

KNOWING THE WHOLE WORLD FROM THE TOP OF A MOUNTAIN: FROM ORDERLY SYSTEMATIZATION TO COMPLEX EXPLANATORY SYSTEMS

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Non-peer reviewed preprint submitted to EarthArXiv
Submitted for review as book chapter in “Understanding Knowledge”,
Editors Marieke Hendriksen & Fokko Jan Dijksterhuis,

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Introduction

Changing notions of system at the end of the 18th century

The term system is used on a daily basis in science and education with widely ranging meanings, such as systematicity, the Earth system, and machines. Tracing the historic changes in the concept of system is particularly relevant to present-day academic fields such as earth system science, climatology and ecosystem science, because it is central to these sciences. This is evidenced by its frequent use in publications, journal names, education, and the conceptual models, scale models and simulation models that the sciences employ to gain further knowledge and understanding about emergent patterns in the world.¹ A concept is a carrier of knowledge, or a concentrate of several substantial meanings, through which we can understand aspects of reality². As such, the notion system constitutes a basic and frequently used knowledge concept that captures and guides the perception, understanding, study and manipulation of reality.

As Koselleck argues, a basic knowledge concept, or Grundbegriff, may change over time in what it concentrates and represents, and its history must be traced for the knowledge and understanding to be reconstructable.³ In the case of systems, the German term Begriffsgeschichte is even more appropriate than the English term conceptual history, as Begriff means not only a concept that represents something, but also means the understanding that comes with the representation or imagination of something⁴.

Which precise meaning of system is intended in present instances of use is often only inferable from the context of its use in the past in a specific discipline. Moreover, as scientific disciplines employing the term system develop, the notion of system inevitably changes in meaning, adds on layers of meaning and sheds aspects in the meaning that are no longer thought viable. Broadly speaking, the 17th century solar system, the 18th century taxonomic system of species and the 20th century general systems are not the same kind of system, but this is not immediately clear to scientists from the word, and leads to confusion. For example, in many commemorations of his 250th birthday in 2019, Alexander von Humboldt⁵ has been hailed as the founding father of ecosystem science and of earth

¹ For Biology alone, there are tens of journals specifically devoted to systems biology (e.g. <http://info-centre.jenage.de/systems-biology/journals.html>, accessed December 2020). Likewise, the earth-scientific literature, the conferences and the curricula are rife, if not rampant, with references to systems and complexity. For example, some of the open access Copernicus journals of the European Geosciences Union and the journals of the American Geophysical Union, which have a large minority of international members from all continents, mention 'systems' (and associated terms holism, resilience and regime shifts) in the description and in their names, such as Hydrology and Earth System Science (HESS) and Journal of Advances in Modeling Earth Systems (JAMES). The Google Books Ngram Viewer, accessed December 2020, shows that the terms 'system, cause, species' have similar frequencies of usage, between 1800 and 1980, but the frequency of cause reduced gradually while that of system increased rapidly after the mid-20th century. The Web of Science (accessed December 2020) shows that the word system was used about 100-200 times per year in the early 20th century, rising to nearly half a million times per year in 2020.

² Goering, D.T. 2013, Concepts, history and the game of giving and asking for reasons: a defense of conceptual history. *Journal of the Philosophy of History* 7, 426-452, <https://doi.org/10.1163/18722636-12341260>

³ R. Koselleck (2002), Social history and conceptual history, Ch. 2 in *The practice of conceptual history*. Stanford University Press

⁴ <https://www.dwds.de/wb/Begriff>

⁵ Friedrich Wilhelm Heinrich Alexander von Humboldt, known as Alexander, younger brother of Wilhelm, was born on 14 September 1769 and died 6 May 1859.

system science^{6,7}. But a modern read of a historic work should raise questions whether the concept 'system' means the same things as it does at present. In this case, it did not.

A fast and fascinating change in views on nature and its emergent patterns occurred in the late 17th and early 18th century. In Humboldt's 1807 *Essay on the geography of plants* (henceforth Plant Geography)⁸, plant species are not described as part of a taxonomic system, but positioned geographically as vegetation zones in the context of observations of atmospheric conditions, topography and geology. A detailed and often reproduced Tableau (Naturgemälde) depicted an idealized mountain with vegetation zones in conjunction with observations of physical climate conditions (Figure 1). Humboldt argued in words and in image that the combined physical conditions, that he measured on his expeditions, are causes of the geographical distribution and the diversity of plant species that he observed. This causality was an innovation. As shown later in this chapter, Humboldt seems to attribute his ordering principles to nature, and he distanced himself in several places from the ordering principle of many knowledge systems developed until then. The causal, explanatory aspects of Humboldt's representation of nature were developed further in his later, seminal work *Kosmos, Entwurf einer physischen Weltbeschreibung* (henceforth Cosmos)⁹. The Cosmos described how Humboldt saw the interconnectedness of all the observed phenomena in the world, not only the climate and the plants but also the animals, the humans, and the solar system. As illustrated in the citations above, present-day ecosystem scientists and earth system scientists read in this central idea of the Cosmos that they share common ground with Humboldt, which is questionable.

The questions addressed in this chapter are what the notion of system meant, and how its meaning changed around the end of the 18th century, and how Humboldt's notion of system had roots in works before him and how it may have changed the later views of others.¹⁰ The notion of system will be traced in the two aforementioned works of Humboldt, linked with earlier and contemporary works that influenced Humboldt and contrasted with present-day meanings of system. Evidence presented in this chapter shows that, in his Plant Geography, Humboldt intended to explain the ordering of vegetation as the effect of natural forces. This contrasted with the imposed, a priori

⁶ E.g. Schrodte et al. (2019, Journal of Biogeography, DOI: 10.1111/jbi.13616), Pausas and Bond (2019, Journal of Ecology, DOI: 10.1111/1365-2745.13109), Moret et al. (2019, PNAS, <https://www.pnas.org/cgi/doi/10.1073/pnas.1904585116>), an Editorial on Humboldt's legacy (2019, Nature Ecology & Evolution <https://doi.org/10.1038/s41559-019-0980-5>), Steffen et al. (2020, Nature Reviews Earth & Environment, <https://doi.org/10.1038/s43017-019-0005-6>) followed by a comment by a historian: Rispoli (2020, <https://doi.org/10.1038/s43017-019-0012-7>). For a particularly Whiggish and bombastic narrative, see Schellnhuber (1999, Nature, <https://doi.org/10.1038/35011515>).

⁷ Also in Jackson's preface to Romanowski's 2009 translation the present and past notions of system and systematics are not pried apart but seemingly interpreted from the perspective of present system science.

⁸ Von Humboldt, A. and Bonpland, A. (1807). *Essay on the geography of plants and the Tableau Physique*. Paris: Fr. Schoell. Translated from the original French, first edition by S. Romanowski, The University of Chicago Press 2009, Chicago, USA. The first edition of 1807 in German is also used here: *Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer*, printed by F.G. Cotta, Tübingen, <https://archive.org/download/mobot31753000974581/mobot31753000974581.pdf>.

⁹ Von Humboldt, A. (1845). *Cosmos: a sketch of a physical description of the universe*. Translated in 1858 from German by E.C. Otté, Harper and Brothers, New York. The first edition is also used here; this was printed in German in Fraktur by Cotta, Stuttgart (Tübingen) and scanned in 2013 by the Deutsches Textarchiv, http://www.deutschestextarchiv.de/book/show/humboldt_kosmos01_1845.

¹⁰ The connotation of understanding in the German Begriffsgeschichte is apt in the context of Humboldt's works and his intentions with them. The notion of understanding refers to a relation between an agent and knowledge. Unlike the notion of explanation, understanding is about intelligibility and refers to epistemic skills gained by an actor, by engaging with a theory, sensory experiences and intervention (De Regt 2017). Humboldt's poetic and tactile descriptions of nature experienced through all his senses were intended to convey his understanding to the reader, to change how his contemporaries perceived and understood reality. De Regt, H.W. 2017, *Understanding scientific understanding*, OUP, 301 pages.

ordering principles that were common in the second half of the 18th century, such as the alphabet or morphological properties and number of parts in organisms as in Linnaeus *Systema Naturae*¹¹. Yet, these notions are interrelated: other systems that used physical forces as the ordering principle already existed, such as Laplace's *Système du monde* or Kant's *Physische Geographie* (henceforth *Physical Geography*)¹². Humboldt ordered the vegetation in his *Plant Geography* mainly by physical forces, which were also an ordering principle in Laplace and Kant. The important difference was that Humboldt believed he needed an additional, vital force, or forces, in conjunction with the other forces to explain the ordering of matter into organisms, their metamorphosis, and the ordering of vegetation on mountains and planet-wide.

I will show that Humboldt, surprisingly, did not use the word system for the spatial ordering of vegetation on the planet, while he did use the word for the ordered knowledge systems and was at pains to make clear that his view of nature was different from those systems. So it is not with Humboldt that the word system transforms to its present-day meaning in ecosystem science and earth system science. Nevertheless, his notion of the physical, chemical, biological and human interrelations in nature at the scale of habitats, mountains and continents is that of a complex system. This notion may seem to resemble the present-day notion of interrelatedness in ecosystems and earth systems, as is the idea that natural forces underlie the ordering principles. However, I will argue that Humboldt's version of that global system is permeated with 18th century vitalism, which is not acceptable for present-day natural scientists. In this sense, Humboldt's view on nature is at odds with the notion of complex systems that developed in the 1920s and 1950s to deal with emergent organisation—without vital forces.

Past and present notions of system

The word system derives from the classic Greek σύστημα, which means a whole compounded of several parts. Here, the parts may refer to soul and body, to an organization or company of people, to a human construct such as the intervals and scales in music, a literary or logical composition or a group of buildings, to metrical and mathematical systems including the solar system, to physiological phenomena, or to machines.¹³ The term system has had several possible meanings simultaneously. The *Chambers Cyclopaedia* defines system as “a certain assemblage, or chain of principles and conclusions, or the whole of any doctrine, the several parts whereof are bound together, and follow or depend on each other”. This definition is followed by a similar list of items as in the classic Greek definition given above.¹⁴ The first known treatise on systems by Lambert (1782)¹⁵, is mainly concerned with the question of how much of a philosophical system should be based on a priori reasoning and on experience, and striking a balance between the required rigor and accuracy in the logical proof for propositions underlying the system on the one hand, and the understanding of the reader on the other. The examples given by Lambert are mainly about mathematics, metaphysics

¹¹ Carl Linnaeus (1758), *Systema Naturae*, 10th edition, book 1, <https://www.biodiversitylibrary.org/item/10277#page/3/mode/1up> and the English translation by William Turton (1806). *A general system of nature: through the three grand kingdoms of animals, vegetables, and minerals, systematically divided into their several classes, orders, genera, species, and varieties*. London: Lackington, Allen, and Co. Volume 1 (which is about the animal kingdom).

¹² Immanuel Kant (1802) *Physische Geographie, Ersten Bandes erste Abtheilung welche die mathematischen Vorkenntnissen und die allgemeine Beschreibung der Meere enthält*. Königsberg, D.F. Rink, <https://babel.hathitrust.org/cgi/pt?id=uc1.31822042776674&view=1up&seq=7> accessed August 2020.

¹³ H.G. Liddell and R. Scott (1940), *A Greek-English Lexicon*, revised and augmented throughout by H.S. Jones with the assistance of R. McKenzie. Oxford Clarendon Press. 1940, <http://www.perseus.tufts.edu/hopper/text?doc=Perseus%3Atext%3A1999.04.0057%3Aentry%3Dsu%2Fsthma>

¹⁴ *Cyclopaedia: or, An Universal Dictionary of Arts and Sciences* by Ephraim Chambers in London, 1728, <https://archive.org/details/Cyclopediachambers-Volume2/page/n821/mode/2up?q=system>.

¹⁵ J. H. Lambert (1782), *Logische und philosophische Abhandlungen*. Bd. 1, 2 Bde., Berlin/Dessau. Citations from chapter XLVII, *Theorie des Systems* p.510-517.

and the Ptolemaic system of the cosmos. As many authors before him¹⁶, Lambert saw systematics mainly as an extension of a mathematical, a priori way of ordering¹⁷.

A German etymology suggests that in the 16th century the word system was used to describe the order and structure of the solar system. In the first half of the 17th century it meant a totality of views, knowledge or teachings. In the early 18th century it meant a meaningful, ordered, factually structured body of knowledge, while in the mid-18th century it was also in use for the interacting parts of the human body and for social and political institutions. In the latter sense, the word systematical was also used to denote the ordered proceeding through a system by whomever mastered the system, or a planned, orderly development of a discipline.¹⁸ Likewise, the use of system in the Cambridge History of Science volumes from ancient to 18th century science are mainly about astronomy, mathematics, music, anatomy and taxonomy.¹⁹ The Oxford English Dictionary also

¹⁶ A list of titles since 1600 is given on <http://www.muellerscience.com/SPEZIALITAETEN/System/Lit.System%281556-2001%29.htm>, accessed August 2020.

¹⁷ J.E. Lesch (1990), Systematics and the geometrical spirit, in: T. Frangsmyr, J.L. Heilbron and R.E. Rider, eds, The Quantifying Spirit in the Eighteenth Century. University of California Press, Berkeley.

¹⁸ Digitales Wörterbuch der deutschen Sprache, <https://www.dwds.de/wb/System>, including etymology and thesaurus, accessed December 2020. The etymology of System is: 'sinnvoll in sich gegliedertes, geordnetes Ganzes'. In den Formen Sistemata Plur. (Mitte 16. Jh.), Systemate (aus dem Plur. gebildeter Dativ Sing., 1. Hälfte 18. Jh.), Systema und System (Mitte 18. Jh.) Entlehnung von spätlat. systēma n., griech. sýstēma (σύστημα) 'aus Einzelteilen zusammengefügt und gegliedertes Ganzes, Vereinigung, Gruppe, die in einem Staat Zusammenlebenden, Staatsgebäude, Staatsverfassung, aus mehreren Lehrsätzen zusammengesetztes Lehrgebäude (einer Kunst oder Wissenschaft)', zu griech. synistánai (συνιστάναι) 'zusammenstellen, -fügen, -bringen, vereinigen, zustande bringen'; vgl. griech. histánai (ιστάναι) '(hin)stellen, aufstellen, errichten'. Zunächst von der Ordnung und dem Gefüge der Himmelskörper, dem Weltgebäude (Mitte 16. Jh.; vgl. Planeten-, Sonnensystem), dann (Mitte 18. Jh.) von zusammenwirkenden Teilen des menschlichen Körpers (vgl. Gefäß-, Kreislauf-, Nervensystem) sowie der gesellschaftlichen bzw. politischen Einrichtungen (vgl. Staats-, Verwaltungs-, Wirtschaftssystem). System ist vor allem ein Begriff der Philosophie und der Wissenschaft im Sinne einer 'gegliederten Gesamtheit von Anschauungen, Erkenntnissen, Lehren' (1. Hälfte 17. Jh.), allgemein 'Plan, Konzept, Methode' (2. Hälfte 18. Jh.), vgl. ein System entwerfen, ändern, System in etw. bringen. systematisch Adj. 'ein System betreffend, sinnvoll, geordnet, sachlich gegliedert' (Anfang 18. Jh.), spätlat. systēmaticus, griech. systēmatikós (συστηματικός) 'zu einem Ganzen zusammenfassend'; davon abgeleitet Systematik f. 'planmäßiger, geordneter Aufbau einer Wissenschaft' (Ende 18. Jh.) und Systematiker m. 'wer ein System beherrscht, wer systematisch vorgeht, arbeitet' (2. Hälfte 18. Jh.) systematisieren Vb. 'in ein System bringen, nach einem Ordnungsprinzip gliedern und aufbauen' (Anfang 19. Jh.). Translated and shortened by the author with DeepL version 1.12.2, <https://www.deepl.com>. System: 'meaningfully structured, ordered whole'. In certain forms (mid-16th century, 1st half of 18th c. and mid-18th c.) borrowing from Late Latin systēma and Greek sýstēma (σύστημα) 'a whole composed of individual parts and subdivided, an association, a group, those living together in a state, a state building, a state constitution, a doctrinal building (of an art or science) composed of several doctrines', to Greek synistánai (συνιστάναι) 'to put together, to join, to bring together, to unite, to bring about'; cf. Greek histánai (ιστάναι) '(to) place, to set up, to erect'. First of the order and structure of the heavenly bodies, the world building (mid-16th century; cf. planetary, solar system), then (mid-18th century) of interacting parts of the human body (cf. vascular, circulatory, nervous system) as well as of social or political institutions (cf. state, administrative, economic system). System is above all a term of philosophy and science in the sense of a 'structured totality of views, insights, teachings' (1st half of 17th century), generally 'plan, concept, method' (2nd half of 18th century), cf. design a system, change, bring system into something, as adjective systematically 'relating to a system, meaningful, ordered, factually structured' (early 18th century), late Latin adj. 'relating to a system, meaningful, ordered, factually structured' (early 18th century). Late 18th century, late Latin systēmaticus, Greek systēmatikós (συστηματικός) 'summarising into a whole'; from which systematics f. 'planned, orderly structure of a science' (late 18th century) and systematiker m. 'who masters a system, who proceeds systematically, works' (2nd half of 18th century), systematise 'to bring into a system, to arrange and build up according to an organising principle' (early 19th century).

¹⁹ Cambridge University Press, Vol. 1 Ancient Science, Eds. A. Jones and L.Taub (2018), 33 search results all related to mathematics, astronomy, music, anatomy and diagnosis, taxonomy, Vol. 2 Medieval Science, Eds. D.C. Lindberg and M.H. Shank (2013), 23 results, with added themes of philosophical systems, language,

mainly lists sources since 1600 in these categories.²⁰ In the 19th century, natural or taxonomic systems were constructed by various notions of similarity and difference. This often amounted to a systematic ordering on the basis of external, observable properties, but some systems were developed with evolutionary ideas that focussed not so much on classification as on inferred familial relations and inheritance.²¹ In contemporary language, system still refers to a structure of statements that together form a whole, such as the heliocentric solar system, a taxonomic system for plant classification, a meaningfully structured body of knowledge, a political or social construct, a network such as for transport or irrigation, or a self-regulating, open system such as an organism. As synonyms, the (German) words organization, structure, ordering, mechanism, interconnectedness and machine are suggested. Clearly, the notions of system have included many phenomena that are composed of interacting parts, such as organisms, machines, constructed knowledge systems, and constructed systems in society.

There are many general definitions of system in use by present-day scientists from various disciplines. Ladyman et al.'s discussion of current understandings of complex systems in science resulted in a definition that captures a core set of features: a complex system is an ensemble of many elements which are interacting in a disordered way, resulting in robust organization and memory²². This definition means the following. Without the order emerging from disorder, a system may be merely complicated rather than complex, such as a gas at equilibrium, which can be studied at the level of its components by statistical mechanics and thermodynamics. The organization is hierarchical at several levels and scales, such as in a living organism which is composed of matter organized in cells, organs and subsystems such as the nerve system. A complex system has memory in the sense that the internal structure is preserved and its state is to some degree dependent on the recent past. Complex systems such as ecosystems and earth systems are open, which means that some kind of energy or matter is exchanged with the larger system around it. As such, delineation of the system is somewhat arbitrary and the notion of complex system is ascribed to things and processes that are thought to exist in nature as well as an unobservable abstraction, or model, of an entity delineated in the world. A living organism, for example, is seen as a system with stable organization and dynamics that work against the tendency of the environment to disorganize it in agreement with the second law of thermodynamics. In other words, a complex system is thought to have emergent properties and behaviour and is holistic rather than reductionistic. This notion of system became generally used in the second half of the 20th century²³ alongside its other meanings related to systematicity .

Humboldt's use of the word system

In the *Plant Geography*, published in 1807, Humboldt only used the word system 5 times (in French), of which 2 times for the nerve system, 2 times for the solar system and once for the system of forces that created geological layers, and similarly 11 times in the German translation published in 1807 and 6 times in the English translation of 2009.

knowledge classification in general, geography, educational institutions, Vol. 3 Early Modern Science, Eds. K. Park and L. Daston (2006), 37 results, which added a colonial system, and Vol. 4 Eighteenth Century Science, Ed. R. Porter (2003), 42 results, which added societal systems of exclusion by caste or gender.

²⁰ Oxford English Dictionary, accessed December 2020 with the search term system. The modern meaning of system is found only since the 1920s in sources of technical and digital systems and from the 1950s onwards the general systems theory and systems approach are referred to.

²¹ R.J. O'Hara (1991) Representations of the natural system in the nineteenth century, *Biology and Philosophy* 6, 255-275.

²² p. 57 in Ladyman, J., Lambert, J. and Wiesner, K. (2013). What is a complex system? *Euro Jnl Phil Sci* 3, 33-67.

²³ Ludwig von Bertalanffy (1969), *General System Theory*, George Braziller, New York, see for discussion M. Drack (2009, Ludwig von Bertalanffy's early system approach, *Systems Research and Behavioral Science*, DOI:10.1002/sres.992).

In the first volume of the *Cosmos*, published in 1845, Humboldt used the word system 70 times for the solar system, planet-moon systems and planetary rings, 14 times for his invention of isolines of earth magnetism, temperature or gravity, 9 times for sedimentary strata with distinct fossils, particularly those of the Silurian and Permian periods, 7 times for continents and mountain ranges and rivers, 5 times for systematic groupings or taxonomic principles, 3 times for theological or philosophical systems and 1 time for the vascular systems in plants and animals.²⁴ This shows that he used the word for all the different notions that were in use at the end of the previous, 18th century. In the following section, the ordering principles of the Plant Geography will be compared with those of earlier works that Humboldt refers to.

Ordering principles in systems in the second half of the 18th century

Systems of the physical universe and everything

Many scholars have systematized knowledge but there are important differences that illustrate how the notion of system was changing in the second half of the 18th century. The ordering principle of a system can perhaps be interpreted as a reflection of the epistemological stance or even the metaphysical belief of the maker of a system. In the *Cosmos* Humboldt refers to several kinds of systems and their makers, which are well known and only briefly introduced here before we turn to Humboldt's ordering principles and the question how much those are rooted in earlier works.

First, taxonomic systems, particularly the *Systema Naturae* (1735-1758) of Linnaeus, constructed three kingdoms, that of the animals, vegetables and minerals, which were further subdivided into classes, orders, genres and species. The plant species were systematized by observable, but a priori established morphological and numerical similarities and differences. The ordering principle of the Linnaean taxonomy was by morphology and number, that is, effects without an attempt to identify causes.

Second, the alphabetic ordering of knowledge in encyclopedias, such as that of d'Alembert's and Diderot's *Encyclopédie* (1751-1772) perhaps assumes the least about nature, regardless of the metaphysics in the individual lemmas.

Third, Laplace constructed his model of the solar system, the *Système du monde* (1796), not merely as an idealized image of the regularity of celestial bodies, unlike earlier solar system models. Laplace developed the nebular hypothesis of Kant to explain how the solar system came about, including the orientation of orbits and direction of motion of the planets around the Sun. The *Système du monde* linked the celestial bodies in space and time to the (physical) forces of nature known at the time. Laplace conducted astronomical calculations based on Newtonian mechanics, where the forces of gravity and chemical attraction are seen as causes of the stability of the solar system that Laplace hoped to prove.

Fourth, Kant's lectures on Physical Geography, published at the turn of the century, are about a system with, as ordering principles, physical forces and a concept of time and space. Kant's thinking is complex and difficult to understand from a present-day perspective²⁵, and undoubtedly there are

²⁴ Likewise, Somerville uses the word system in the same meanings as Humboldt and more sparsely. (Mary Somerville, 1849, *Physical Geography*, 2nd edition, John Murray, London, volume 1, <https://archive.org/details/physicalgeograp01somegoog> and volume 2 <https://archive.org/details/physicalgeograp02somegoog>, also see Sanderson (1974, *Mary Somerville: her work in physical geography*, *Geographical Review* 64(3), 410-420).

²⁵ In 'Objectivity', Daston and Galison (2007, Zone Books) describe how the concepts of subjective and objective changed between late medieval times and Kant's work, and argue that it was frequently misunderstood.

relations between his Physical Geography and his philosophical works. However, it is the Physical Geography that matters most to the tracing of the notion of system in Humboldts works, for, as demonstrated by Hartshorne, Humboldt contrasted his view of geography with the *systema naturae* in very similar phrases as Kant did, of whose work he was well aware, but without reference to source²⁶. Kant argued that understanding of nature cannot be gained by pure reasoning or by pure empiricism; rather, both senses and reasoning about the order that is imposed on nature, colour the way we perceive the world. Kant warns against artificial ordering procedures such as that of the *Systema Naturae* and against teleological explanations²⁷. In contrast, his Physical Geography is intended as a holistic framework, where physical forces positioned in the a priori postulated structure of space and time necessarily lead to an explanation of the phenomena in it. For explanations by physical forces, for instance, air pressure and tides, he refers to work by Newton, Bernoulli and other physicists. The holistic character is apparent from the well-known ‘house-building analogy’ in the introduction of Physical Geography:

*“Wer z.B. ein Haus bauen will, der macht sich zuerst eine Idee für das Ganze, aus der hernach alle Theile abgeleitet werden. So ist also auch unsere gegenwärtige Vorbereitung eine Idee von der Kenntniss der Welt. Wir machen uns hier nämlich gleichfalls einen architectonischen Begriff, welches ein Begriff ist, bey dem das Mannigfaltige aus dem Ganzen abgeleitet wird.”*²⁸

Kant needs to place the phenomena of interest within the context of a preconceived architecture in order to derive explanations for specific parts from the whole. In other words, for Kant a system is a construct, a model representation of the real world, wherein the ordering is partly imposed by a concept of time and space, and partly imposed by physical forces. Especially in this causal aspect it is different from systematized knowledge, and, as I will show later, has similarities with Humboldts view on nature.

A vital force of life as the organizing principle of living nature

Much has been written about the history of the notion of a vital force, but the relevance here is that the vital force was the putative ordering principle behind the morphology of plants and taxonomic systems²⁹. In the second half of the 18th century, it was argued that physiological activities demonstrated no immediately visible and proportional cause, unlike physical, mechanical and chemical effects. Instead, life-forms self-organized to have certain morphologies, behaviours and metamorphoses, connections between parts of living organisms could not be discerned, and physiological effects often exceeded their immediate causes in duration, intensity and extent. Experiments on freshwater polyps, which are a few cm in length, had shown that parts cut off regenerated—grew back like plants or crystals—into whole organisms with the entire digestive tract. All this led vitalists to deny the mechanical world view, as physical forces of attraction and repulsion

²⁶ Hartshorne (1958) and Elden (2009).

²⁷ Büttner (1973, *Studia Leibnitiana*, <http://www.jstor.com/stable/40693708>): Zum Übergang von der teleologischen zur kausalmechanischen Betrachtung der geographisch-kosmologischen Fakten. Ein Beitrag zur Geschichte der Geographie von Wolff bis Kant.

²⁸ *Physische Geographie* p.9. DeepL translation: “If you want to build a house, for example, you first have to come up with an idea for the whole thing, from which all the parts are then derived. So our present preparation is also an idea of the knowledge of the world. Here we are also making an architectonic concept, which is a concept by which the manifold is derived from the whole.”

²⁹ In relation to this, the frontispiece to the German translation of the *Plant Geography* was dedicated to Goethe. Poetry, in the form of Apollo, as a compliment to Goethe, unveils Artemis, the goddess of nature. Artemis is dressed in systematically organized animal species. At her feet lies Goethe’s book *Versuch die Metamorphose der Pflanzen zu erklären* (1790), which may be an indirect reference to *Bildungstrieb*, or ‘vital drive’. Goethe and Humboldt discussed this idea extensively after the lectures by Blumenbach that Humboldt attended. The frontispiece suggests that Humboldt believed that the organization of the archetypal forms in nature, collected systematically in taxonomies, to be caused by a vital force.

could not account for organic phenomena, nor for some chemical and electrical phenomena³⁰. Instead, some began to look at systematic interconnectedness of parts as a possible cause of life.³¹ It was in this context that Humboldt was educated at the university of Göttingen. Here, Johann Friedrich Blumenbach and others argued that living organisms are shaped and metamorphosed by a driving force: the *Bildungstrieb*³². This formative power not only causes the different morphologies of species, but also their internal organization of the parts that together only function as a whole. This idea was attractive to builders of taxonomic systems, because it suggests a cause beyond a priority established observables. For example, Goethe thought that such an organizational drive could explain his 'Urformen': archetypical forms that he idealized from the similarities in morphology of plants³³, and for which the drive of life, or vital force, potentially was an ordering principle. The problem remained, of course, that its nature was unknown, but this was not considered a reason for rejection of the idea. Blumenbach and other held that, where Newton could posit the unknown entity of gravity in his method of celestial mechanics to mathematically link physical phenomena, the vitalists could similarly posit an unknown life force and use that to link a broad range of animate phenomena. Wolfe argued that posing a vitalic force as such neither implied an ontological claim nor a direct connection between between a vitalic principle and observable phenomena. Instead, it is a device that explains a range of phenomena while it is itself unexplained and unobservable, analogous to electricity or the gravitational force, of which the causes are also unknown and only effects are observable³⁴. For Blumenbach and other contemporary vitalists, the drive of life was what Charles Wolfe calls a provisionally inexplicable, explicative device, and vitality was conceived without locating it in a substance.³⁵

However, others, including the young Humboldt, attempted to identify vital force experimentally. For example, at the end of the eighteenth century, Galvani laboured to find a connection between galvanism, electricity and vital forces, because it had long been known that animals and humans responded to 'irritation'. Galvani had discovered that the muscles of dead frogs contracted when exposed to two different metals and by sparks from static electricity. He thought that nerves transmitted the electricity and muscles could store it, and inferred that electricity was the key to the animation of living matter. Likewise, Alexander von Humboldt wondered whether galvanism could be made into a general principle that accounted for a large range of physical and biological processes³⁶. He conducted thousands of experiments on galvanic forces. The muscles of insects,

³⁰ The abandoning during the eighteenth century of the mechanistic worldview, where microscopic corpuscles explain the behaviour of macroscopic bodies without distinguishing between organic and inorganic matter, is discussed by Gaukroger (2016), *The Natural and the Human: Science and the Shaping of Modernity, 1739–1841*, Chapter 3: Rethinking the nature of matter. Micro- corpuscularianism especially failed to provide explanations for chemical, electrical and botanical phenomena.

³¹ Reill, P.H. (2005), *Vitalizing nature in the enlightenment*, University of California Press, Berkeley, CA

³² J.F. Blumenbach (1791), *Über den Bildungstrieb*, https://books.google.nl/books?hl=nl&lr=&id=TJ3suD_yMvsC&oi=fnd&pg=PA3&dq=Blumenbach+%C3%9Cber+den+Bildungstrieb#v=onepage&q=Blumenbach%20%C3%9Cber%20den%20Bildungstrieb&f=false. Humboldt attended his lectures.

³³ W. von Goethe (1790) *Versuch die Metamorphose der Pflanzen zu erklären*.

³⁴ Richards describes the historical context of the exchange of ideas between Kant and Blumenbach and the relation between Newtonian forces and the *Bildungstrieb* (2000, *Stud. Hist. Phil. Biol. & Biomed. Sci.*, Vol. 31, No. 1, pp. 11–32, 2000). Richards showed that Kant interpreted Blumenbach's theory to imply that living, organized matter can generate new organized matter, but Blumenbach intended the *Bildungstrieb* to explain organization of matter from disorganized matter.

³⁵ Charles Wolfe (2014) *On the role of Newtonian analogies in the eighteenth century life science: vitalism and provisionally inexplicable explicative devices*, p. 223–261, in: *Newton and empiricism*, eds. Zvie Biener and Eric Schliesser, Oxford University Press, New York.

³⁶ Finger et al. (2013a,b) *J. of the History of Neurosciences*, <https://doi.org/10.1080/0964704X.2012.732727> and <https://doi.org/10.1080/0964704X.2012.732728>) describe what Humboldt did for the galvanic research program. The question here is what galvanism did for Humboldt.

frogs, lizards, horses, mice and men, including Humboldt himself, were exposed to various kinds of chemicals and metals in order to uncover the force that triggered convulsions of animal muscles. Some galvanic actions even took place at a distance as he experimentally demonstrated with frog legs, zinc and silver, and on some occasions his moist breath caused strong muscle convulsions when they were not yet connected to both metals. Humboldt suggests that there exists an atmosphere, or action sphere, through which biological substances exerted, or were subject to, influences such as galvanic force and his breath of life. Finger et al. showed that Humboldt continued to believe in the galvanic nature of animal forces and remained skeptical of animal electricity until he met Volta in 1805. Alessandro Volta (1745–1827) conducted a great number of experiments with metals, animal tissue and live organisms, including himself. He initially believed that Galvani was right but later discovered that the electrical currents were generated between different kinds of metal rather than by intrinsic electricity in animal tissue. Upon Humboldt's visit to Italy, Volta demonstrated his pile and conducted experiments with galvanic devices and static electricity. After this visit, Humboldt accepted the idea that live animals showed intrinsic electricity³⁷. How this was to be related precisely to a vital force remained unclear, but clearly Humboldt had found a drive of life a necessary complement to the known physical forces to explain self-organization of lifeforms and the interconnectedness of their parts.

How physical geography and the drive of life join forces in Humboldt

Causal ordering principles in Humboldt's Plant Geography

Humboldt published his Tableau, or Naturgemälde (Figure 1), as part of the *Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer*. The first ordering procedure used in the Plant Geography is geographical: by elevation, but the Tableau also presents abiotic variables in columns next to the Tableau. This juxtaposes the geography by observed regularities in physical and chemical properties, such as air temperature and pressure, which must have, according to Humboldt, the greatest influence on the vital functions of plants³⁸. With the ordering, the idea is not merely to put the observed patterns in spatial context, but to explain them:

*“But the physical tableau of the equinoctial regions is useful not only for developing new ideas regarding the geography of plants; I believe that it could also help us understand the totality of our knowledge about everything that varies with the altitudes rising above sea level. This consideration encouraged me to bring together in 14 scales many numbers resulting from the large quantity of research conducted in various branches of general physics.”*³⁹

³⁷ On his travels along the Orinoco river, Humboldt experimented on electrical eels and never managed to measure electrical discharge or observe sparks, and also found that the shocks of electrical fish would not pass through materials that were known to be electrical conductors. These and other findings made him write about galvanic forces, rather than animal electricity. Volta had expanded the findings of Galvani but also refuted some of Galvani's and Humboldt's conclusions. Volta showed how his Voltaic pile, or battery, produced a relatively high electrical current (though not more than a few Volts) at a low potential, unlike the Leyden jar used by Humboldt that produced a low current at high potential. Both are electrical but the physiological effects differ: a high potential is perceived as a shock, but cannot do much damage without a high current that is needed for sufficient power. Humboldt visited Volta in 1805, after his travels in South America on which he based the Plant Geography (Finger et al. 2013a,b).

³⁸ Naturgemälde p. 111: “Der Luftdruck muss den wichtigsten Einfluss auf die vitalen Functionen der Pflanzen, besonders auf die Respiration ihrer Integumente äussern.” In the 2009 translation, p. 109: “Air pressure must have the greatest influence on the vital functions of plants and especially on the breathing of their teguments.”

³⁹ Essay on the Geography of Plants, p. 99 in Romanowski's 2009 translation from the French original. The text on p. 89 of the German 1807 edition is: “So viel von dem Theile meines Naturgemälde, welches die Vertheilung der Gewächse betrifft. Ich gehe nun zu anderen physikahschen Verhältnissen über; denn diese Arbeit ist dazu bestimmt, alles zu umfassen, was als veränderlich durch die Höhe des Standorts betrachtet

The systematic ordering principle is a set of observable climatic conditions that he believes caused this order in nature. While the plants are ordered spatially by elevation, their juxtaposition with the physical, causal conditions is intended as explanatory. But the 'new ideas' are not only the explanation of the ordering he saw in the 'vegetable bands' on mountains. Humboldt claims that it is fruitful to consider the totality of patterns in search of deeper explanations. The juxtaposition of many variables shows that an ensemble of balancing forces results in a natural state, such as the zonation of vegetation:

*"In this great chain of causes and effects, no single fact can be considered in isolation. The general equilibrium obtaining in the midst of these disturbances and apparent disorder is the result of an infinite number of mechanical forces and chemical attractions which balance each other"*⁴⁰

Humboldt looks through the apparent disorder of the jumble and tumble of all physical dynamics and lifeforms to see a general equilibrium arise out of the multitude of forces in action. And it is the emerging equilibrium that interests him: this is the result of a chain of causes and effects⁴¹, a whole that is the organized result of interactions of its parts. However, Humboldt is also explicit about his metaphysics: it is not nature that is completely organized in a system where everything hangs together, but it is the knowledge of nature that is best described as interconnected. It is explanatory, unlike knowledge systematized by alphabet or by consequence, because the forces between inorganic and organic components together are thought to explain the global patterns of all physical and biological phenomena. Here Humboldt means both the physical and chemical forces and the vitalic force. As argued below, the Tableau is a model that allows him to predict patterns elsewhere and ask new questions.

The Tableau is an idealized depiction of the vegetation patterns and species on volcanoes the highest mountains in the Andes, and is therefore a simplification and generalization. The staggering number of observations and measurements that Humboldt collected during his travels only made sense after data 'reduction' by systematization and idealization⁴². In this sense it differs from the attempt at a true representation of nature by the *Systema Naturae*: the Tableau is an abstract

werden kann. Vierzehn Scalen , welche das Bild einschhefsen , enthalten gleichsam das Resultat von dem, was die Naturlehre in ihrem gegenwärtigen Zustande in Zahlen darbietet." The DeepL translation is "So much for the part of my nature painting that concerns the distribution of the plants. I now proceed to other physical relations; for this work is intended to embrace everything that can be regarded as variable by the altitude of the site. Fourteen scales, which enclose the picture, contain, as it were, the result of what natural science in its present state presents in figures."

⁴⁰ Essay on the Geography of Plants, p. 79 in Romanowski's 2009 translation from the French original. The text on p. 39 of the German 1807 edition is: "In der großen Verkettung von Ursachen und Wirkungen darf kein Stoff, keine Thätigkeit isolirt betrachtet werden. Das Gleichgewicht, welches mitten unter den Perturbationen scheinbar streitender Elemente herrscht, diefs Gleichgewicht geht aus dem freyen Spiel dynamischer Kräfte hervor". The DeepL translation is "In the great concatenation of causes and effects, no substance, no activity may be considered in isolation. The equilibrium which prevails in the midst of the perturbations of apparently contending elements, this equilibrium emerges from the free play of dynamic forces." This direct translation from the first German edition, approved by Humboldt, suggests that Humboldt sees the equilibrium as an emergent phenomenon from free interplay of forces.

⁴¹ The use of the word 'great' in the great chain suggests that Humboldt paraphrases the Great chain of being or *scala naturae*. This suggestion is reinforced by the fact that the German phrase is *großen Kette der Wesen*, where *Kette*, or chain, was also used in *Verkettung* in the first German edition. By replacing 'being' with 'causes and effects' rejects the teleological and normative aspects of the ordering of 'lower' and 'higher' lifeforms.

⁴² See Romanovski (2009, Analysis of the Tableau in Humboldt's Pictorial Science). Idealization also meant modification: a critical reanalysis by Moret et al. (2019, PNAS, <https://www.pnas.org/cgi/doi/10.1073/pnas.1904585116>) shows that the data presented by Humboldt were selectively presented, manipulated and changed between different publications.

model⁴³. It is also different from the typical maps of collected rivers and mountains (Figure 2), wherein the physiographical features are simply ordered by size, namely height of mountain tops and length of rivers, but no hint of causality or explanation of this central ordering principle why size matters. The Tableau, on the other hand, contains the most important physical and chemical variables that represent climate, because Humboldt wants to predict something else with it, namely global patterns. The location was therefore picked with care: the high Andean volcanoes offer the largest possible range of climatic conditions over a small distance. Humboldt explains that the ordering on a tropical mountain is a model for the climatic zonation on the entire planet, and how one need only climb up a very small distance to enter a new world, so to speak, compared to the latitudinal travelling distance to another zone⁴⁴.

What other insights does Humboldt gain with his epistemic image? Two kinds of questions are obvious, namely spatial and temporal changes. The causality of the climatic explanation of the patterns allows Humboldt to raise novel questions about differences and analogies between plants in similar zones, such as African plants and those of the New World, and alpine plants of the Andes and of the Pyrenees. By presenting climate as the explanation of patterns, and listing evidence for migration of plants and fossils of tropical plants and animals in temperate or arctic zones, Humboldt arrives at new questions about possible causes for climate change. He carefully speculates about geological and astronomical causes for climate change, or the migration of plants through actions of man, and changes in intensity of solar irradiation.⁴⁵

None of Humboldt's new questions could have arisen out of the *Systema Naturae* or the orderings of rivers and mountains by size for lack of the forces that caused the ordering. On the other hand, Kant's geographical system puts the causes before the effects. But this is not enough for Humboldt, who sought to explain the patterns in the world including lifeforms, for which physical forces were inadequate. Humboldt combined physical geography with a vital force, without being specific about its nature, with the intention to use physical causes for physical phenomena and vital causes for biological phenomena. This science, this holistic plant geography, or biogeography, explains the patterns in nature as the result of an ensemble of forces and the contingencies of their past interactions. For contemporary readers, the vital force is not obvious in the Tableau where only climatological factors are visualized, and the absence of vital aspects is a plausible reason why this epistemic image still speaks volumes to modern system scientists.

Humboldt's physical geography and the putative vital force of life

Humboldt's system in the *Plant Geography* is similar to that in Kant in the sense that it is not a systematic description of facts on the basis of some artificial ordering mechanism, but is

⁴³ It is, in the terms of Daston and Galison (1992, *Representations* 40, 81-128, <https://www.jstor.org/stable/2928741>), a working object that illustrates a theory, stands for a whole class of similar objects, here tropical volcanoes but in fact the whole planet, and serves the purpose of publicity of experiences that are otherwise inaccessible to all who cannot travel across the globe. Humboldt is ambiguous about the degree of abstraction: while the Tableau is a model of his view on nature, he also attempts truth to nature by the inclusion of a great many observations and names of species, even though the data were manipulated.

⁴⁴ *Naturgemälde der Tropenländer* p. 35: "So unendlich gering auch, yerglichen mit dem Erddurchmesser, der Abstand ist, um den wir uns von dem Mittelpunkte des Sphäroids entfernen: so ist diese Entfernung doch schon hinlänglich, uns gleichsam in eine Schöpfung zu versetzen, und uns gröfsere Verschiedenheiten in Naturprodukten und Klima bemerken zu lassen, als ein beträchtlicher Wechsel geographischer Breite darbieten würde. Diese Verschiedenheiten sind allerdings allen Zonen eigen, wo die Natur hohe Gebirgsketten gebildet hat: doch sind sie minder auffallend in der gemäfsigten Region, als unter dem Äquator"

⁴⁵ In the *Kosmos*, p. 292 footnote 84, Humboldt explains that he does not limit the interactions with the environment to plants but also speaks of animals as forms that are linked in the chain of being to other forms either living or extinct, such as the extinct mastodont, or mammoth, that were once indigenous to northern latitudes in wholly different climates.

geographically ordered and invokes forces of physics. Furthermore, the causal variables have a history and in this the similarity with Kant's Physical Geography is apparent too. Humboldt's use of the term 'physical geography' makes it plausible that Humboldt adopted a watered-down conception of time and space by Kant as a priori principles for ordering facts. The relationships between geology, climate, plant life and human activity are not simply that "everything hangs together"; he distinguishes between interacting phenomena and independent causes that give direction to the zonation of vegetation, in particular the independent geological phenomena that presently have influence on the patterns⁴⁶. Humboldt knew of Kant's work⁴⁷, but it is the question whether Humboldt modelled his own view of nature on that of Kant. Humboldt differs with Kant in that he thought that the history cannot be explained by physical and chemical properties and forces alone. Humboldt himself states in the *Cosmos* that the main novelty of the Plant Geography was to include life in the geography, and he does so immediately after an oblique reference to Kant's Physical Geography.⁴⁸ On the other hand, Kant's Geography developed as a pragmatic class taught to understand the doings of humans on the planet.⁴⁹

With the addition of life to the set of spheres still in use in present earth system science (lithosphere, land, ocean and atmosphere), a problem arose for Humboldt: mechanistic forces of physics and chemistry were not deemed adequate as causes of the phenomena of life. After his visit to Volta, Humboldt still considered the nature of the drive of life as a known unknown. But how it worked, remained unclear and Humboldt is not even certain whether the 'unity of nature' concerns a single force or multiple forces⁵⁰. Yet there is no doubt that Humboldt believed that some vital drive, power or force was at work in nature in conjunction with the zoo of forces of attraction, gravity, electricity that were known at the time. These forces are not merely drawn together in a systematized manner for the benefit of mankind's systematization of knowledge. Rather, the forces are systemically connected in the interactions between inorganic and organic parts of nature in a 'web of life'. There is room for Newton's forces, but these are not enough to explain the balance of nature that Humboldt sees, and these are not enough to explain how lifeforms came about, while the elusive life forces are⁵¹. To construct his causal, holistic view of nature, including the patterns of life, he invoked an ensemble of forces. Regardless of the diversity of forces, the perceived interrelatedness of all phenomena, or the ensemble of all the parts, made him see the world as a whole. With the

⁴⁶ It is highly plausible that Humboldt knew about Lyell's works, as he briefly worked in the mining industry and cited one of Lyell's followers, Edward Forbes, in the *Cosmos*, and through Lyell he must have known of Hutton. Lyell, in turn, thought that Humboldt is not so interested in changes of the Earth's surface on a geological timescale, as stated in a footnote in part I of the principles: "*Humboldt, in speaking of the vegetation of the present era, considers the laws which govern the distribution of vegetable forms to be sufficiently constant to enable a botanist, who is informed of the number of one class of plants, to conjecture, with tolerable accuracy, the relative number of all others.*"

⁴⁷ Hartshorne (1958) p.101

⁴⁸ *Kosmos* p. 366 (p. 339 in the *Cosmos* translation): "nach der älteren Behandlung der physischen Erdbeschreibung"

⁴⁹ The practical philosophy in the geography has a complicated relation with the critical works of Kant and further analysis is beyond the scope of this chapter. See De Bianchi, S, (2018). The stage on which our ingenious play is performed: Kant's epistemology of Weltkenntnis. *Studies in History and Philosophy of Science* 71 (2018) 58-66, <https://doi.org/10.1016/j.shpsa.2018.06.006>.

⁵⁰ *Kosmos* p. 67: "Wir sind noch weit von dem Zeitpunkte entfernt, wo es möglich sein könnte, alle unsere sinnlichen Anschauungen zur Einheit des Naturbegriffs zu concentriren." This is horribly translated by Otté, p. 75, as "The mythical ideas long entertained of the imponderable substances and vital forces peculiar to each mode of organization, have complicated our views generally, and shed an uncertain light on the path we ought to pursue." Gaukroger (2016, ch.2) argues that the unity of forces was to become a dominant theme in natural philosophy at the end of the eighteenth century, which aligns with the suggestion here that Blumenbach, Humboldt and others on the one hand attempted to investigate the nature of the vital force but on the other were not overly worried because they thought that these forces were all manifestations of a single, underlying force. This point is entirely missed in the English translation of the *Cosmos*.

⁵¹ *Kosmos* p. 367-368, *Cosmos* p. 340-341

interconnectedness, he argued for the unity of nature. This unity is for Humboldt not impaired by inclusion of vital life forces on top of the known physical forces, which he and vitalist contemporaries believe to be no different from the physical and chemical forces. He positioned the perceived patterns in global geography, climate and living nature at a higher hierarchical level than that at which living organisms come about, and where the vital force acts. Humboldt paints nature as a causal, multi-level system, without calling it a system in the modern sense, but with the intention to systematize the observed patterns by inorganic, physical forces, however poorly these are known.

Why not call it a system?

In the sense of the emergence of behaviour through feedbacks and interconnectedness of phenomena, Humboldt describes what we would call a system, but which he described with many words such as interconnected, whole, balance and such. The Plant Geography provides examples of interconnectedness with causal feedbacks between climatological, geological, ecological and human levels. One example pulls together geology, ecology, climatology and human history in a few sentences:

“A moss, Sphagnum palustre, which is common to the tropics and temperate climates, once covered a considerable part of Germany. The frequent peat bogs in the Baltic and Western German countries testify to how widespread this plant once was there: the newer bogs owe their origin to two swamp cryptogams, Sphagnum and Mnium serpillifolium, while the peat of older formations is made up of piled-up sea lettuce (green algae) and brown algae, often resting on a bed of small marine shells. By eradicating the forests, farming peoples have reduced the wetness of the climate. The marshes have gradually dried up and the sphagnum, which made entire stretches of land uninhabitable for the nomads of ancient Germania, has been replaced by usable crops.”⁵²

Here, peatlands are presented as a phenomenon explained by multiple causes, one of which is geological. In turn, peatlands have effects on local climate, which is inferred from bogs still in existence and from the effects of human interference that removed the positive feedback between vegetation and local climate. Once the peatlands were uninhabitable, but after the removal of adjacent forests the peatlands also disappeared. Humboldt describes here what is, also today, known as the bane of all the lowlands in temperate climates: a positive feedback due to human interference leading to a tipping point in land cover. These and many other examples in the introduction of the Plant Geography support the idea that Humboldt has a complex, path-dependent, causal system in mind, not a systematically described body of knowledge.

So why does Humboldt not call his holistic, multicausal and complex description of nature a system? Why not use the word? He is at pains to distance himself from a ‘mere’ systematic description of nature lest it be associated to the a priori ordering principles that he eschewed. In the Plant Geography he rarely uses the word system, and in the Cosmos he explains why. Humboldt contrasts the systematicity of botany and descriptive zoology with his geography of plants and animals, and compares this contrast with that between geology; the spatial ordering of rock facies and fossils; and

⁵² Ideen zu einer Geographie p. 8: “Ein Laubmoos, *Sphagnum palustre*, welches den Tropen und den gemäßigten Klimaten gleich eigen ist, bedeckte ehemals einen beträchtlichen Theil von Deutschland. Die häufigen Torfmoore in den baltischen und westdeutschen Ländern bezeugen, wie weit jene gesellige Pflanze dort einst verbreitet war: denn die neueren Moore verdanken zwey Sumpf-Kryptogamen, dem *Sphagnum* und *Mnium serpillifolium*, ihren Ursprung, während dafs der Torf älterer Formation aus zusammengehäuften Meer-Ulven und kochsalzhaltigen Fucus-Arten entstanden ist, und daher oft auf einem Bette kleiner Seemuscheln ruht. Durch Ausrottung der Wälder haben ackerbauende Völker die Nässe des Klima vermindert. Die Sümpfe sind nach und nach abgetrocknet, und das *Sphagnum*, welches den Nomaden des alten Germaniens ganze Länderstrecken unbewohnbar machte, ist durch nutzbare Gewächse verdrängt worden.” The English translation is here based on DeepL because the Plant Geography p. 66-67 has changed the order of the sentences, which removes the intended order that illuminates cause and effect.

mineralogy; the composition of rocks and geometry of crystals. The 'botany, zoology and mineralogy' (a reference to the *Systema*) are simply at another level than their ordering in space. Humboldt sees these as disconnected facts, whereas the distribution in climate and elevation is seen as the relation to the whole. The relations are due to the connecting links of the physical forces that act here on Earth and in the universe. Moreover, Humboldt sees disconnected facts compiled in encyclopedias, and by inference also the facts collated in botany, zoology and mineralogy, as vague, ill-defined and perhaps even inferior, because there they remain disconnected from the whole for lack of a causal ordering principle⁵³. The explicit reference in the *Cosmos* to the *Tableau* strongly suggests that Humboldt's notion of the causal ordering principles in the *Cosmos* was the same as when he wrote the *Plant Geography*.

This tension suggests that he hesitates to name his view 'system' out of fear that it is associated with systems based on a priori ordering principles, which would explain why Humboldt did not use the word system in places where he could have done so. On the other hand, the 1858 translation of the *Cosmos* by Otté has no such scruples and the word system appears in the description of the *Tableau*⁵⁴ where in the original German text, Humboldt did not use the word system. Instead, he uses the phrase 'leitenden Ideen', or guiding ideas, and 'Reihenfolge', meaning the ordering of data in a sequence in time or space by 'Intensität', or intensity⁵⁵.

Conclusion

A changing concept of system

So was there a change in the notion of system in Humboldt's work? The addition of the force, or drive, of life to the causal system of Kant only became necessary because Humboldt deemed the physical and chemical forces to be impotent explanations of organization of organic matter into lifeforms and their activity. Humboldt treats the life forces similarly to physical forces, which could be seen as a living apart-together fix. But the life force was not nearly as well known as the physical forces, and direct measurements of vitality were absent in the *Tableau* unlike direct measurements of physical climate.

There are two levels of ambiguity in Humboldt's notion of system. The first is that he does not use the word where it could have been used, because he does not want to associate it with the a priori systematization of ostentatious knowledge systems. But the direct association in the *Cosmos* of those 'prunkvollen' *systema naturae*, which he carefully calls admirable, with Humboldt's preferred spatial and climatological ordering principles, creates a tension. Possibly he realized that the word system would have been appropriate for his ordering principles, and the cost of avoiding the impression that he endorsed those other systems was not using the word. Consequently, the word system does not play the same functional role that the concept of system could perhaps have played in Humboldt's works⁵⁶.

The second level of ambiguity is that Humboldt's causal system makes stronger ontological claims about nature than previous systems but without evidence for some of the forces of nature. The forces do the ordering in Humboldt's system, whereas earlier, a priori ordering principles of systematized knowledge in taxonomies and encyclopedias were not intended as causal, but as one of the many possible readings of the signs in the book of nature. However, Humboldt has been unable to provide a clear exposition of which physical and life forces are involved, because the

⁵³ *Kosmos*, p. 39-40 and 55

⁵⁴ *Cosmos*, p. 28-29, from the 1858 Harper & Brothers edition translated by Otté

⁵⁵ *Kosmos*, p. 29, translation by <https://www.dwds.de/wb/Reihenfolge>

⁵⁶ As argued in Goering (2013), a concept changes when it fulfills a different function in the conceptual framework, which in this case causality.

nature of these forces, especially the vital, is still unclear; a fact he had to face after his own galvanic experiments. This tension is, however, not problematic for Humboldt, because his view is not about the activities and metamorphoses of species. Humboldt's view on nature is positioned at the spatially higher hierarchical level of their distribution on the planet, which is explained by the climatic influence on the functioning of plants, regardless of how these lifeforms came about⁵⁷. In the *Cosmos*, the aim is an explanation of general patterns on the planet at a higher level than that of organisms in terms of powerful, beautiful impressions as well as numerical calculation. Humboldt's view on nature is a system at the level of emergent patterns on the planet's surface, not at the level of organisms, individual causal relationships or forces. A vital force is only needed inasmuch that the 'vegetables' would not exist without them.

Humboldt built a causal, explanatory system of vegetation zonation in relation to climate, but never called this system. Like Kant, he systematically ordered his phenomena geographically and historically, but an a priori conception of space was not the main point for Humboldt. By relating vegetation zones to climate conditions, causality permeated into the system with physical forces as the ordering principle. The addition of a vital force as an ordering principle made sense as no other cause was known for life. The greater step was to expand the causal, structuring power of the ensemble of forces to the level of the whole of nature and the patterns that he observed in it. The 'vegetable bands' emerge on the physical and chemical conditions and forces and they are the barely tractable result of a long history of a vast number of interactions between innumerable lifeforms that themselves interact in many ways. In the modern sense, this is a complex system that functions as a non-reductionistic model of a large set of aspects of reality that were hitherto unexplained.

The meaning of the term system gradually shifted from pure systematicity to increasingly causal systems where a natural force is thought to impose the ordering. That is not to say that the systematicity aspect disappeared. There is multiplicity in the meaning of system within Humboldt's writings, who uses the word system about 160 times in the *Cosmos* in all the senses discussed above: for solar systems, for systematicity and for causal systems. He amplifies the latter point in the Introduction to the *Cosmos*: taxonomies, or "catalogues of organized beings", are called "pretended systems of nature" because they do not show us how the organic beings are distributed on the planet in relation to physical causes of latitude, elevation and climate. Humboldt sees nature as a whole that functions only with all the parts in it, but does not call this a system. His biogeographical system resulted in great predictive power of the patterns in the world. The forces themselves that underlie the causes, whatever these forces are precisely, are accepted as ontological background assumptions in Humboldt's system. What mattered was that everyone could see that all forces of nature operate in concert to cause the emergent patterns of the whole world.

Can Humboldt's system be traced to later concepts of system?

As eloquently described by biographer Andrea Wulf⁵⁸, Humboldt's new view on nature was discussed by scholars, was reprinted in many translations, inspired many subsequent works including the *Origin of the Species* by Charles Darwin. This lay the basis for nature conservation movements and the foundation of the national parks in the United States of America. In this sense social history is coupled to the conceptual history as meant by Koselleck. Humboldt allowed a shift in meaning of the knowledge concept of a system that emerges as a result of the forces of nature, rather than a priori imposed ordering, expressed in words and Tableau. This new idea voiced the changing way others saw nature and the place of man in it. Furthermore, Humboldt's systemic view on nature

⁵⁷ Others were likewise concerned with higher levels, such as the level of society captured in statistics by Quetelet.

⁵⁸ Andrea Wulf (2015), *The invention of Nature*, John Murray, London.

entered into social consciousness, and contributed to a different attitude towards nature.⁵⁹ This had long-lasting effects as evidenced by the traces of contingency between Humboldt and the conception of national parks, as Wulf's biography shows. However, that did not mean that contemporary readers fully understood nature in the terms of Humboldt, or agreed with it. For example, Mary Somerville paid lip service to the *Cosmos* in her 1858 overview of physics, but is mostly concerned with single physical, causal interactions rather than complex multi-level systems with feedbacks⁶⁰. Observations continued to be drawn up in atlases, but were oftentimes limited to systematic comparison of lengths of rivers and heights of mountains (Figure 2) and a systemic synthesis such as found in the Tableau was rare, if not absent.

The history of the changing concept of system is not simply continuous as suggested by the ecologists and geographers cited in the introduction. Authors of the system theories in the early twentieth century did not recognize the *Cosmos* as a shift in the direction of causal systems thinking as it is done now. It is beyond the scope of this work to uncover the precise reasons for this. Wulf suggests that Humboldt was generally forgotten in this period, but he may also have been ignored for nationalistic reasons. The later abandonment and dislike of vitalism may also have played a role. One of the first treatises on general system theory mentions Wilhelm von Humboldt, the older brother of Humboldt, suggesting that the author must have heard of Alexander von Humboldt's works. The author, Ludwig von Bertalanffy (1901-1972), developed the General Systems Theory in the 1920s in Vienna to explain growth of living organisms. Bertalanffy explains at length why vitalism is fatally flawed and why a systems framework needed to be freed from such 'obscure metaphysical connotations', which suggests that he rejected Humboldt's work in general.⁶¹ Ironically, Humboldt conceived his view on the cosmos because he thought reductionism inadequate for the explanation of aspects of life, which was also the motivation of the system theorists such as Bertalanffy in the 20th century. The concept of system thus expanded from systematicity imposed on nature until the 18th century, to Humboldt's complex system that is not named system in the early 19th century, with pattern formation caused by physical, chemical and vital forces, to complex open system with similar scope as Humboldt's but without the vital forces in the 20th century. The notion of system itself is complex in that it continues to be used in the sense systematicity.

When Alexander von Humboldt looked out over the world from the slopes of the Chimborazo volcano on 23 June, 1802, about 6000 m above sea level, he may have seen, all in his mind's eye, the system in the patterns in the Earth's vegetation, the relationships between the minutest lifeforms in a 'web of life', the atmosphere and the crust, and the physical and vital forces that arrange all phenomena with great regularity on the Earth as they do in the remotest nebulae and revolving double stars. He painted a novel picture of the living world for his readers that changed their view on nature and made them understand how all things inorganic and alive are connected in one great system. The Tableau, as a model, was partly based on observational data and causal relations between climate and vegetation, and allowed an overview that is, in reality, nearly impossible to have at a single glance from my experience. On the rounded top of a mountain, all one can see on a sunny day is a bit of the top unclothed by plants but nothing of the lower slopes. Beyond the immediate horizon of rocks there are other mountains and valleys rendered unsharp and discoloured by the large distance. Humboldt's view of nature, the web of life and how it all hangs together, was woven in his mind as a model for the world including himself and his readers.

⁵⁹ Koselleck (2002), p. 32

⁶⁰ As Humboldt argues in the *Cosmos*, Somerville links the solar energy to processes and lifeforms on Earth and writes about feedbacks from human actions on local climate and extinction of species (chapter 33). However, all 34 references to Humboldt in Somerville's *Physical Geography* (part 1 and 2) pertain observations and *curiosa*.

⁶¹ Ludwig von Bertalanffy (1969)

The historic knowledge concept of causal system that was implicit but central in Humboldt's work, differs from the modern meaning of 'complex system'. In the modern concept of systems, complexity has replaced the vitality that Humboldt connected to his system, but the purpose of both notions is to explain the emergence of lifeforms, their dynamics and a vast number of life-related and lifeless tendencies of spatiotemporal pattern formation alike. In my interpretation, Humboldt saw the need for discourse on the notion of system and avoided the term lest he be misunderstood, whilst few present-day scientists see the need for such discourse and consequently miss the changes in meaning. Yet this discourse is needed at present to avoid misinterpretation of Humboldt's works, misuse of Humboldt's generalizations in secondary school geography, and generally meaningless overuse of the notion of system.

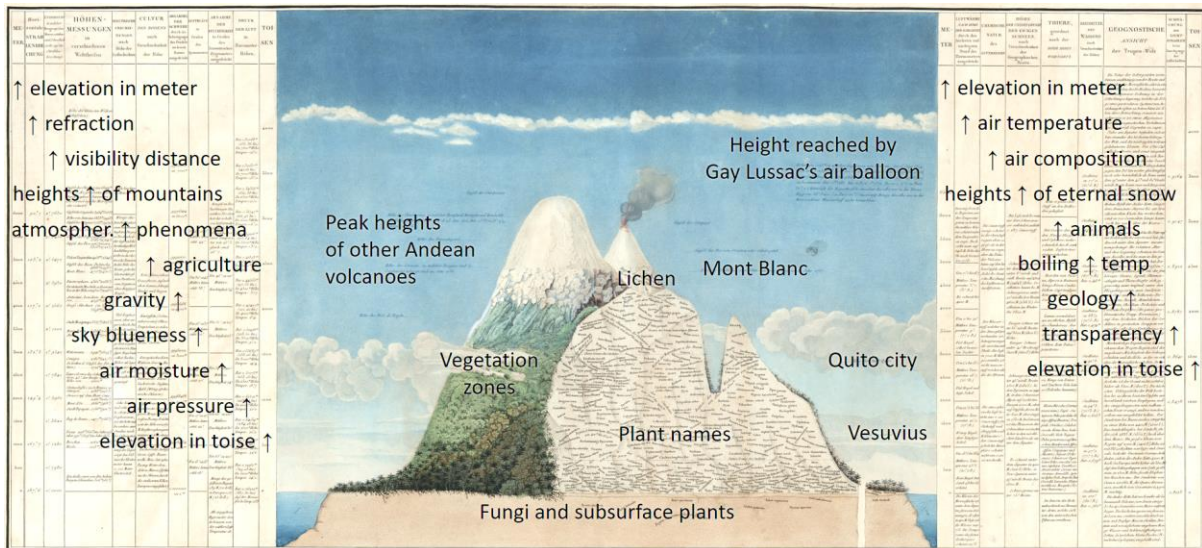


Figure 1. Tableau, or Naturgemälde of the Plant Geography drawn by Alexander von Humboldt for the tropics, organized by physical aspects of climate listed in the columns next to the image (here annotated with main terms)⁶². For mountains, the climate changes with elevation, but in the Cosmos, Humboldt used the climate zones of the world as the explanation for vegetation zones and biodiversity. While the Tableau was drawn up to the height of the Chimborazo volcano, presently in Ecuador, it is a generalization of observations on many Andean volcanoes as also indicated by their elevations show left of the mountain. The sketch is exaggerated in vertical scale and the profile does not resemble that of any of the volcanoes. Elevations of the highest European mountain and some other elevations are provided for context on the right side. The active volcano in the back represents the Cotopaxi, which Humboldt thought interesting because of its explosive sounds, and which hints at the dynamics of the Earth. The crevasse on the right is perhaps a reference to the chasm, several hundreds of meters below the top, that prevented von Humboldt and Bonpland to climb all the way to the top. Gay Lussac had measured the atmospheric composition with his air balloon.

⁶² The title of the German translation shown here is: "Geographie der Pflanzen in den Tropen-Ländern, ein Naturgemälde der Anden, gegründet auf Beobachtungen und Messungen, welche vom 10^{ten} Grade nördlicher bis zum 10^{ten} Grade südlicher Breite angestellt worden sind, in den Jahren 1799 bis 1803. Von Alexander von Humboldt und A.G. Bonpland." Source of scan: Zentralbibliothek Zürich (https://commons.wikimedia.org/wiki/File:Zentralbibliothek_Z%C3%BCrich_-_Ideen_zu_einer_Geographie_der_Pflanzen_nebst_einem_Naturgem%C3%A4lde_der_Tropenl%C3%A4nder_-_000012142.jpg). See Romanowski's analysis of the Tableau in Humboldt's Pictorial Science (2009).



Figure 2. Tableau Comparatif et figuré: a systematic ordering by elevation of the highest mountains of the world and by length of the largest rivers of the world drawn up by geographers J. Goujon and J. Andriveau in Paris in 1836.⁶³ The mountains are numbered and their names, heights (in toises and in meters), mountain range and country listed by continent in tables next to the map. Many such maps were drawn in the early 19th century with length or elevation as the ordering principle.

⁶³ modified from

https://commons.wikimedia.org/wiki/File:1836_Andriveau_Goujon_Comparative_Mountains_and_Rivers_Chart_-_Geographicus_-_MountainsRivers-andriveau-1836.jpg