every leap in an assertion. (16)

Given the context developed above, Goethe's appeal to algebra appears more than a mere metaphor or loose comparison. In fact, though most Goethe scholarship relegates his relation to mathematics to strict rejection of computational tools, a subtle but

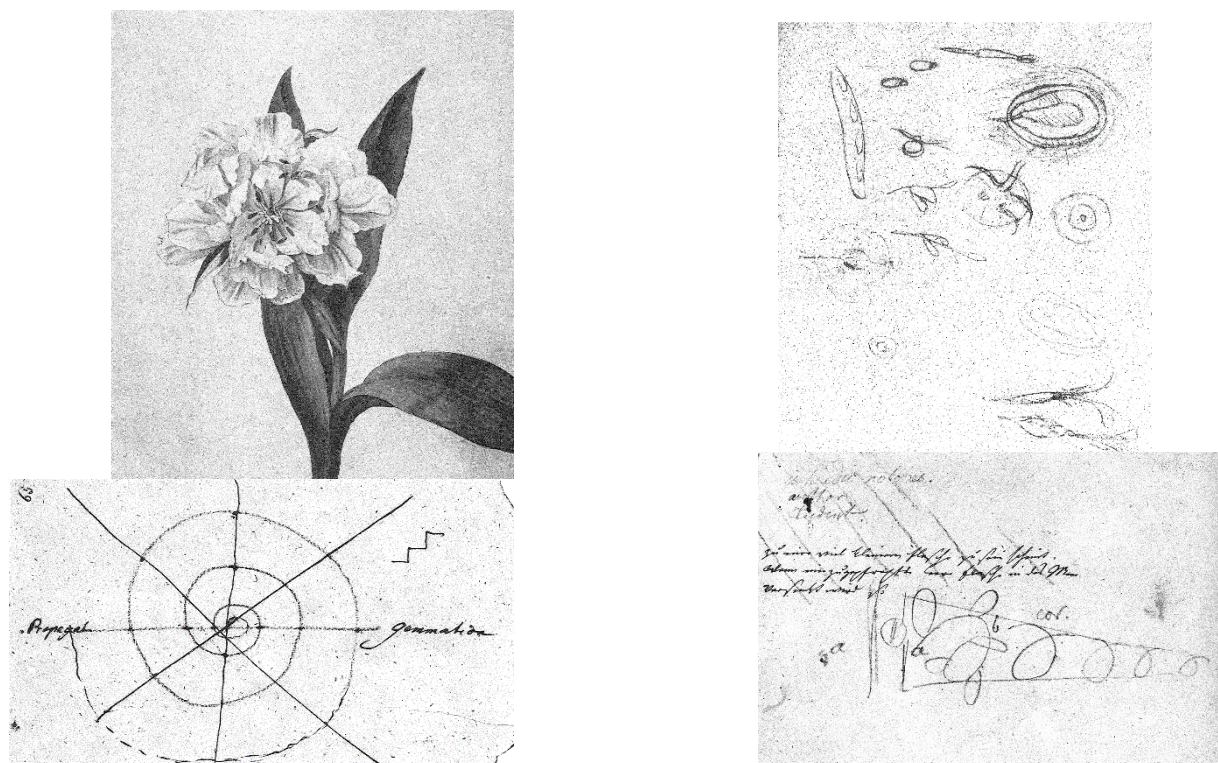
convincing alternative reading stress the influence of the mathematical method^{xl} on Goethean Morphology. The main argument for such a reading rests on the distinction between applied mathematics and “pure mathematics,” namely algebra. As H. N. Jacke’s study of algebraic analysis in Germany between 1780-1850 has shown, algebraic analysis originating “from Euler’s *Introductio in analysin infinitorum* [via] the “Combinatorial School” (...) was influential in Germany at the turn of the nineteenth century and became the basis for the mathematical syllabus of the Prussian gymnasium in the Humboldt educational reforms.”^{xli} As Martin Dyck remarks, Goethe was no exception and participated in this enthusiastic reception of algebraic analysis, and in fact seems to have been in contact with state-of-the-art developments in this field, since he “received instruction in mathematics from private tutors at Frankfurt, attended a course in mathematics at the University of Leipzig, took lessons in algebra from Professor Wiedeburg at Jena in the spring of 1786; owned some thirty mathematical texts (...), wrote two treatises on mathematics as well as the mathematical section in his *Farbenlehre*, and left several hundred observations on mathematics in his works, letters, diaries, conversations.”^{xlii} Significantly, Goethe’s scientific writings assign high praise to Italian mathematician Joseph-Louis Lagrange, who succeeded Euler as the director of mathematics at the Prussian Academy of Sciences in Berlin^{xliii} and, together with him, penned the Euler-Lagrange equations on the calculus of variation. Moreover, among the various letters referring to mathematics in Goethe’s collected documents, is one from mathematician and physician Konrad D. M. Stahl, who worked in the field of mathematical analysis and combinatorics in 1798. The letter was so precious to Goethe that he kept it among his possessions for his whole life.^{xliv} It underlines the exploratory nature of algebra, claiming that “der Zweck der Algebra ist, vermittelst Gleichungen das Unbekannte durch das Bekannte zu finden”^{xlvi} (The purpose of the algebra is to discover the Unknown through the Known by using equations), and distinguishes among various kinds of mathematical approaches, including what Stahl calls “higher arithmetic” (*Höhere Arithmetik*), a movement that goes “vom Zusammengesetzten zum Einfachen und sucht dadurch zu Sätzen zu kommen, welche als noch nicht bekannte angesehen werden”^{xlvi} (from the composed to the simple and thereby tries to get at theorems that are not viewed as previously known). This description is reminiscent of Goethe’s above-mentioned “different approach (...) with its efforts directed from the whole to the parts.”^{xlvi} Finally, as Jacke underscores, in the practice of algebraic analysis in Goethe’s time,

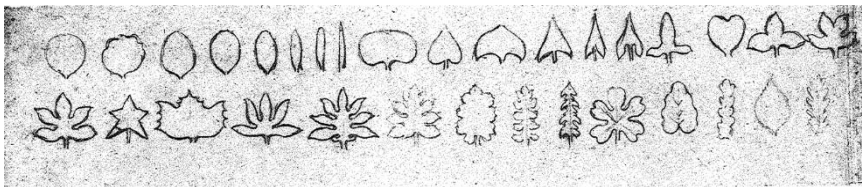
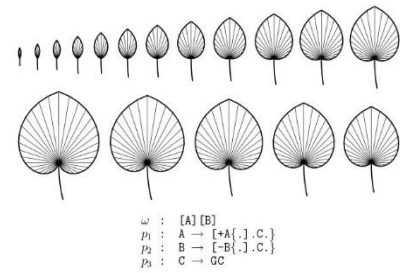
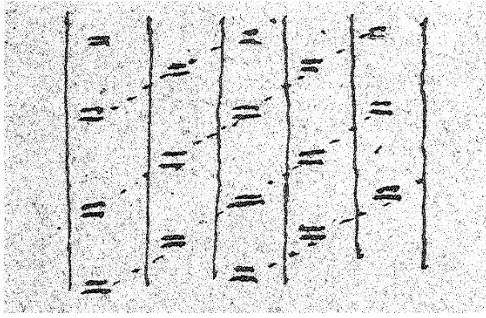
The emphasis fell on understanding certain relations from their own presuppositions in a purely conceptual way. To understand given relations in and of themselves one must generalize them and see them abstractly. Recurring to the theory of art, we can speak of an act of *alienation*. In fact, since this time the analogy between art and mathematics has held a special attraction for many pure mathematicians. (...) A definition of mathematics as a “theory of forms” (*Formenlehre*) became common at that time.^{xlviii}

Consequently, though Goethe did not apply mathematics directly to morphogenesis, he nonetheless seems to have advocated mobilizing typical algebraic properties, such as condensation (“instantly expose every leap in an assertion”)^{xlix} and derivation, in his morphological method.^l Algebraic formula in fact constitutes a formal reduction or condensation of a specific type of relation,^{li} from which it is possible to deduce one or more variables expressing that relation. It is in this sense that it is

reminiscent of the Goethean Urtyp. We can therefore hypothesize that algebraic analysis was attractive to Goethe – who was trying to single out morphology as an autonomous science by disentangling it from matter-related sciences such as biology, chemistry, and physics – because it provided an elaborate method for departing from spatio-temporal human perception to approach other morphological manifestations. Algebraic forms thus understood are systems of abstract relationships, rather than material entities, able to evolve according to open-end rules of transformation. I therefore suggest that Terzidis’s comment on contemporary formal explorations in architecture (algorithmic forms)^{lii} is particularly relevant for retroactively illuminating the originality of Goethe’s approach to natural forms: “Form is not always conceived literally as made out of matter. In fact, form is rather an abstract entity that possesses certain geometric characteristics. The attachment of material qualities constrains the behaviour of form (...). In contrast, the lack of materiality liberates form from its constraints and introduces behaviours closer to intuition rather than perception.”^{liii}

A closer look at Goethe’s practice of “observational” drawing provides strong support for this reading of his morphology as a science interested mainly in the exploration of virtual forms and their expressive power and in which “expressiveness impl[ies] tendency, inclination, propensity, disposition or proclivity”^{liv} rather than staticness, preformation, or definition. Indeed, of the hundreds of botanical drawings Goethe made over the course of his lifetime, only twenty percent display fixed, determined outlines with details and colours that correspond to the materiality of the featured specimen (fig. 1). The remaining eighty percent are much less determined: they constitute quickly scribbled sketches composed of evasive dots, open-ended lines, and spirals (fig. 2); gestures toward nature’s exuberant and never-ending productivity that function as support for navigating experimental thought processes in the virtual space of plant morphologies; and diagrams (figs. 3, 4, 5) or even proto-simulations of structural morphogenetic transformations, pointing toward how similar contemporary projects turn to computer graphics, as we shall see in the next section (figs. 6, 7).





The lack of strict definition in most of Goethe's drawings suggests we should consider them as "allusive devices"^{lv} – or rather, as diagrams in the sense Gilles Châtelet uses the term. Far from being simplified illustrations of pre-existing relations, diagrams employ empirical realism to open up a new abstract plane where they become "for themselves [their] own experiment."^{lvi} Châtelet explains: "The gesture that it captures and particularly those that it arouses are no longer directed toward things, but take their place in a line of diagrams, within a technical development."^{lvii} By freeing themselves from what has been pre-conditioned and by generating their own logical space with related virtualities, diagrams are particularly fitting for exploring the logic of what could become. Moreover, as Charles Pierce's work on icons notes, diagrams share common properties with algebra ("mak[ing] perceptible, via algebraic signs the relations between given quantities")^{lviii} to the extent that, in his words, an algebraic formula is "nothing other than a kind of diagram"^{lix} expressed via numbers instead of marks and lines.

There is consequently a deep solidarity between Goethe's algebraic understanding of the Urtyp and his use of drawing as a diagrammatic tool: both enable visualisation of the virtual and dynamical play between expanding and contracting forces (or, in contemporary terms, between activators and inhibitors) that drives morphogenetic processes. Goethe's transformation of the practice of observational drawing and botanical art into a diagrammatic tool – especially when compared to common eighteenth-century botanical art's static depiction of idealized specimens^{lx} – thus suggests Goethe is less interested in nature's contingent material actualisations than in exploring nature's virtual morphologies and expressive powers. As we shall see below, this exploratory use of drawing anticipates contemporary uses of computer graphics in both model verification and pattern exploration. In this sense, twentieth-century biologist Richard Dawkins's comments about D'Arcy W. Thompson, one of Goethe's greatest devotees, also apply to Goethe's scientific research: "It is one of the minor tragedies of biology that D'Arcy Thompson died before the computer age, for almost every page of his great book cries out for a computer"^{lxi} – or rather, to take up Terzidis's distinction between computerization and computation, for the "computational power of a computer."^{lxii}

The Goethean Legacy in Contemporary Algorithmic Pattern Recognition and Generation

Thompson's *On Growth and Form* (1917) is an important mediator of Goethe's scientific writings in the twentieth century, bringing them into conversation with the use of computational developmental algorithms in solving morphological issues, be they biological, artificial or artistic. Famously inspired by Goethean morphology,^{lxiii} Thompson shared Goethe's great interest in the intimate relationship between aesthetics and the natural sciences. Indeed, Thompson's sustained attention to the mathematical beauty of natural patterns is largely indebted to the work on art and nature of predecessors such as T. Cook in *Spiral in Nature and Art*, E. Haeckel in *Art forms in Nature* and G. Heilmann's drawings.^{lxiv} The difference between Thompson and Goethe, however, lies in the roles each attributed to mathematics and geometry in uncovering nature's internal principles of morphology. Even if, as my analysis above has shown, Goethe did not reject mathematics to the extent Goethe scholars usually claim, the lack of non-mechanistic, non-deterministic, and non-linear mathematics during his lifetime certainly limited him to conceptual use of the contraction-expansion algebraic formula and, at most, underscored the need for proper computational tools able to formalize the morphological transformations at stake in nature.

In his seminal book, Thompson strongly underscores the novelty in how his method avoids replicating the *aporia* of Cartesian mechanism and dualism of Kant's First Critique – which both project human-made mathematical formula onto the natural world rather than capture nature's inner logic. Against this dominant mechanistic paradigm, echoing Kant in the Third Critique, Thompson calls for investigation of the mathematics of nature, such as the recurrence of the Golden Number or the Fibonacci sequence in various natural formations: "Kant had said that it was Nature herself, and not the mathematician, who brings mathematics into natural philosophy."^{lxv} More audaciously, following "physical-mathematical or dynamic investigations in morphology,"^{lxvi} Thompson argues that "mechanism and teleology are interwoven together and we must not cleave to the one nor despise the other for their union is rooted in the very nature of totality."^{lxvii} It is this Thompsonian thought that gave birth to the unorthodox field of biomathematics, which appeals to non-linear mathematical models to generate the laws of transformation governing the development of natural structures. Indeed, in Thompson's view, natural products are temporary, meta-stable crystallizations of a diagrammatic play of forces always prone to further re-configurations and transformations. By attempting to mathematically and graphically model the morphogenetic fields responsible for producing and developing natural structures and patterns, Thompson paved the way for the emergence of digital morphogenesis and computational development^{lxviii} and helped catalyse the fruitful application of these tools first in the field of theoretical biology and Artificial Life then, a few decades later, in design and architecture – domains with which they share common formal problems.^{lxix}

In fact, theoretical biologists increasingly tend to view life as a general, logical, and relational process^{lxx} that can be abstracted away from any particular medium, a view that has been termed "the strong ALife position,"^{lxxi} while cutting-edge research in computational arts and crafts expresses more and more interest in exploring unknown formal potentialities by turning to the creative and alienating (in the sense of rendering *alien* or unexpected) resources of the computational medium itself, detached from ready-made material solutions.^{lxxii} In fact, as the theoretical work of contemporary architect Achim Menges underlines, the emergent architectural field of material computation promotes study of "tension-driven material systems" and "the development of an

architectural design framework that allows for these complex material interdependencies to be not only resolved, but explored as multiple possible equilibrium states. As a computational process that moves between virtual generation and physical materialisation, the process structure is capable of evolving morphologically complex yet viable tension-active formations.”^{lxxiii}

Goethe’s and Thompson’s seminal research on morphological transformations in nature and biomathematics has produced a fruitful legacy in the mid-twentieth century through the work of British mathematician Alan Turing. By the 1950s, Turing, the father of computer science and system theories, had become increasingly interested in the application of mathematical modelling to morphological phenomena, especially patterns and forms in nature. Twenty years after the creation of the first computer,^{lxxiv} in 1952 Turing published “The Chemical Basis of Morphogenesis,”^{lxxv} which provides a mathematical model for the chemical “reaction-diffusion” processes responsible for the patterns displayed by natural products. Notably, the final (and shortest) section of this seminal paper, entitled “Non-linear theory. Use of Digital Computers,” discusses the idea that “it might be possible, however, to treat a few particular cases [of the diffusion-reaction] process in detail with the aid of a digital computer.”^{lxxvi} The paper even announces an entirely new line of research on “[t]he morphogen theory of phyllotaxis,” which Turing states, will be addressed “in a later paper” with “this computational method. Non-linear equations will be used.”^{lxxvii} Though Turing’s death in 1954 unfortunately foreclosed these promising paths of inquiry, the last section of this paper nonetheless enabled researchers to envision approaching issues in developmental biology with computational techniques and later with computer graphics, thereby enabling the launch of a research program first conceptually envisioned by Goethean morphology two centuries earlier.

To conclude, I would like to turn to two practical examples that support this argument and can be viewed as late-modern updates of Goethean Morphology: one dates to the late twentieth century and the other to the early 2000’s. As we shall see, although both extend Goethe’s research program via contemporary computational and digital means, they divergently appropriate its potential to ground both “technoeuphoria and regimes of surveillance.”^{lxxviii}

The first case dates to the 1990s, with the publication of computer scientist Przemyslaw Prusinkiewicz’s and biologist Aristid Lindenmayer’s pioneering book *The Algorithmic Beauty of Plants*, probably the most successful revitalization of the Goethean program in the Alife field. Explicitly rooting their approach in Goethe’s and Thompson’s legacy, Prusinkiewicz and Lindenmayer aim to produce a “virtual laboratory”^{lxxix} populated by virtual plant structures that are visually generated by developmental algorithms and computer graphics (see Fig. 7 above). While Goethe could only dream of an algebraic formula able to self-generate virtual and transforming vegetal forms, Prusinkiewicz and Lindenmayer, following the inner logic of plant growth, model precisely such an open-end algorithm, then use computer software able to translate it visually.^{lxxx} They do so by making use of Lindenmayer’s L-System, which the authors describe as “a technique for defining complex objects by successively replacing parts of a simple initial object using a set of rewriting rules or productions.”^{lxxxi}

In his botanical writings, Goethe had notably remarked that plants and animals, in their initial and most undifferentiated states, have the appearance of a “Lebenspunkt” (WA, 6, 13; vital point) whose gradual differentiation and context-sensitive bifurcations lead to the formation of various natural morphologies. Lindenmayer’s L-System similarly begins with a simple unit, a letter or point, and progresses toward differentiation,

bifurcation, and even open-ended variation (when stochastic OL-Systems^{lxxxii} are added to the turtle graphic interpretation of the L-System to produce specimen variations). Moreover, in what seems an answer to the prayers of Turing – who, at the end of his life, grew obsessed with the perfect Fibonacci sequence displayed by the main stems of flowers such as daisies^{lxxxiii} -- Prusinkiewicz's and Lindenmayer's book even provides "two models suitable for the synthesis of realistic images of flowers and fruits that exhibit spiral phyllotactic patterns."^{lxxxiv} Visualization plays a considerable role in this project, just as it did in Goethe's and Thompson's, since their translation of this morphological program into a digital image of a virtual plant both validates their model and serves as a means for further exploring plant-related developmental issues:

After the incorporation of geometric features, plant models expressed using L-systems became detailed enough to allow the use of computer graphics for realistic visualization of plant structures and developmental processes. The emphasis on graphics has several motivations. A visual comparison of models with real structures is an important component of model validation. The display of parameters and processes not observable directly in living organisms may assist in the analysis of their physiology (...) The quest for photorealism challenges modeling and rendering algorithms, while a departure from realism may offer a fresh view of known structures.^{lxxxv}

Thus, like Goethe, Prusinkiewicz and Lindenmayer call for an innovative use of reduction that renders it not merely a heuristic simplification of phenomenological reality, as occurs in the mechanistic reductionism of the natural sciences, but rather as a tool enabling the exploration of transcendental structures and genesis of complexity. Today, as a great number of projects and publications indicate, we are witnessing a fruitful transplantation of a series of Alife techniques and findings in computational arts and crafts projects, especially in contexts aimed at finding sustainable solutions in architecture and design.^{lxxxvi} This, I would argue, is the "technophoric", liberating, open-ended, and *expansive* side of Goethean Morphology and its legacy.

Goethe's method, however, oscillates between expansion and contraction, and thus has also given birth to more conservative tendencies. As we shall see, these latter pathways aim toward identification, recognition, and classification – processes increasingly grounding late capitalist technologically mediated regimes of control and biopolitics. This second lineage of Goethean morphology is less interested in pattern generation and exploration than in pattern recognition and identification. In this context, it is the economic aspect of Goethe's Urtype as a classificatory device that is of interest, as his innovative approach to processing and comparing large sets of data is exploited and extended in order to accelerate performance in the fields of machine-learning, computer vision, and data-mining. In fact, in a massive footnote to *Goethe e Darwin: la filosofia delle forme vivanti* (Goethe and Darwin: The Philosophy of Living Forms) Goethe scholar Federica Cislighi highlights a conceptual through-line departing from Goethean morphology that passes through Wittgenstein, Pierce, and Russel and opens into contemporary fuzzy logic, particularly the conceptual framework grounding contemporary innovations in the above-mentioned techno-intelligence fields.^{lxxxvii} To my knowledge, Cislighi is the only researcher so far to make this connection. Given the importance of fuzzy logic for contemporary developments in techno-intelligence pertaining to non-conscious or pre-cognitive decision-making^{lxxxviii} – as elaborated in the 2008 paper "Fuzzy Prototypes: From a Cognitive View to a Machine Learning

Principle”^{lxxxix} by intelligent systems scholars Marie-Jeanne Lesot, Maria Rifqi, and Bernadette Bouchon-Meunier – the topic deserves more comprehensive critical attention.

In what follows, I briefly outline this conceptual genealogy, evaluating Goethean morphology as a remarkable example of the “non-contemporaneity of a thought to its time”^{xc} and of “paradoxical temporality in which staying behind coincides with being ahead.”^{xc} In fact, I argue that Goethean morphology conceptually paved the way for the “new configuration of logical reasoning”^{xcii} grounding contemporary innovations in techno-intelligence. Following Katherine Hayles, Luciana Parisi has described this latter configuration as a shift from deductive truths to ruling procedures “where rules cannot be pre-designed, but are, as it were, achieved by the computational behaviour of data”^{xciii} and in which “the question is not to deduce an output from a given algorithm, but rather to find the algorithm that produces this output.”^{xciv} In this context, fuzzy logic and fuzzy prototypes are means for finding specific formulas.

Born in the 1960s as mathematician and computer scientist Lotfi Zadeh’s response to the *aporia* produced by the binarism of classical mathematical logic, which considers only true or false answers as valid, fuzzy logic is grounded in the observation that human cognition and natural categories do not behave in a binary way. Consequently, computer science and graphics dealing with those fields require a logic more akin to the brain’s plasticity and to the fuzziness of nature’s nonconscious cognitive processes and manifest shapes. Fuzzy logic thus aims to make it possible for algorithms to deal with classes of objects lacking sharp boundaries or definition. In their 2008 paper, Lesot, Rifqi, and Bouchon-Meunier emphasize the sheer originality of fuzzy set theory in relation to traditional ways of categorizing objects, significantly locating it within a lineage of logical innovations emerging from Wittgenstein’s late philosophy:

Previously, a crisp relationship between objects and categories was assumed, based on the existence of necessary and sufficient properties to determine membership (...) Now in the case of natural categories, it is often the case that no feature is common to all the category members: as modelled in the family resemblance model of Wittgenstein, each object shares different common features with other members of the category, but no globally shared feature can be identified.^{xcv}

Notably, a significant number of Wittgenstein scholars in past few decades have insisted on the decisive impact of Goethean morphology on Wittgenstein’s late philosophy,^{xcvi} sometimes even presenting the latter as the completion of the former.^{xcvii} In the context of our present enquiry, the common overlap between both methods worth emphasizing is their innovative articulation of the relationship between the universal and the particular. Indeed, as German studies scholar Fritz A. Breithaupt stresses, both Goethe and Wittgenstein sought a way to order the chaotic diversity of data encountered in phenomenality. What distinguishes them from their predecessors is the fact that they both started “with a confused middle notion that is to be separated.”^{xcviii} However, “no preexisting method can guide this separation since the comparison [in the case of Goethe] of plants can only presuppose comparability. And this presupposed comparability is the *Urphänomen*.”^{xcix} Consequently, the *Urtyp* plays the role of a dynamic “comparative third term”^c in the exploration and classification of empirical data. To perform this task, the *Urtyp* has to be general enough to extract the universal from the singular but also open (or fuzzy) enough to allow potential reconfigurations in the encounter with new data. Wittgenstein’s notion of “blurriness”, anticipating contemporary “fuzziness,” helps clarify

how the Urtyp sustains this constant interplay between the universal and the singular. In this context, paragraphs 71-74 of Wittgenstein's *Philosophical Investigations* constitute a seminal gesture toward fuzzy logic and computer vision, as well as to their current use of developmental algorithms to perform classification, clustering, and recognition tasks. Wittgenstein writes,

One might say that the concept 'game' is a concept with blurred edges.—But is a blurred concept a concept at all?—Is an indistinct photograph a picture of a person at all? Is it even always an advantage to replace an indistinct picture by a sharp one? Isn't the indistinct one often exactly what we need? (...) *Seeing what is common*. Suppose I show someone various multicoloured pictures, and say: "The colour you see in all these is called 'yellow ochre'—This is a definition, and the other will get to understand it by looking for and seeing what is common to the pictures."^{ci}

The process at stake in this thought-experiment mirrors how Goethe's expert eighteenth-century naturalist eye deploys a pre-data-mining gaze as a comparative tool and means of perceptual data storage to exploit collected data and build a common notion (the Urtyp) that can virtually comprise a range of particular cases and the rules producing them. Two centuries after Goethe's innovative yet ultimately incomplete research program, Lesot, Rifqi, and Bouchon-Meunier establish a clear computational method for building the Urtyp of a given set of phenomena:

Step 1. Compute the *internal resemblance* degree of an object with the other members of its category and its *external dissimilarity* degree with the members of the outside categories.

Step 2. Aggregate the internal resemblance and the external dissimilarity degrees to obtain the *typicality degree* of the considered object.

Step 3. Aggregate the objects that are typical "enough", i.e. with a typicality degree higher than a predefined threshold to obtain the fuzzy prototype.^{cii}

In their hands, the Goethean/Wittgensteinian fuzzy prototype functions as an automated, plastic, self-learning "regulative organ of perception in the comparison and ordering of further forms."^{ciii} Unsurprisingly, the first field of application of this project is visual recognition and data classification in cross-disciplinary fields. As a recent paper about the development of fuzzy system technologies in engineering, management, medicine, economics, and environmental and social issues states,

The applications of fuzzy logic, once thought to be an obscure mathematical curiosity, can be found in many engineering and scientific works. Fuzzy logic has been used in numerous applications such as (...) facial pattern recognition, transmission systems, control of subway systems (...) knowledge-based systems for multiobjective optimization of power systems, weather forecasting systems, models for new product pricing or project risk assessment, medical diagnosis and treatment plans, and stock trading. (...) This branch of mathematics has instilled new life into scientific fields that have been dormant for a long time."^{civ}

The same can be said of the Goethean Urtyp: once considered an obscure curiosity of eighteenth-century naturalism, the legacy of its conceptual, methodological, and logical innovations can now be found in various emerging computing and machine-learning

methods currently used to develop intelligent systems for decision making, identification, pattern recognition, optimization, and control, but also in cutting-edge pattern generation and exploration methods.

Conclusion

In this article, I have offered a reading of Goethean morphology as an original practice of reduction, which moves from the phenomenological realm to intuit nature's self-generating processes. In addition, I have argued that it is impossible to accurately understand this intuitive gesture without addressing the technological mediations grounding it. Though the idea of mediated intuition may seem paradoxical, it becomes less so when we consider, as Hayles underscores in *Unthought*, how contemporary technologies exceed the speeds of conscious processes when performing cognitive functions, especially information processing and clustering. This velocity gestures towards the immediacy usually attributed to intuition in classical philosophy, and in this sense seems to overcome the contradiction between intuition and technological mediation. Setting up a retroactive dialogue, I have insisted on the late modern characteristics of the visual and computational techniques developed by Goethe: on the one hand, a proto-machinic gaze displaying crypto-data-mining behaviour that enables the quasi-automated comparison of a wide range of samples and the construction of an Urtyp open to further modification in the encounter with empirical data; on the other hand, a reshaping of the naturalistic practice of observational drawing into a diagrammatic tool aiming at exploring virtual, logic-driving morphogenetic processes.

According to my reading, the novelty of Goethe's approach to nature thus rests on a fundamental transition from a representational approach to a generative one that is able to create new life forms and thus to extend the scope of the actual. Insisting on this point, as well as on the virtual nature of the Urtyp, allows us to trace Goethe's legacy in some of the most innovative branches of pattern recognition, generation, and exploration: both the use of computer graphics in natural computing contexts and computational creative thinking as well as the use of automated pattern recognition techniques, based on fuzzy prototypes, can be seen as contemporary updates of the Goethean research program. To my knowledge, this cross-fertilization between Goethe's research program and cutting-edge developments in the new generation of techno-intelligence has not been fully explored by existing Goethe scholarship. To do so, however, allows for a reading of Goethe's scientific work that points to its remarkable contemporaneity.

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ⁱ Michael Bies's book *Im Grunde ein Bild* (Göttingen: Wallstein Verlag, 2012) is a good example of this dominant state of the art. The book deals with visual techniques and naturalist research in the work of Kant, Goethe, and von Humboldt. Though remarkably erudite and informative, Bies mainly employs a contextual and historical approach to explain the emergence of innovative techniques of visualisation over the course of the eighteenth century within naturalist research. In so doing, he misses the opportunity to draw out the conceptual consequences of his topic especially with regard to its legacy in the contemporary period. The present paper attempts to bridge this gap. During the process of moving from conception through revisions, the paper has benefited greatly from three philosophical events that allowed me to present and discuss some of its main results with scholars of German Idealism, Post-Kantianism, and *Naturphilosophie*: the *Structure and Nature* workshop organized by Daniel Whistler, Phoebe Page, and Lydia Azadpour (London, Royal Holloway, Nov. 2019); the *Aesthetics and Critique* workshop, organized by Christoph Haffter and Emmanuel Alloa (Fribourg, Fribourg University, Nov. 2020); and the online *Concept of Nature in German Idealism* international conference, organized by Luis Felipe Garcia (April 2021). I especially want to thank Daniel Whistler, Christoph Haffter, Emmanuel Alloa, Jutta Eckle, Troy Vine, Patricia Simpson, and Charles Alunni for their comments on my work, together with the anonymous peer-reviewers of the *Goethe Yearbook*.

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- ⁱⁱ Johann Wolfgang von Goethe, *Goethes Werke* II. 6 (Weimar: Weimarer Ausgabe, 1893) 303-304. Subsequent quotations from this edition will be referenced as WA, followed by the volume and page number. The English translation here, and subsequently, is from Johann Wolfgang von Goethe, *Scientific Studies*, trans. and ed. Douglas Miller (Princeton NJ: Princeton UP, 1988), here 75. All references to this translation follow in parenthesis in the text.
- ⁱⁱⁱ Jane Burry participated in the completion of Gaudi's Sagrada Familia Basilica and was awarded a Robots in Architecture Pioneer Award in 2016. Her research focuses specifically on mathematics in contemporary design.
- ^{iv} Jane Burry, "Philosophy of Mathematics for Computational Design." *Computational Design Thinking*, eds. Achim Menges and Sean Ahlquist (Chichester: John Wiley & Sons Ltd, 2011) 168-178, here 168.
- ^v See for instance Henri Bortoft, *Goethe's Scientific Consciousness* (Eastbourne: Gardners Books, 1998) or Daniel C. Wahl, "Zarte Empirie: Goethean Science as a Way of Knowing." *Janus Head* 8, no. 1, (2001): 58-76.
- ^{vi} On cross-fertilization between theoretical biology and computational architecture, see for instance Stanislav Roudavski, "Towards Morphogenesis in Architecture." *Architecture in International Journal of Architectural Computing* 7, no. 3 (2009): 345-374.
- ^{vii} Kostas Terzidis, *Algorithmic Architecture* (Oxford: Architectural Press, 2006) xi.
- ^{viii} Terzidis, *Algorithmic Architecture*, xi.
- ^{ix} Nancy K. Hayles, *Unthought* (Chicago: University of Chicago Press, 2017).
- ^x John Johnston, *The Allure of Machinic Life* (Cambridge MA: The MIT Press, 2008).
- ^{xi} Luciana Parisi, *Contagious Architecture* (Cambridge MA: The MIT Press, 2013).
- ^{xii} Terzidis, *Algorithmic Architecture*.
- ^{xiii} Kostas Terzidis, *Expressive Form. A Conceptual Approach to Computational Design* (New-York: Spon Press, 2003) 65.
- ^{xiv} See Eckart Förster, "Die Bedeutung von § 76, 77 der "Kritik der Urteilskraft" für die Entwicklung der nachkantischen Philosophie [Teil II]" *Zeitschrift für philosophische Forschungen* 56, no. 3 (2002): 321-345; Eckart Förster, *The Twenty-five Years of Philosophy*, trans. Brady Bowman (Cambridge and London: Harvard UP, 2012); Jean Petitot, *Morphologie et Esthétique* (Paris: Maisonneuve et Larose, 2004); Dalia Nassar, "From a Philosophy of Self to a Philosophy of Nature: Goethe and the Development of Schelling's Naturphilosophie" *Archiv für Geschichte der Philosophie* 92, no. 3 (November 2010): 304-321; Jennifer Mensch, "Intuition and Nature in Kant and Goethe" *European Journal of Philosophy* 19, no. 3 (September 2011): 431-53.
- ^{xv} On the projective paradigm grounding Kant's pre-critical and critical writings, see Constantin Rauer, "Kant's Philosophy of Projection: The Camera Obscura of the Inaugural Dissertation" *Rethinking German Idealism*, eds. Joseph Carew and Sean McGrath (London: Palgrave Macmillan, 2016) 21-50.
- ^{xvi} Immanuel Kant, *Critique of Judgment*, trans. James Creed Meredith (Oxford: Oxford UP, 2007) 214. Subsequent quotations from this edition will be referenced as CJ, followed by the page number.
- ^{xvii} On the notion of realism and its various meanings in Kant's work, see Dietmar Heidemann, "Kant and the form of realisms" *Synthese* (2019) and Paula Abela, *Kant's Empirical Realism* (Oxford: Oxford Scholarship, 2002).
- ^{xviii} Iain H. Grant, *Philosophies of Nature after Schelling* (London: Continuum, 2006) viii.
- ^{xix} Rauer, "Kant's Philosophy of Projection," 30. My emphasis.
- ^{xx} Rauer, 31.
- ^{xxi} Svetlana Alpers, *The Art of Describing. Dutch Art in the Seventeenth Century* (Chicago: U of Chicago P, 1983) 23.
- ^{xxii} *Artificial Life. An Overview*, ed. Christopher G. Langton, (Cambridge and London: The MIT Press, 1997) x.
- ^{xxiii} Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone Books, 2007) 55.
- ^{xxiv} Daston and Galison, *Objectivity*, 69.
- ^{xxv} In his writings on comparative anatomy, Goethe encourages the *Naturforscher* confronted with nature's contingent multiplicity to "grasp the whole" as if "looking at a general picture" Goethe, *Scientific Writings*, 118 from which one could deduce an anatomical Urtyp – a lesson to which Wittgenstein would listen carefully when developing his concept of the synoptic picture during the second phase of his work on language and his amendment to *Tractatus's* logic.
- ^{xxvi} Goethe, *Metamorphosis of Plants* (Cambridge MA: The MIT Press, 2009) 92.
- ^{xxvii} Luciana Parisi, "Automated Architecture : Speculative Reason in the Age of the Algorithm," *#Accelerate*, eds. Robin Mackay and Armen Avanessian (Falmouth: Urbanomic, 2014) 404.
- ^{xxviii} See Jean Petitot, *Morphologie et esthétique*; Mark Schneider, "Goethe and the Structuralist Tradition" *Studies in Romanticism* 18, no. 3 (1979) and more recently, Michael Saman, "Towards Goethean Anthropology: On Morphology, Structuralism and Social Observation," *Goethe Yearbook* 27, 2020. Saman draws on Mark Schneider's work and applies it to the anthropological field.
- ^{xxix} This is one of the main characteristics of the structuralist method according to Jean Piaget in *Le structuralisme* (Paris: PUF, 1968) 6.
- ^{xxx} Goethe, *Metamorphosis of Plants*, 80.

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- ^{xxxix} See *Glossary of Morphology*, eds. Salvatore Tedesco and Federico Vercellone (Cham: Springer Nature, 2020).
- ^{xxxix} On this topic, see “Glückliche Ereignis” (WA, 11, 18-21).
- ^{xxxix} Gilles Deleuze, “How do we recognize structuralism?” in *Desert Islands and Other Texts 1953-1974*, trans. Michael Taomina (Los Angeles/New York: Semiotext(e), 2004) 170-92, here 179.
- ^{xxxix} Schneider, “Goethe and the Structuralist Tradition,” 453-78, here 456.
- ^{xxxix} Gilles Deleuze and Félix Guattari, *A Thousand Plateaus*, trans. Brian Massumi, (Minneapolis and London: University of Minnesota P, 1987) 254. Also see Sean Ahlquist’s and Achim Menges’s claim that Goethe “clearly laid the foundation for linking geometric behaviour with a functional logic and understanding the general principles mathematically” in *Computational Design Thinking*, 16.
- ^{xxxix} Here I used the English translation by Schneider, “Goethe and the Structuralist Tradition,” 457.
- ^{xxxix} On the topic of algebra as “an autonomous theory which is established by its internal coherence and harmony,” sometimes revealing “an anti-Kantian attitude that sought to overcome the link of mathematics to the intuition of space and time” in the context of Germany at the turn of the nineteenth century, see Hans Niels Jahncke, “Algebraic Analysis in Germany, 1780-1840: Some Mathematical and Philosophical Issues,” *Historia Mathematica* 20 (1993).
- ^{xxxix} Elizabeth Wilkinson, “Goethe’s conception of form” *Goethe: Poet and Thinker*, eds. Elizabeth Wilkinson and Leonard Willoughby (London: Edward Arnold, 1962) 178. Quoted in Schneider, “Goethe and the Structuralist Tradition,” 462.
- ^{xxxix} Goethe, *Metamorphosis of Plants* §102.
- ^{xl} See Martin Dyck, “Goethe’s View on Pure Mathematics” *Germanic Review* (1956): 49-69; Renatus Ziegler, *Goethes Ideen zur Mathematik* (Dornach: Philosophisch-Anthroposophischer Verlag, 1993) and, more recently, Troy Vine, “Newton, Goethe and the Mathematical Style of Thinking” *Dialogue* 1, Sept 2020. I want to thank Troy Vine for pointing out to me Jahncke’s and Dyck’s papers, which helped in the development of this section.
- ^{xli} Jahncke, “Algebraic Analysis in Germany,” 265.
- ^{xlii} Martin Dyck, “Goethe’s Thought in the Light of his Pronouncement on Applied and Misapplied Mathematics,” *PMLA* 73, no. 5, Part 1 (1958): 505-515.
- ^{xliii} On this topic, see Johann Wolfgang von Goethe, “On Mathematics and Mathematicians,” trans. David Wood in *Symphilosophie : International Journal of Philosophical Romanticism* 3 (2021). (Forthcoming).
- ^{xliiv} I want to thank Jutta Eckle, director of Goethe’s Weimar Archiv and guest editor of the Leopoldina-Ausgabe, for pointing this out to me.
- ^{xli} Johann Wolfgang von Goethe, *Die Schriften zur Naturwissenschaft* (Leopoldina), Abt 2. Band 1A, eds. Dorothea Kuhn et al., (Weimar: Verlag Hermann Böhlhaus, 2011) 176.
- ^{xli} Goethe, *Die Schriften zur Naturwissenschaft*, 175.
- ^{xli} Goethe, *Scientific Writings*, 20.
- ^{xli} Jahncke, “Algebraic Analysis in Germany,” 267.
- ^{xli} Goethe, *Scientific Writings*, 16.
- ^l Two centuries later, René Thom’s catastrophe theory advances the non-linear mathematics required to formalize Goethe’s method.
- ^{li} On the condensing properties of algebra and diagrams, see Charles Alunni, “Diagrammes & catégories comme prolégomènes à la question : Qu’est-ce que s’orienter diagrammatiquement dans la pensée ?,” *Penser par le diagramme de Gilles Deleuze à Gilles Châtelet*, ed. Noëlle Blatt (Paris: Centre National du Livre, 2004) 83-95.
- ^{lii} Kostas Terzidis, “Algorithmic Form,” *Computational Design Thinking*, 94.
- ^{liii} Terzidis, “Algorithmic Form,” 2.
- ^{liiv} Terzidis, “Algorithmic Form,” 1.
- ^{liv} Gilles Châtelet, *Figuring Space*, trans. Robert Shore and Muriel Zagha (Dordrecht: Springer Science, 2000) 12.
- ^{lvi} Châtelet, *Figuring Space*, 12.
- ^{lvii} Châtelet, *Figuring Space*, 12.
- ^{lviii} Charles Sanders Pierce, “Sur une nouvelle liste des catégories” *Actes de l’Académie Américaine des Arts et des Sciences* (1867), quoted by Noëlle Blatt in “L’expérience diagrammatique : un nouveau régime de pensée,” *Penser par le diagramme de Gilles Deleuze à Gilles Châtelet* (2004) 8. My translation from French.
- ^{lix} Pierce, “Sur une nouvelle liste des catégories,” 8.
- ^{lx} See, for instance, Carl von Martius, *The Book of Palms* (Cologne: Taschen, 2015).
- ^{lxi} Richard Dawkins, *Climbing Mount Improbable* (New York: W.W Norton & Co, 1996) 200. Quoted by Jarron, Matthew, “Cell and Tissue, shell and bone, leaf and flower - On Growth and Form in Context” *Mechanisms of Development* 145 (2017) 22-25, here 24.
- ^{lxii} Terzidis, *Algorithmic Architecture*, 16.
- ^{lxiii} See, for instance, Arhat Abzhonov, “The old and new faces of morphology : The legacy of D’Arcy Thompson’s theory of transformations and laws of growth” *Development* 144 (2017) 4284-4297.

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- lxiv Jarron, "Cell and Tissue", 24.
- lxv D'Arcy W. Thompson, *On Growth and Form* (Cambridge, Cambridge UP, 1942) 2.
- lxvi D'Arcy W. Thompson, *On Growth and Form*, 2.
- lxvii D'Arcy W. Thompson, *On Growth and Form*, 7.
- lxviii Kumar Sanjeev and Peter. J. Bentley, "An introduction to Computational Development" *On Growth, Form and Computer* (London : Elsevier Academic Press, 2003) 2.
- lxix On the seminal entanglement between architecture and structural biology, see S. J. Gould's and R. C. Lewontin's paper "The Spandrels of San Marco and the Panglossian paradigm : a critique of the adaptionist programme" *Biological Sciences* 205, no.1161 (1979): 581-598. For a contemporary take on the subject, see R.T.D. Prabhakaran et al., "Plants and Architecture : The Role of Biology and Biomimetics in Material Development for Buildings" *Intelligent Building International* 11, no. 3-4 (2019) and Stanislav Roudavski, *Towards Morphogenesis*.
- lxx On this point, see for instance Victor Marques, "Positing the Presuppositions – Dialectical Biology and the Minimal Structure of Life" *Slavoj Zizek and Dialectical Materialism*, eds. Agon Hamza and Frank Ruda, (New York: Palgrave Macmillan, 2016) 122-123: "The system as a whole is a locus of real physical influences, a source of causal influence— but it is not a substantial reality; its mode of existence is relational. As Varela says, life is in the configuration and in the dynamical pattern, but life is not in any particular structure nor in a localized property—it doesn't exist anywhere solidly."
- lxxi On this topic, see Johnston, *The Allure of Machinic Life*.
- lxxii On this topic, see Terzidis, *Algorithmic Architecture*.
- lxxiii Achim Menges, "Material Computation: Higher Integration in Morphogenetic Design" *Architectural Design*, ed. Achim Menges (2012) 20.
- lxxiv The SSEM, at the University of Manchester, where Turing served as Deputy Director of the Royal Society Computing Machine Laboratory.
- lxxv Alan Turing, "The Chemical Basis of Morphogenesis," *Philosophical Transactions of the Royal Society of London*. Series B, Biological Sciences 237, no. 641 (1952) 37-72.
- lxxvi Turing, "The Chemical Basis," 72.
- lxxvii Turing, "The Chemical Basis," 72.
- lxxviii This sentence alludes to the title of a recent symposium held by the Zentrum für Netzkunst (Berlin). See <https://netzkunst.berlin/cc/node/symposium>.
- lxxix See <http://algorithmicbotany.org/>
- lxxx See the "Software" tag on the "Algorithmic Botany" website of the University of Calgary : http://algorithmicbotany.org/virtual_laboratory/
- lxxxi Przemyslaw Prusinkiewicz and Aristide Lindenmayer, *The Algorithmic Beauty of Plants* (New York : Springer Verlag, 1990) 1.
- lxxxii Prusinkiewicz and Lindenmayer, *The Algorithmic Beauty*, 16.
- lxxxiii For more on the topic, see Jonathan Swinton, "Watching the Daisies Grow: Turing and Fibonacci Phyllotaxis" *Alan Turing: Life and Legacy of a great Thinker*, ed. Christof Teuscher (Berlin : Springer, 2004) 477-96.
- lxxxiv Prusinkiewicz and Lindenmayer, *The Algorithmic Beauty*, 99.
- lxxxv Prusinkiewicz and Lindenmayer, *The Algorithmic Beauty*, iv.
- lxxxvi On this topic, see *Material Computation*.
- lxxxvii See Federica Cislighi, *Goethe e Darwin : la filosofia delle forme viventi* (Milano : Mimesis, 2008) 51-52-53.
- lxxxviii See Luciana Parisi, "Critical Computation : Digital Automata and General Artificial Thinking" *Theory, Culture and Society* 36, no. 2 (2019): 89-121.
- lxxxix Marie-Jeanne Lesot, Maria Rifqi, Bernadette Bouchon-Meunier, "Fuzzy Prototypes : From A Cognitive View to a Machine Learning Principle", eds. Bustince, Herrera, Montero, *Studies in Fuzziness and Soft Computing* 220, (Berlin: Springer, 2008): 431-452.
- xc Slavoj Zizek, *The Abyss of Freedom/The Ages of the World* (Michigan: University of Michigan, 1997) 4.
- lxi Zizek, *The Abyss of Freedom*, 4.
- xcii Parisi, "Critical Computation," 3.
- xciii Parisi, "Critical Computation," 3.
- xciv Parisi, "Critical Computation," 3.
- xcv Lesot, Rifqi and Bouchon-Meunier, "Fuzzy Prototypes", 432-433.
- xevi See *Goethe and Wittgenstein*, ed. Fritz Breithaupt (Frankfurt: Peter Lang Verlag, 2003).
- xcvii See Marc Müller, 23.09.2018 "On the Grammar of Nature: Looking at Goethe's Method through Wittgenstein's Eyes," International Conference *On the Shoulders of Giants: The Legacy of Newton, Goethe and Turner* in Stourbridge UK, Fields Center.

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- ^{xcviii} Fritz Breithaupt, “Non-referentiality : A Common Strategy in Goethe’s Urphänomen and Wittgenstein’s language game,” *Goethe and Wittgenstein* (2003) 76.
- ^{xcix} Breithaupt, “Non-referentiality,” 76.
- ^c Breithaupt, “Non-referentiality,” 76.
- ^{ci} Ludwig Wittgenstein, *Philosophical Investigations*, trans. G. E. M. Anscombe (Oxford : Basil Blackwell, 1953) 34.
- ^{cii} Lesot, Rifqi, Bouchon-Meunier, “Fuzzy Prototypes,” 433.
- ^{ciii} Wilkinson, “Goethe’s conception of form,” 462.
- ^{civ} Harpreet Singh et al., “Real-Life Application of Fuzzy Logic,” *Advances in Fuzzy Systems* (2013).